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SERVICE ENGINEERING REPORT FOR F-111 SIMULATION STUDY

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FOREWORD

This study was performed by Rockwell International's Autonetics Division for the Sacramento Air Material Area (SMAMA) as a task within the scope of Air Force Contract F04606-73-D-0141. The purpose of the study was to investigate the need and/or feasibility of a digitally controlled F-111 simulation facility at SMAMA. This facility would provide SMAMA with the capability to:

(OPERATIONAL FLIGHT PROGRAMS)

1. Verify and validate OFP's prior to flight test;

2. Investigate problems/changes; AND

3. Formulate and checkout solutions to problems.

These capabilities will be required in order for SMAMA to satisfy their AF Engineering responsibility for F-111D, FB-111A and F-111F flight tapes.

This report contains the answers to specific questions that were asked by SMAMA. Additionally, it describes a simulation approach that will, when implemented, provide the desired capability. This approach is one of many that could be taken, and is based strongly on a concept of providing a satisfactory initial capability that can be expanded or modified during the F-111 operational lifetime. The areas of expansion are also discussed in the report.

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1. INTRODUCTION

1.1 ORGANIZATION

This report is organized in general accordance with Data Item Description DI-S-3601/S-142-1, Service Engineering Reports, as required.

1.2 CONTENT

Sections 2, 3 and 4 consist of summary study results and background information describing the need for the study.

The majority of the detailed information derived during the study is presented in Section 5. This includes: (1) conceptual configurations of both hardware and software baseline approaches recommended by Autonetics with potential growth and alternate uses of the recommended facility; (2) presentation of a realistic development program, including schedules and an estimate of cost/manpower required to obtain the facility and (3) rationale substantiating the need for and benefits to be derived from such a facility.

Section 6 presents the study conclusions and recommendations for specific future actions to be taken by SMAMA. Sections 7 and 8 present references and abbreviations used in the report.

2. SUMMARY

2.1 GENERAL

The study as conducted by Autonetics consisted of two primary efforts. The first was an investigation into the existing capability of SMAMA to produce the required operational software and system level support with existing support equipment. The second was preparation of a conceptual definition for a dynamic simulator to be used in Operational Flight Program (OFP) checkout and evaluation.

Both of these efforts were predicated on the following factors that are identified here for continuity: (1) SMAMA, having had little previous active participation in F-111 OFP preparation and checkout, will be required to provide a minimum of one flight tape per year for each of the three F-111 configurations, (2) Available checkout facilities consist of the MARK II Integration Test Equipment (ITE) and the F-111 nose-bay mockups, (3) the OFP responsibility will continue through the life of the F-111 program, considered for the purpose of this study to be approximately ten years, and (4) OFP checkout consists of ground evaluation (presently using the ITE), followed by flight test at SMAMA and finally, flight evaluation by the using commands.

The ITE and nose-bay mockups provide the capability to operate the various F-111 avionics subassemblies. This test equipment, while satisfying the purpose for which it was intended, is inadequate for a long-term, software maintenance/development program.

The apparent heavy emphasis placed on "simulation" could be misleading to the reader. In actuality the main thrust of the study was to define an integrated, dynamic, software test/verification facility. The purpose of the simulation is to provide a realistic, dynamic environment in which detailed test and evaluation of F-111 software and software/hardware combination can be accomplished. This test and evaluation is implemented through use of the real-time data monitoring and control devices included with the dynamic simulation. In this light, the facility recommended in this report could be considered as an F-111 Simulation/Integration Test Station (SITS).

2.2 RESULTS OF PRIMARY EFFORTS

Following subparagraphs summarize the results of the two primary study efforts.

2.2.1 Existing Capability Evaluation

One goal of this study was to determine if existing test facilities and maintenance procedures are adequate to provide required software and system level support. Factors considered in this study were: (1) the expected level of flight tape maintenance, (2) past, present and expected software/system problems, (3) the test capabilities of the static integration test facilities (ITE) and (4) the debugging/troubleshooting effectiveness of past F-111 flight test programs. Investigation revealed that the existing test facility and software maintenance approach is inadequate and is not cost effective. Perhaps more importantly, complete dependence on this facility could result in failure to achieve the complete potential of the FB-111A, F-111D and F-111F weapon systems. It was determined that an operator oriented dynamic test/simulation facility designed for the purpose of identifying, investigating and solving software problems is required to meet the F-111 operational flight program/system level maintenance requirements. This facility would provide for: (1) timely solutions to field problems or new requirements, (2) a reduction of up to 50 percent in the total amount of flight testing and (3) realization of the complete potential of the F-111 digital avionic system.

Autonetics completed the first FB-111A tape program in 1967 and the first F-111D tape in 1968. During the past six years, there have been eleven tape revisions for the FB aircraft and seven for the D. These revisions, primarily oriented at problem solving, consumed almost monumental software effort by Autonetics, GD/FW and USAF. This effort was expended by personnel who were intimately familiar with the programs/systems by virtue of the fact that they developed and/or worked with the programs for an extensive period of time. In spite of this effort, approximately 150 open items, including apparent problems and enhancements, will remain in the SMAMA F-111 Problem Book after approval of the baseline tapes. Clearly, the methods and techniques used for the OFP checkout and verification have been inadequate.

Highlights of the evaluation of existing capability are presented below. A more detailed discussion of this evaluation is presented in Section 5.6.

2.2.1.1 Test Equipment

The existing (static) ITE was found not to be software checkout oriented. This equipment was designed for system integration/checkout by contractor personnel who had intimate knowledge of the detailed system mechanization. As such this equipment has limited signal control, lack of data monitoring or data gathering capability and no ability to create a controlled dynamic program environment necessary for problem solving.

The process of software problem isolation/solution, flight program debugging and system hardware evaluation requires the capability to monitor program operation and obtain data. The existing ITE has no real-time data gathering capability. Critical interfaces such as exist between the computers and converter cannot be examined. The computer cannot be monitored during tests to provide answers to flight program problems. Total serial data transfer over the subsystem interfaces cannot be dynamically monitored and analyzed.

The majority of F-111 flight computer subprograms involve a dynamic, interactive process. Other than for static mode and control logic functions, the flight programs operate on dynamically changing input signals. Computations for navigation, weapon delivery and steering involve dynamic data sensors such as the inertial platform, attack radar, doppler radar, air data computer, etc. The existing ITE facilities cannot exercise these sensors dynamically to simulate actual flight conditions. This deficiency limits solution of a large number of F-111 flight problems and is discussed briefly in Section 5.6, relative to existing, known problems.

2.2.1.2 Computer Utilization

The F-111 flight programs were found to utilize 98 to 100 percent of the available computer memory and cycle times. Individual changes to these highly efficient flight programs resulted in an interaction throughout the entire flight program. It is virtually impossible to make a program change without affecting other areas of the OFP. Existing test equipment does not provide the visibility to determine these interactions.

2.2.1.3 Air Force F-111 OFP Experience

Detailed Air Force involvement in the preparation and development of F-111 flight programs was virtually non-existent. Little knowledge exists of the details of the subprograms and the rationale behind their development and/or optimization. Problem solving requires intimate knowledge of the flight program. A dynamic test facility can provide this visibility by way of providing both dynamic operating conditions and the instrumentation and access to the inner workings of the system/software while in those conditions.

An attempt by AFLC/SMAMA (or other organization or contractor) to perform the F-111 operational flight programs and system level maintenance tasks with these major test limitations will result in a costly and inadequate maintenance program. A current example of the required flight program validation effort can be seen in the F-111D flight test presently being conducted at Cannon AFB. Forty sorties are planned for flight test validation of the recently received "final" F-111D operational flight program (tape D07 115/215). The requirement for this type of program, being conducted by SMAMA, SPO, Cannon and contractor personnel, is based on experience gained on similar programs conducted at Mountain Home AFB. Even this amount of effort, following extensive contractor tape preparation/checkout, will likely leave numerous uncertainties in the readiness of the flight tape, and hence the weapon system. Autonetics estimates that dynamic simulation could reduce the cost of such a program (for single tape checkout) by half a million dollars, and result in substantially increased confidence in the OFP. The details of this estimate, along with other requirements rationale, are presented in Section 5.6.

2.2.2 F-111 Simulation/Integration Test System (SITS) Summary

The need for a dynamic simulation and test capability was summarized in Section 2.2.1. However, the architecture of such a system must be structured to facilitate problem solution and operational flight program updates from the test operator's standpoint. Provision should exist for test mission profiles to be flown with full test operator monitoring and sequence control. In summary, it must be an operator-controlled simulation system. Moreover, for efficiency, the system should provide a high degree of commonality among the three F-111 systems. This commonality encompasses interface hardware, test software, test operator procedures, and growth provisions. The system approach discussed in Section 5.2 satisfies these commonality and operator-controlled goals. Figure 2-1 is a simplified block diagram of the F-111 simulation system approach. It is noted that the relative sizes of the "interface hardware" blocks show the intent of satisfying the commonality goal. The next few paragraphs indicate some of the major features of the approach.

One of the basic features allows (for the first time) the F-111 operational flight programs to be tested and verified collectively. There is no "contamination" of the flight programs with such typical add-ons as data pumps and monitors. These functions, necessary for proper monitoring and test control, are performed by

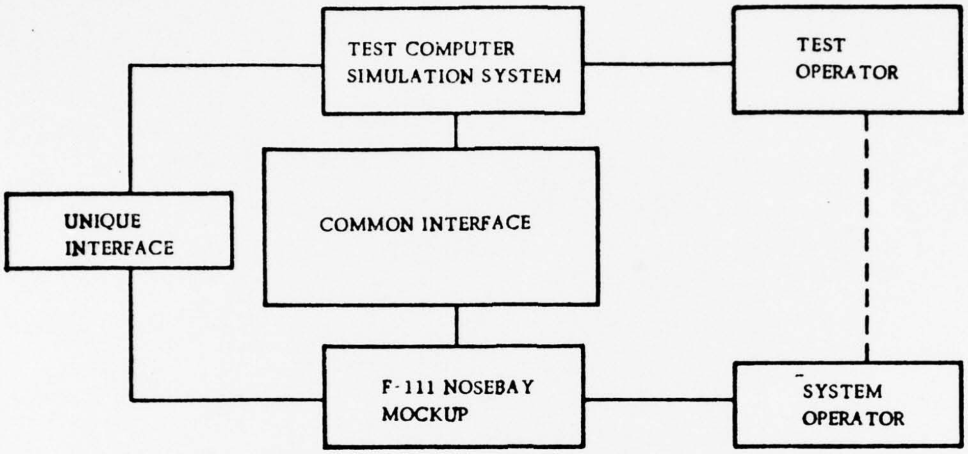


Figure 2-1. F-111 Simulation System General Block Diagram

hardware which interfaces with the internal and external memory and data buses of the computers. Moreover, the test operator, via the test computer simulation system, has direct control over these bus interface units. Therefore, he can start, stop, monitor, skip and generally "walk" the simulation system through almost all sequence steps.

Another major feature is the variety of interactive devices available. The keyboards provide the major interface with the test system. Using the various options, the test operator can, as a minimum:

1. Call for a menu of test setups and select the desired one
2. Call for test setup procedures to be displayed on the CRT(s)
3. Load F-111 flight programs and specific changes for the current test setup
4. Initialize the air vehicle dynamic simulator which provides the real world reference for F-111 test/evaluation
5. Identify the type of simulation to be performed (e.g., canned profile, static under keyboard control, system operator control using actual stick and throttle inputs to the real world air vehicle simulator)
6. Monitor simulator performance on CRT(s)

7. Monitor F-111 performance on CRT(s)

8. Record, for later analysis, both simulator and F-111 parameters on printers, magnetic tapes, etc.

These options and more provide the test operator with complete flexibility to simulate the actual flight environment. He can then reproduce a problem, establish possible solutions, and verify the selected solution in a dynamic atmosphere without necessitating any flight tests. The same interactive devices allow him to evaluate new modes, functions, weapons, tactics, etc., with the realism of actual flight conditions.

The design and development of the F-111 simulation system is envisioned in phases. Phase 1 would provide about 90 percent of the total dynamic simulation capability. Phases 2 and 3 would add subsystem simulations and provide for expanded static testing. A realistic Phase 1 schedule has been estimated at eighteen months with an assumed go-ahead of January 1974. Estimated resources required to obtain such facilities as are described herein, within the eighteen month schedule, total approximately 285 manmonths and $590,000. This investment would provide both hardware and software for two Simulation/Integration Test Stations (F-111D and FB-111A/F-111F). Details of the development including estimated cost breakdown are discussed in Section 5.5.

The proposed simulation system is responsive to the need for testing and verifying operational flight programs. The test philosophy is common for both the F-111D and FB-111A/F-111F configurations. The development plan and schedule is realistic with no major problems envisioned.

3. STATEMENT OF THE PROBLEM

3.1 GENERAL

The F-111 Avionics System is presently in a state of transition. Contractor development is at an end and the Air Force Systems Command is turning responsibility for maintenance engineering over to the Air Force Logistics Command (AFLC/SMAMA). The avionics hardware and software could be supported either by the contractor or organically. Contractor services for maintenance engineering support are expensive and require a high degree of expertise on the part of the Air Force to properly manage the contractor efforts. The skills needed to manage the contract are similar to those needed to actually perform the work. Therefore, it is in the best interest of the Air Force to obtain an organic capability supplemented with contractor specialty skills.

The maintenance of the F-111 flight programs requires the use of special tools developed expressly for the purpose. At present, SMAMA uses only the Integration Test Equipment (ITE) developed by Autonetics during the early phases of F-111 development for integration of the Mark II avionics. This equipment is a hot mockup of the Mark II avionics with simulated signals which can be manually set by an operator. Although the simulation is essentially static, it is dynamic in the sense that aircraft velocity is an input, and the situation originally created can be changed by the operator, within the limits of manual dexterity, controlling one input signal at a time. The equipment has severe limitations, and cannot provide the same set of time varying signals that an aircraft in flight would present to the avionic system. In the future, nosebay mockups and subsystem testers will be added to the support facility. These equipments do not greatly increase the ability to control the inputs or provide a more realistic set of input signals.

The process of maintaining the operational flight programs can be broken into several phases. Each phase has its own unique requirements for support tools. The principal phases follow.

3.1.1 Problem Identification and Problem Recreation

One of the first steps in the solution of any problem is to identify the complete set of symptoms associated with a problem and to recreate the situation causing the problem at will. This step is necessary not only to provide the necessary foundation for problem resolution, but equally, to insure that tests can be performed to verify the correctness of a given solution. Tools must be developed which exercise the flight program. The following characteristics must be provided.

3.1.1.1 Man in the Loop

Due to the sketchy descriptions available for most problems, an iterative process is necessary. Initial attempts at identifying and reproducing problems will be highly speculative, with successive iterations slowly zeroing in on the problem area. The process is extremely judgemental. Such characteristics dictate a very flexible system with a man in the loop if the length of each iterative cycle is to be short enough to allow identification of the problem within a reasonable time.

3.1.1.2 Total System Configuration

In order to exercise an area of code, all inputs into that area must be supplied. The inputs must be realistic and in agreement with the other inputs being supplied. Since it is not known beforehand which areas of the program will be exercised, provision must be made to supply every input to the Mark II system in a realistic manner. As an example, if the coefficients of the Kalman filter were being checked, inputs from the Inertial Navigation Set, Central Air Data Computer, Auxiliary Flight Reference System, J-Box, Doppler Radar and Astrocompass (not all items are in every aircraft configuration) must be provided. Each input must provide the correct stimulus for the assumed position in space and state of the aircraft (e.g., inertial velocity may not be zero with a non-zero system velocity).

3.1.1.3 Perturbated Inputs

Not all problems are caused by true program errors. In some cases the program reaction is caused because the inputs are not as ideal as was assumed. In order to investigate such problems, control of equipment failure, noise, bias, and out of tolerance signals is required.

3.1.1.4 Repeatable and Controllable Inputs

The high cost of software maintenance is primarily attributable to the cost of skilled personnel. The amount of time spent in attempting to duplicate a problem can be reduced if control of the exercise is optimized to reduce operator setup time. Another problem is that once a problem has been made to occur, it may not be reproduceable. This could be caused either by the fact that the exact analog voltage necessary cannot be reset or through operator oversight, a switch position is different than the first time the problem was produced in the laboratory. Both of these types of problem can be overcome using digital techniques.

3.1.1.5 Recording and Analysis

The use of various recording and analysis techniques can give the engineer a significantly larger data base which can be used to speed the analysis of a problem.

3.1.2 Solution Development

Once a problem can be created in the laboratory and a set of symptoms found, various engineering analysis techniques can be used to formulate trial solutions. These solutions must then be tested in the flight program to observe the correctness of the solution. During this phase of program development the effectiveness of an engineer's time, and therefore, program maintenance costs, can be optimized if he has tools which provide:

3.1.2.1 Alterability of the Flight Program

The ability to enter changes into the flight program for analysis purposes is mandatory. The ability to do this without introducing entry errors is desirable if time and equipment are to be used effectively. Using the present computer control panels on the ITE, if an address is entered incorrectly, the change can be entered into the wrong area of memory. Later attempts to locate and remove the erroneous change may be futile. The only solution is to reload the computer and start over. The ability to check the information before it is loaded is therefore, highly desirable. This can be done when changes are entered under the control of another computer. This method allows easy removal of a change when it is no longer desired.

3.1.2.2 Documentation Update and Configuration Control

The use of automatic recording of changes provides greater confidence that the documentation reflects the actual flight program configuration. It eliminates the possibility that someone will forget to document the entry of a change. It eliminates the tedious copying of changes into an official log and prevents transcription errors. It also provides a convenient method of maintaining configuration control.

3.1.3 Testing

Once all of the various changes have been developed, they are all entered into the flight program and tested as a unit. The test program has a different set of constraints than the earlier development phases. However, some of the requirements are common with the earlier requirements. Key characteristics required to exercise and test the operational flight program follow.

3.1.3.1 Exercise of All Modes

The requirements are similar to those for problem identification and recreation. All inputs to the system must be available and controllable if all parts of the program are to be checked to insure that they were not impacted by changes in other areas. Before a new flight program version is released, a thorough check of each section of the program should be made in a systematic manner. For effectivity this implies not only the ability to exercise all modes, but also the next requirements.

3.1.3.2 Scenario Generation

This phase of tape development no longer requires man in the loop testing. A formal test procedure is required. The rigid and structured nature of such a procedure lends itself to automated checkout control. Automated control not only allows faster setup of the proper test conditions and therefore, speeds the testing program, but insures proper test conduct by limiting operator errors and allows repeatability of the procedure. A further advantage is that test procedures can build upon previous procedures to the point where a very comprehensive test procedure can be developed and maintained with minimal effort.

3.1.3.3 Real Time Analysis

The use of real time analysis techniques allows a continuous evaluation of each portion of the program under test. The inclusion of performance criteria in the test program also insures that a thorough analysis of requirements has been made and contributes to the confidence in both the checkout procedures, and the final results. A further advantage of real time analysis is the capability for greater depth of analysis. Using present equipment and procedures, the amount of data that can be gathered by an operator is limited. Performing the necessary conversions on the data before analysis further slows and limits the manual capabilities. Tools which allow faster, more accurate, and greater data gathering, conversion and analysis greatly enhance the ability to perform maintenance engineering.

3.1.3.4 Test Documentation

One of the requirements for any testing program is adequate documentation. Information on the test procedure, evaluation criteria, a record of events, results of analysis, etc., are necessary. Accurate documentation using manual methods is very difficult and time consuming to obtain. However, it can easily be obtained as a fall-out item in an automated system.

3.1.3.5 Error Recording and Recovery

If by chance an error is found, it is necessary to have information on how the error was generated, what the symptoms are and areas of the program affected. Information on how the error was made can be found in a trace of the instructions and data prior to the error detection. This can be done using data recording techniques. Symptoms and areas of the program affected can be found by selective dumps and analysis of the flight computer memory. Error recovery is necessary so that once all information about a problem is known, the test can continue and other possible errors found. Without this feature each error would have to be corrected in sequence before the test could be resumed. If errors are interrelated, this could cause long and unnecessary delays.

3.1.3.6 Complete Computer Control

The above requirements are best implemented by eliminating the human interface element and allowing complete computer control of the test program. Without it, the manhours expended increase development costs. Simple errors cause program delays and confidence in the final product is lessened.

3.1.3.7 Tool Provision

There are two possible ways to provide a set of tools meeting the above requirements.

3.1.3.7.1 Totally Digital Simulation. Using this technique, the flight computer, converter, and all interface units are simulated on a general purpose computer. It has the advantage that access to data within the 'flight computer" is very easy to obtain and the analysis of problems is simplified. More analysis can be made as the program proceeds because the operational flight program is not executed or exercised in real time. However, the non-real time operation has definite disadvantages also. First, real time to execution time ratios of 300:1 are possible. This makes the large scale general purpose computer time very expensive. Secondly, the slowness of operation means that a complete evaluation of a program can cause considerable delays in the development compared to the same checks being made in real time. Further, man in the loop control is extremely difficult to implement in non-real time. Another problem with this implementation is that the simulation of the flight computer is never an exact model of the real thing. Therefore, confidence in the results is less than if the program were exercised in the actual flight computer. A further problem is the size of computer required. Fully digital simulation requires large, powerful general purpose computers. These are extremely difficult to obtain, control is harder to achieve, and their cost for initial installation and maintenance is very high.

3.1.3.7.2 Hybrid Simulation. This technique utilizes the actual flight computer and converter set and any of the avionics subsystems that operate identically on the ground or in the air. Those portions of the system that are sensitive to their environment are simulated. The airframe, atmosphere and sensors are simulated as in a fully digital simulation. The hybrid configuration has the advantages of operating in real time, providing confidence that the computer complex will not behave differently than the airborne computer complex. Additional advantages include the ability to give man in the loop capabilities, and the usefullness of smaller and more inexpensive computers. The price of all of this is that it is harder to obtain visibility of the computer programs as they operate.

3.1.3.8 Hybrid Approach

In view of the relative advantages and disadvantages between pure digital and hybrid simulation, SMAMA felt that the most useful approach to satisfy the overall requirements for tape development was the hybrid approach. This study is an evaluation of that approach.

3.2 POTENTIAL APPROACHES CONSIDERED

3.2.1 Groundrules

Certain groundrules had to be established near the beginning of the study to assure that the recommended tape verification facility would satisfy basic requirements and also to somewhat limit the number of approaches considered. These groundrules were determined by looking at the general problem of maintaining and validating the F-111 operational flight programs and reviewing existing capabilities in this area in order to point out deficiencies which must be reduced or, if possible, eliminated.

Two methods currently exist that could be used for verifying operation of the flight programs. These methods were used by Autonetics during the avionics development program. First, the program for each computer (General Navigation Computer [GNC], Weapon Delivery Computer [WDC], and Navigation Computer Unit [NCU]) is tested in a stand-alone configuration. This method is called tape verification tests (TVT). Next, the three programs are integrated in static compatibility demonstration test using the ITE. In this latter test, the three programs are integrated only during a 'free inertial" navigation run. For subsequent demonstration tests, the NCU does not participate. The ITE was primarily designed as an interface test aid, but can also be used to a limited extent for flight tape checkout. The inadequacies of the ITE for this purpose are pointed out in detail in Section 5.6. Basically, these deficiencies are limited control of inputs, insufficient capability for data monitoring and gathering, and inability to create actual dynamic flight conditions. Although the ITE has been shown to be inadequate for overall flight program verification, it is the only capability SMAMA has. Therefore, it is recommended that the test station be left intact to be used as an interface test aid and, to a limited extent, as a backup facility.

TVT was the method used by Autonetics for the formal functional qualification of the F-111 program tapes during the initial stages of tape development. It consisted of a collection of software tests which verified the functions contained on the GNC and WDC program flight tapes (separately) using only the IBM 4-PI computer to simulate necessary flight equipment and interface signals. The only flight hardware used were the two 4-PI computers as shown in Figure 3-1. One computer contained the test control software and was designated the primary computer. This software then exercised the functions contained on the flight program tape, which was loaded in the secondary computer. This fact alone points out one of the major TVT deficiencies in that only one flight program could be verified at one time with no simultaneous operation of the GNC and WDC program tapes. Another major deficiency was that the only actual flight hardware used were the two computers. All the other hardware necessary to exercise the flight programs were simulated with software. This not only meant that there was no way to check the interface and synchronization of the system, but also it resulted in the test control program being very dependent on the flight program. It is difficult to use software to simulate all the detailed characteristics of the actual hardware. In many cases, changes were made to the flight program which were still compatible with the hardware, but turned out to be incompatible with the software simulation. This required that modifications be made to the test control program, causing long time delays in verifying a flight program after a new assembly had been made.

TVT was primarily designed for final program tape verification. A predetermined flight profile was "flown" automatically. Manual control was awkward which made it practically useless as a troubleshooting or debugging tool. It was difficult to make repeated tests of a specific function without rerunning the entire mission profile because there was no convenient way of reinitializing the flight program to a particular set of conditions.

TVT was run open loop. There were no data resulting from flight program computations being sent back through the system. These data were only recorded and compared against a set of predetermined verification values. Recording of these data required modifications to the flight program to create a data pump. These modifications consisted of a small interface subroutine which was placed in unused memory locations. In some instances there was not sufficient unused memory and some of the flight program code had to be overlayed. In both cases, the flight program being exercised with TVT is not identical to the program tape actually being flown in the aircraft.

In the initial stages of development of the F-111 program tapes, some effort was put into building an F-111 hybrid simulator. Although the project was discontinued before it reached its full potential, it was operational to an extent which allowed some modes to be exercised. It was primarily designed to check navigation steering and weapon delivery mechanization. There were two phases of development. In the first phase, some of the simulation was done with an analog computer, particularly the aerodynamic model. The second phase was completely digital. Due to the lack of reliability and accuracy of the analog equipment, the digital simulation was found to be far superior.

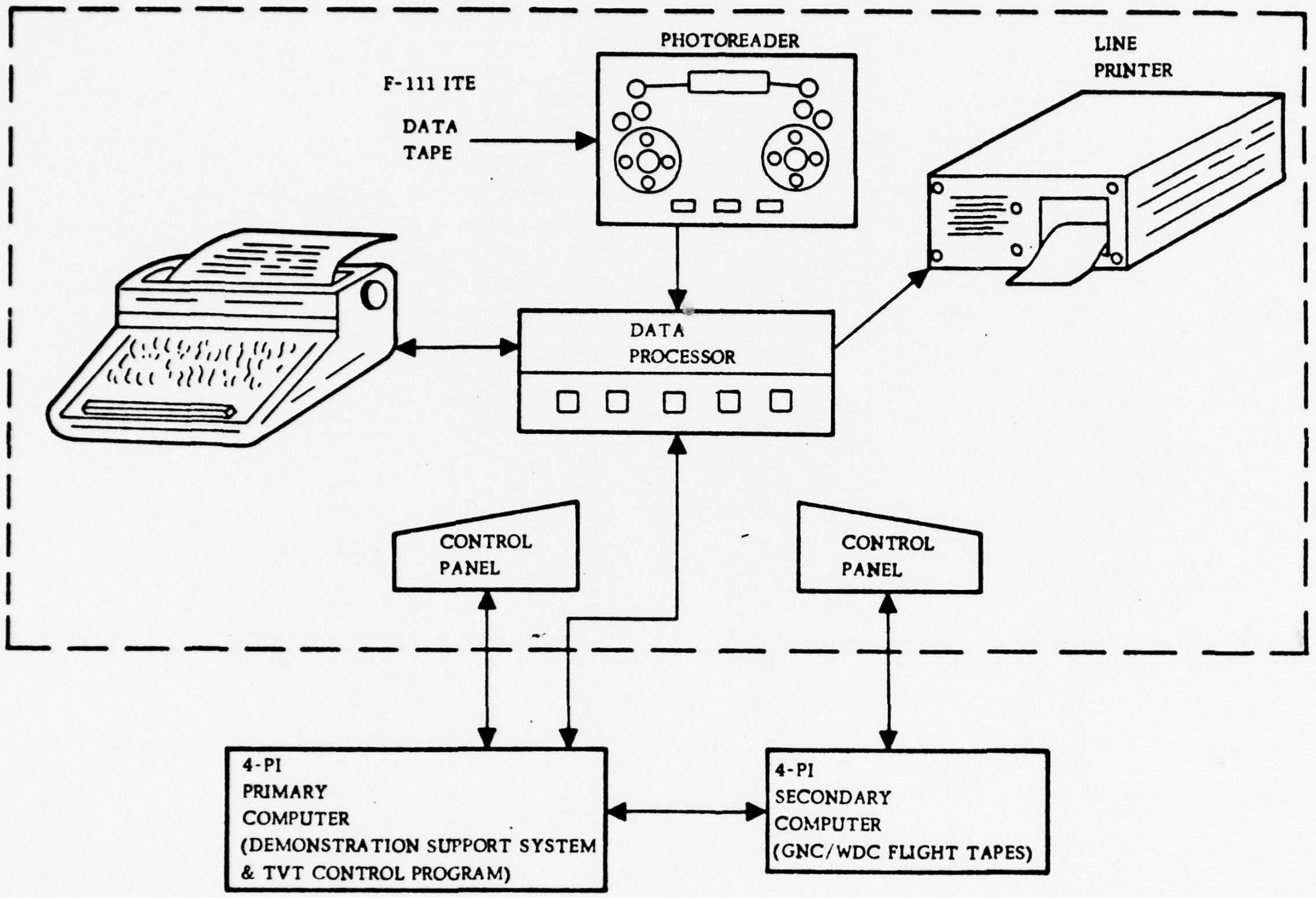


Figure 3-1. Tape Checkout Station Hardware Configuration

After reviewing the past and present simulation capabilities, and pointing out deficiencies with consideration of the problem at hand, the following groundrules were established as guidelines for the approach to be taken.

1. Simulation computers to be digital.
2. Capability to exercise the flight computers as a system (i.e., simultaneous operation of the GNC, WDC, and NCU).
3. Capability to run closed loop.
4. No contamination of the flight program.
5. Include as much actual avionics hardware as possible, considering time, cost, and realism.

3.2.2 Configuration Options

Once the basic groundrules had been established, other options were studied. Some of these were consideration of modifying the ITE to be included as part of the simulator, automatic control versus "man in the loop" operations, and decisions as to what hardware should be used and what should be simulated.

It was decided to use the existing nosebay mockups to house the avionics hardware. Rationale for this decision is presented in Section 5.4.

It was also determined that "man in the loop" and automatic control are complimentary in flight program maintenance and verification. The need for both exists. One of the basic requirements of a simulator is the ability to search for a problem. To do this efficiently, the inputs should be under control of the operator. This would be advantageous in that the simulation would not be constrained to a pre-determined mission profile. For reproducing and solving problems, the ability to run specific modes or functions individually is needed. Once a problem area has been isolated, repeated tests could be made exercising that specific portion of the flight program. The man in the loop would have complete control of the simulated flight and would be free to select any mode of operation and variances of these modes. A "man in the loop" simulation could also be used in support of final tape verification. Used in this sense, it would be more of a mode verification in that it would verify whether a mode functioned properly, but it would be lacking in checking the accuracy of the flight tape mechanization. There would be a loss of accuracy due to the inability to manually duplicate inputs in repeated runs. The major portion of final tape verification requires that precise inputs be used and that outputs be checked against precomputed answers for accuracy. This is best done by removing the man from the loop and generating a predetermined (canned) flight profile run entirely under computer control. Final checkout would be made by comparing results against a standard profile. This standard profile would not change between different versions of the flight program unless the actual functions were altered.

The distinct phases of flight program maintenance, problem reproduction, problem solving, debugging and final verification could be handled efficiently with these two capabilities.

It would seem that the optimum way to build a simulator would be with all of the avionics hardware included to duplicate the operational system. However, this introduces the problem of "how to stimulate the sensors." It would then be necessary to simulate the environment for which each of the sensors operate. The cost and time to develop these environments would be tremendous and reliability, maintenance/calibration and resulting availability problems would increase. The net result in using the actual sensors is that the task of simulating these sensors is transformed into a more difficult task of simulating their environment. Since the primary purpose of the simulator is to maintain the flight programs, software simulation of the sensors would give them more flexibility and possibly more realism. Additional hardware versus simulated hardware rationale as well as detailed equipment listing are presented in Section 5.

3.2.3 Phase Development

To get maximum use out of a simulator as soon as possible, it is necessary to plan a multiphased development. A detailed plan is given in Section 5.5. In general, Phase 1 will support operation of all the modes and functions of the flight program tape with the exception of the following.

1. Astrocompass Model (FB-111 only)
2. Air-to-Air Radar modes (F-111D only)
3. Takeoff and landing modes
4. Error/Noise injection into models

The above could be added during Phase 2 or when desired/required.

Phase 3 will include:

1. SRAM Missile model
2. HUD stability and accuracy tests

In order to keep a smooth transition between different phases, it is recommended that the simulation routines be modular. The addition of new models would have no effect on existing models. The only modifications necessary would be to the executive subprogram to include scheduling of additional models. This type of structure would also be beneficial for maintenance and control over the total software simulation package.

4. HISTORY OF PROJECT

4.1 GENERAL

The F-111 avionics program has completed the production cycle and the equipment is becoming operational. The Air Force Engineering responsibility for the F-111 flight programs is presently being transferred to SMAMA. As a result of its role as prime contractor for the MARK II Avionics, Autonetics is presently under contract to SMAMA for perform F-111 MARK II Engineering Services. This contract was amended in July 1973, to include an engineering study to establish the feasibility of a digitally controlled simulation facility that would be used by SMAMA for F-111 flight program maintenance and/or development.

The SMAMA responsibility covers programs for the FB-111A, F-111F and F-111D. Implicit within the responsibility is the requirement to provide program revisions to the operating commands at least once each year. SMAMA has defined procedures for preparation and configuration control of the programs. There are several possible alternate approaches toward tape verification and checkout that are discussed in other sections of this report.

It should be noted here that tape program support has become extremely important in modern avionics due to increasing use of computer controlled weapon delivery systems. Lack of provisions for dynamic ground testing results in expensive and time consuming flight test verifications that will never catch all of the errors in the computer program. This is due in part to inadequacy of in-flight instrumentation and inability to identify, intentionally enter and exactly reproduce conditions in which subtle problems can occur. The result of incomplete software validation is decreased operational capability and flight-crew confidence along with apparent maintenance problems within the operational commands.

The study was started with a thorough review of the F-111 hybrid simulation previously performed by Autonetics. It was concluded from this review that substantial documentation is available to support a fully digital simulation program and that such a program is feasible.

The F-111 "problem book" was reviewed and the problems documented as of 1 July 1973 were organized by categories that indicated a need for dynamic verification of problem solution for approximately 25 percent of the existing, identified problems. Additionally, solutions of a majority of all of the identified problems will require tape revision (>80 percent for FB-111A).

A baseline simulation concept was defined that was ultimately refined to the hardware/software configuration described in this report. This refinement was performed with guidance from two primary areas: on-site participation by Mr. Larry Thompson of SMAMA, who provided insight into SMAMA's task and goals; and; visit and consultation with personnel at Naval Weapons Center, China Lake, California, who have a similar tape responsibility for the A-7 flight programs.

5. SUPPORTING DOCUMENTATION

5.1 GENERAL

This section contains the detailed results of the study. These results consist of the following information:

1. Definition of the hardware baseline recommendations. This baseline, with associated software, is sufficient to allow the dynamic software test and evaluation and can be expanded in hardware/software mix and complexity as desired to extend or modify the approach.
2. Conceptual definition of the software. The recommended software partitioning is defined with emphasis in detail placed on the Real World Simulation System (RWSS) and the Subsystem Simulation System (SSS).

   Autonetics feels that these two software systems should receive primary early development emphasis within bounds, limitations or groundrules of the other systems.
3. A discussion of alternate discrete sensor approaches and variations in intended use of the simulator.
4. Discussion of the trade-offs considered during the conceptual design and the reasons for the choices selected.
5. Description of the recommended program (and magnitude costs) for attaining the recommended simulation capability.
6. Rationale for extending the existing capability to include dynamic simulation.

5.2 BASELINE APPROACH

The F-111 baseline simulation system was derived by examining four major factors. These were (1) the requirement to rapidly reproduce and correct operational flight program (OFP) problems (2) to maintain the integrity of the OFP during test and evaluation, (3) to test, verify and evaluate all OFP's collectively in a dynamic environment short of flight testing, and (4) comparison of the aforementioned factors with existing and/or post-simulation facilities. The factor which contributed most to the baseline design approach was maintaining the integrity of the OFP's. This meant that no contamination of any OFP would be allowed during test and verification. Hence, debugging aids such as data pumps, external synchronization, etc., were not to be used. The no risk approach to achieve this goal is described below.

5.2.1 Hardware for the Baseline Simulation System

Figure 5-1 is a block diagram of the F-111 baseline simulation system. The system can be characterized as being digital, modular, and under complete manual or computer control at the operator's option. It is envisioned that two identical system configurations will exist; one for the F-111D and one for the FB-111A/F-111F. The

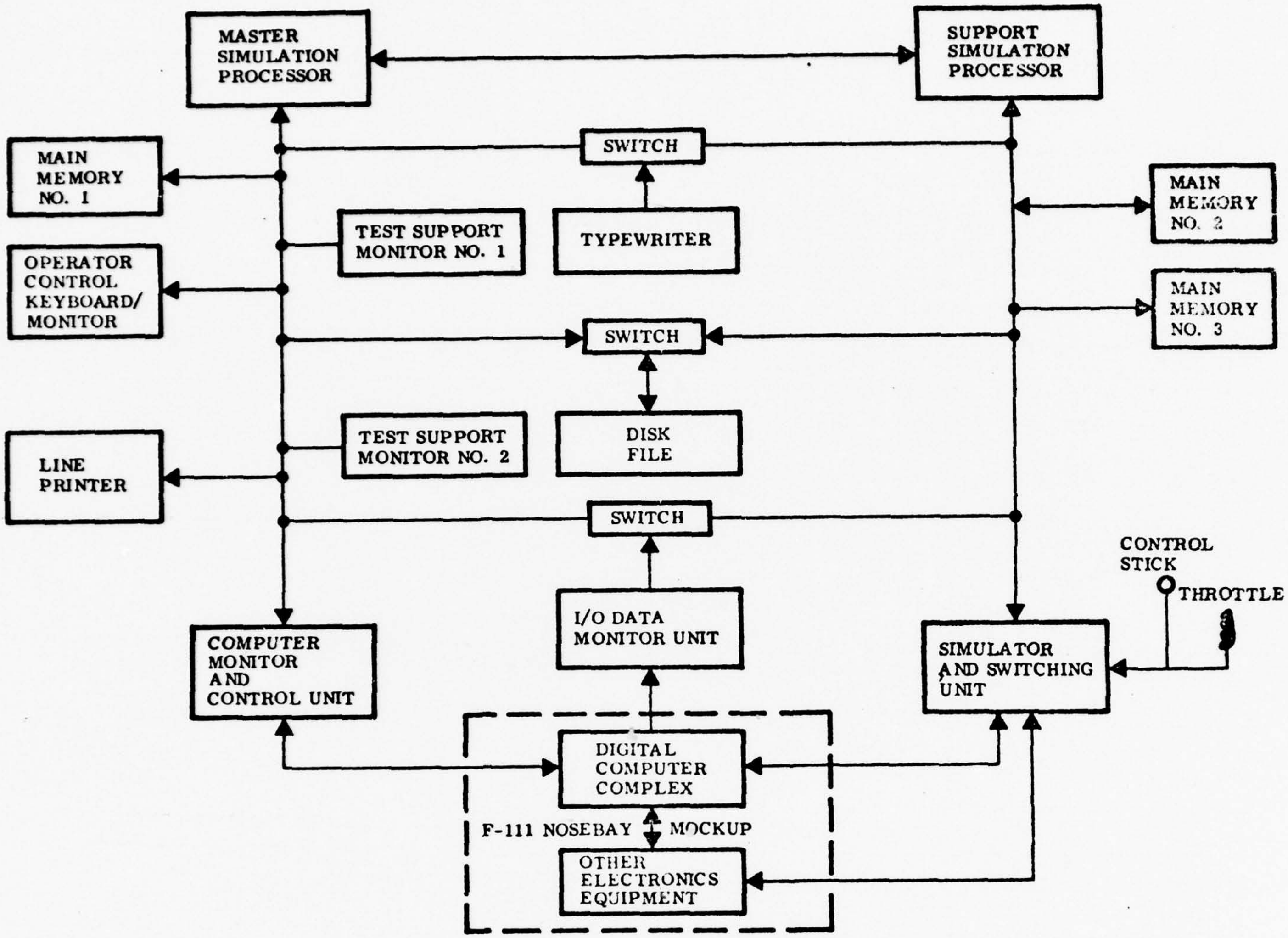


Figure 5-1. F-111 Baseline Simulation System

only hardware that is unique for each system configuration is the simulator and switching unit. However, even within this unit there are functional modules which are identical for all F-111 systems. The paragraphs below describe each major hardware item shown in Figure 5-1. In addition, the primary role within the simulation system is noted.

5.2.1.1 Bus Interfaces

All hardware, connected to either simulation processor, is interfaced via an asynchronous high speed bus. All data transfer is initiated by the processor. The maximum throughput of either bus is one million (16-bit) words-per-second.

In addition, a link exists between the processors. This link provides for the transfer of a single word or block of words over a direct memory access (DMA) channel. The maximum throughput is 250,000 (16-bit) words-per-second.

The above two interfaces are based on the PDP-11 family of computers. In particular, they correspond to the UNIBUS data path and DMA UNIBUS link respectively.

5.2.1.2 Switches

The bus switches shown are used to time-share a device between two processors. Each switch is both software and manually controllable. The switch is based on the PDP-11 UNIBUS switch.

5.2.1.3 Master Simulation Processor

The role of this processor is to act as the system supervisor (or test controller). The majority of the man/machine interactions will be handled by this processor. Such functions as interface switching, test setups, test operator commands and/or requests, and control of the other processor are handled herein. The processor selected is the PDP-11/45 with floating point capability.

5.2.1.4 Support Simulation Processor

The primary role of this processor is to execute the subsystem and air vehicle digital models. The data interchange required with the F-111 system under test is with the simulator and switching unit. When dynamic (time varying inputs) simulation is desired, control can be either from the master simulation processor or overriden by the control stick and throttle interface as shown in Figure 5-1. The processor selected is the PDP-11/45 with floating point capability.

5.2.1.5 Main Memory No. 1

This memory, associated with the master simulation processor, will contain 48K (16-bit) words. The cycle time is 900 nanoseconds. The memory selected is the PDP-11/45 magnetic core memory.

5.2.1.6 Main Memory No. 2

This memory is associated with the support simulation processor. It will contain 32K (16-bit) words with a cycle time of 450 nanoseconds (MOS Memory) and

16K (16-bit) words of core memory. This higher speed memory (from the core) is required because of the large number of matrix, transcendental and trigonometric manipulations associated with the models. Further, many calculations involve double precision floating point which require four memory accesses. Because of the expected high duty cycle usage (based on Autonetics hybrid simulator effort and data from the A-7 simulator system at the Naval Weapons Center, China Lake), the faster memory is justified.

5.2.1.7 Main Memory No. 3

This memory is identical to Main Memory No. 1 except is contains only 16K (16-bit) words. Its primary usage will be to enable interprocessor data transfers over the DMA UNIBUS link. It will also store those software modules not directly associated with model execution.

5.2.1.8 Typewriter

This peripheral will be time-shared between the two simulation processors. Its primary role is to provide individual off-line computer control during system build-up and initial turn-on sequences. The device selected is the DEC writer data terminal.

5.2.1.9 Operator Control Keyboard/Monitor

This device is the primary test operator interface with the F-111 system under test. Using software stored in the master simulation processor, the operator can command and/or make requests to control the simulation system. Operator actions include F-111 system mode control, data entry, display requests, key-in patch corrections to the OFP and model/mission profile setups. All keyboard entries will be recorded either on the line printer or the typewriter. When this device is operative, no other keyboard device can be used to initiate system control actions. The specific unit selected is the DEC alphanumeric video display terminal. The CRT can display up to 1440 characters simultaneously. Other features include direct character addressability and display of video from a TV camera simultaneously with computer-generated alpha-numeric data.

5.2.1.10 Test Support Monitor No. 1

This unit will be primarily used to control the simulation of serial channels to the F-111 converter set. Up to three channels can be setup via this device. The monitor is a CRT which will display the data being transmitted over the serial channel. Also included would be the control bits status and data addresses. The display of all data variables will be in either engineering units or binary as requested by the operator. The unit selected is identical to the operator control keyboard/monitor described previously. This monitor will be used as backup for the primary operator control keyboard/monitor should the latter fail.

5.2.1.11 Test Support Monitor No. 2

The primary role of this device is to monitor the parallel transfers among the elements of the Digital Computer Complex (DCC). These data transfers occur at four points as shown and discussed in para 5.2.1.14. Monitoring at points 1 and 2 provides the capability to display all external data entering and leaving computer memory.

It also provides the means to monitor I/O throughput. Points 3 and 4 will permit monitoring the intercomputer data transfers. The same display/keyboard options exist as discussed for Test Support Monitor No. 1. This unit is also a DEC alphanumeric video display terminal.

5.2.1.12 Line Printer

This peripheral will provide for large printouts of data, memory dumps, traces, etc. It can also be used to record all operator interactive conversation with the PDP-11/45 computers. The device selected is a medium speed (300 LPM), 132 column, 96 character printer or equivalent.

5.2.1.13 Disk Drive

This mass memory device will store all test modules to be executed in the simulation processors. In addition, data associated with static and dynamic testing of F-111 systems is stored. The switch permits either simulation processor to access the desk individually. Further, the OFP's for the GNC and WDC will be stored in this device. Initial loads of the DCC will be controlled from the operator control keyboard/monitor after the simulation processors have been brought on-line. The device selected is a DEC moving head disk system. The capacity provided is 1.2 million (16-bit) words on a removable disk pack. It is primarily via the removable disk pack that an FB-111A test setup can be converted to an F-111F setup.

The hardware descriptions thus far have been related to the PDP-11 family and associated peripherals. This hardware represents an investment which can be used for any system, not just F-111. While the complement of equipments is tailored to fit the early needs for an F-111 simulation system facility, the growth to accommodate a larger complex is inherent in the PDP-11 design. This growth, unique to the F-111 systems, is discussed later in this section.

The equipment to be described now relates specifically to the F-111. They are the "black boxes" necessary to provide the interfaces between the test control hardware (PDP-11 family) and the F-111 system under test.

5.2.1.14 I/O Data Monitor Unit

The primary role of this unit is to monitor selected data sets being transferred within the DCC. The interfaces to be monitored are shown in Figure 5-2. Interfaces 1 and 2 are externally controlled inputs (ECI), i.e., the converter set must initiate all information transfers to/from the computers (the computers are IBM 4PI CP-2 digital computers). Information transferred can be data or I/O instructions, the latter going from the computer to the CS only. Computer memory accessible to the CS (and hence the data monitor) lie between addresses 2048 and 4095. To the CS, these addresses correspond to 0 to 2047, respectively. Based on the current F-111 memory map design, the I/O instructions (which are accessed by the CS for execution) are stored in the lower end of the 2048 word block. The external I/O data are stored in the upper portion.

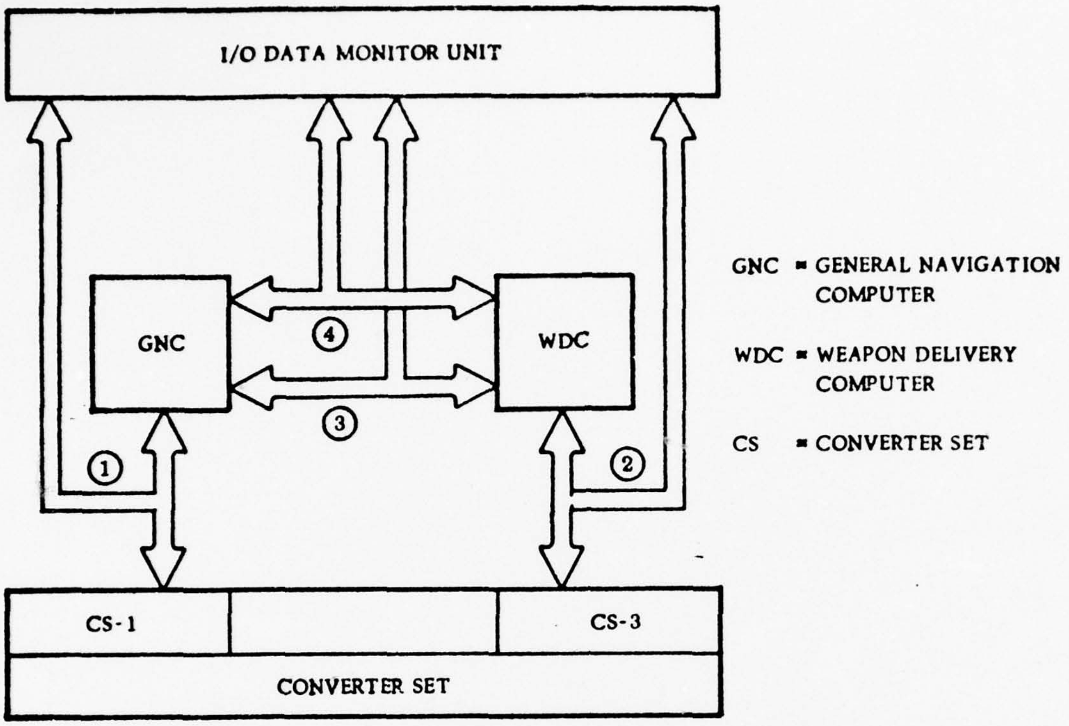


Figure 5-2. I/O Data Monitor Interfaces With DCC

The I/O data monitor unit will be designed to provide the following capabilities:

1. Monitor all words to/from any serial channel in a block
2. Monitor any single word to/from any serial channel
3. Monitor any group of consecutively addressed nonserial words
4. Monitor any single or paired nonserial words (such as radar altitude or sine/cosine pitch, respectively).
5. Monitor all I/O instructions for a particular rate group
6. Measure the I/O throughput for each rate group

To accommodate the worst case rate group, a 512 (17-bit) word buffer would be provided in the data monitor unit.

Besides the monitor capability of interfaces 1 and 2 (Figure 5-2), growth will be provided to load parameters directly into the 2048 computer memory block or extract data. That is, this unit will be able to simulate the CS interface and initiate data transfers with computer memory. This capability will enable the test operator to perform a tape verification test of the F-111 OFP resident in both IBM 4PI computers. This collective testing of flight programs would add another measure of confidence to the acceptability of the software.

Interfaces 3 and 4 (Figure 5-2) will be monitored to enable the test operators to verify proper intercomputer data transfers. These parallel channels are Program Controlled Outputs (PCO), i.e., all transfers are initiated by the sending computer. The importance of monitoring this channel is related to the functional redundancy and partitioning concept. For example, during a full operational configuration (a fullup DCC), the target acquisition parameters used by the weapon delivery computer, originate in the GNC. They must be transferred from the GNC to the WDC. Such problems as transport lag and intercomputer synchronization would be easier to identify and resolve with this monitoring capability. The growth to simulate the PCO operation will also be accommodated for interfaces 3 and 4. This will enable the test operator to insert variables directly into computer memory. However, this would be primarily a debugging aid rather than an operational test and verification tool.

The specific operation of this unit will be under control of the test operator. Test Support Monitor No. 2 will be the primary interactive device. All data for display will be routed through the master simulation processor in order to generate the proper format. The I/O data unit will be designed in a modular fashion to ensure growth capability for data injection as well as ease of maintenance.

5.2.1.15 Computer Monitor and Control Unit

Just as the I/O data monitor unit "listens" to transfers external to the computer (IBM 4PI), this unit enables the test operators to "listen" to information transfers internal to the computers. Its primary purpose is to assist in testing, checkout, optimization and measuring duty cycle and instruction mixes in real-time. The unit will provide an interface with each IBM 4PI computer memory bus through the AGE connectors. This interface enables the test facility to monitor all memory transfers between the CPU and I/O. This capability would obviate the necessity to provide a software data pump in either or both OFP's.

This device has already been designed and built for a version of another IBM 4PI computer, specifically the one used in the A-7 aircraft. However, the memory bus structures are identical. The unit is being used currently at the Naval Weapons Center, China Lake. Some of the typical functions of this unit include (for each 4PI computer):

1. Display of the contents of any word in memory. The displayed information would be updated each time the selected address contents was read from or loaded into the memory cell.

2. Provide a breakpoint register. Whenever the memory location specified in the breakpoint register is accessed, an interrupt would cause computer operation to halt. This action would also be used to control simulation/test activity. This feature would also stop real-time clock counter operation so that a restart could occur without major reinitializations.

3. Provide upper and lower limit registers. Whenever the memory location being accessed is between the register limits, a signal can be generated. Under operator control, the signal would cause a halt (similar to breakpoint), identify when a multiple loop has been entered, or find the execution time of a loop.

4. Perform a continuous trace function. The unit would store the last "n" data and instruction addresses. An indicator to differentiate between the two would be provided. Whenever a computer stoppage occurs, the trace would provide the information to debug the cause of the error trap, malfunctioning loop or unexpected halt.

5. Allow single step instruction execution once the computer had been halted. (Either automatically via breakpoint, etc., or manually.)

6. Provide for miscellaneous aids such as determining (1) execution time of any routine or segment thereof, and (2) instruction mixes, etc.

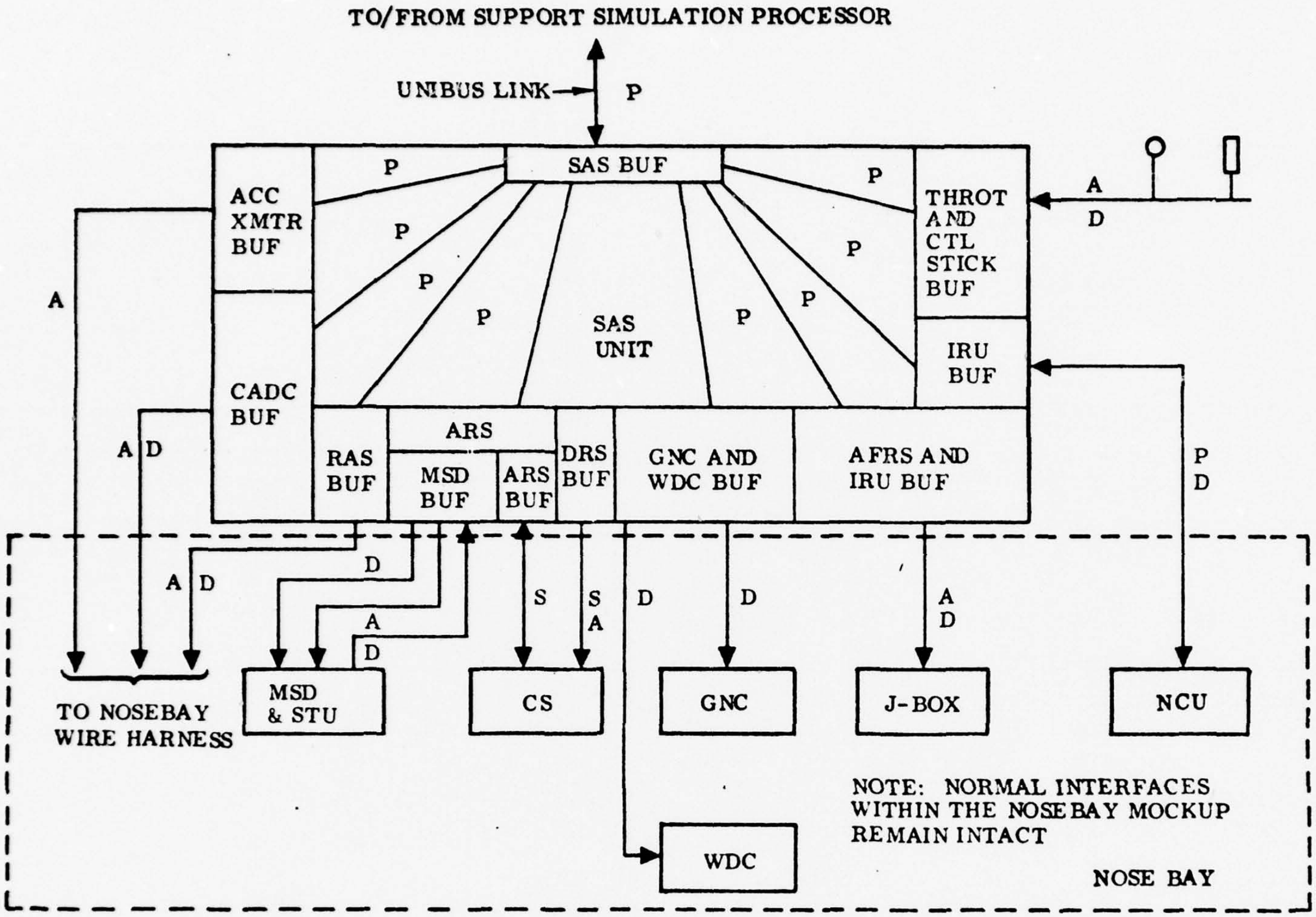
One of the most important uses of this interface unit will be to load the OFP's initially into the 4PI computers. In addition, the capability to load key-in patches and dump memory onto the line printer is also facilitated by the unit. Further design details of this unit can be found in Ref 8.

5.2.1.16 Simulator and Switching Unit

To test an F-111 system, there are two items in the baseline simulation that must be unique. One is the disk pack. The other is the simulator and switching unit. This unit provides the direct interface with the applicable F-111 converter set for all simulated signals computed in the support simulation processor (see Figure 5-3). In addition, manually entered data for any serial channel transfer to the converter set will also be routed through this unit.

The functions of this unit can be characterized by examining its interfaces. There are four primary interfaces; DCC, nosebay mockup, control stick/throttle, and support simulation processor. The DCC interface will provide electrical compatibility for all signals generated by any portion of the simulation system. These include discrete inputs to both IBM 4PI computers, and discrete, serial and analog inputs to the converter set. The mechanization of this interface must be such that whenever a simulated signal is to be routed to the DCC, the actual signal originating within the nosebay mockup must be switched out. This switching function if not accomplished by physically unplugging the connector, will be handled in this unit. It is noted that not all signals simulated by the simulation system will enter the DCC directly. Some, such as air vehicle pitch and roll, will be routed to the J-Box in the mockup. These simulated signals would replace those normally coming from the attitude sensors (such as the inertial reference unit and auxiliary flight reference system). The specific subsystems whose signal interfaces must be accommodated by this unit are identified in Figure 5. 3.

The second interface of this unit is with the F-111 nosebay mockup exclusive of the DCC. Any simulated signal must also have its actual counterpart routed into this unit for appropriate switching. An example would be the doppler radar. Since it would be desirable to permit this radar to interface in its normal manner with the DCC, as well as be simulated, its interface must be routed through this simulator and switching unit. The test operator would, as part of the test setup, make the appropriate hookup (i.e., actual or simulated). Also, as mentioned above, certain simulated signals will be routed directly to the nosebay. For example, the Central Air Data



P = PARALLEL
S = SERIAL
A = ANALOG
D = DISCRETE

Figure 5-3. SAS Unit Functional Interfaces Approach

Computer (CADC) will be simulated. This unit would provide outputs identical to those of the actual CADC. Hence, they can be routed directly to the applicable hardware in the nosebay mockup.

The Navigation Computer Unit (NCU) is a digital computer, not a part of the DCC. It is dedicated to operate with the inertial reference unit (IRU) and normally receives a clock interrupt signal from the IRU. Since the IRU will be simulated, this clock signal must be provided for in the design of the simulator and switching unit. The clock provides the system timing for the inertial computations being executed in the NCU. The clock signal must provide for a 64/sec clock interrupt to the NCU located in the nosebay. As a possible means to minimize the number of different clock sources used by the various test and operational computers, it is recommended that this 64/sec clock signal also drive both simulation processors.

The third function of the simulation and switching unit is to accept inputs from a simulated control stick and throttle. Provision is being made, via this interface, to permit the test operator to "fly" the digital air vehicle models manually in addition to implementing canned mission profiles. Hence, anytime these hand grips are activated, the air vehicle models will use them as an override. Reverting back to canned mission profiles will require positive test operator action via the control keyboard/monitor device.

The final interface is with the support simulation processor via the UNIBUS data channel. All signals destined for the F-111 system under test will be transferred over this bus. It is important to note that some simulated interface modules will be common among the F-111 systems. For example, the IRU interface with the NCU is identical for all F-111 systems. Similarly, the CADC interface is very nearly the same. Since both of these would be simulated in any test configuration for any system, their hardware interface modules should be designed to be compatible with any simulator and switching unit. In order to provide commonality, time-sharing of hardware circuits is not recommended for these modules. Also, by having identical hardware interface modules among the systems, the software control/test modules can also be used in various systems.

5.2.2 Software for the F-111 Baseline Simulation System

The software to be developed and/or acquired for execution within the Baseline Simulation System has been segmented into six categories. These are:

1. Executive Operating System (EOS)
2. Man/Machine Interactive System (MMIS)
3. Subsystem Simulation System (SSS)
4. Real World Simulation System (RWSS)
5. Peripheral Device Handlers (PDH)
6. Data Base Management System (DBMS)

The partitioning of these software packages into the three primary simulation system hardware items is shown in Figure 5-4. Each software package is described below.

5.2.2.1 Executive Operating System (EOS)

This software will be a modified version of DEC real time system executive (RSX-11D). The primary functions are:

1. PDP turn-on initialization
2. Multi-PDP handshaking
3. Scheduling of test/simulation modules
4. PDP simulation system test
5. Real Time Control and monitoring
6. System I/O control

It is envisioned that the majority of test/simulation software modules will be resident in main memory. These modules are loaded initially from disk storage. The emphasis

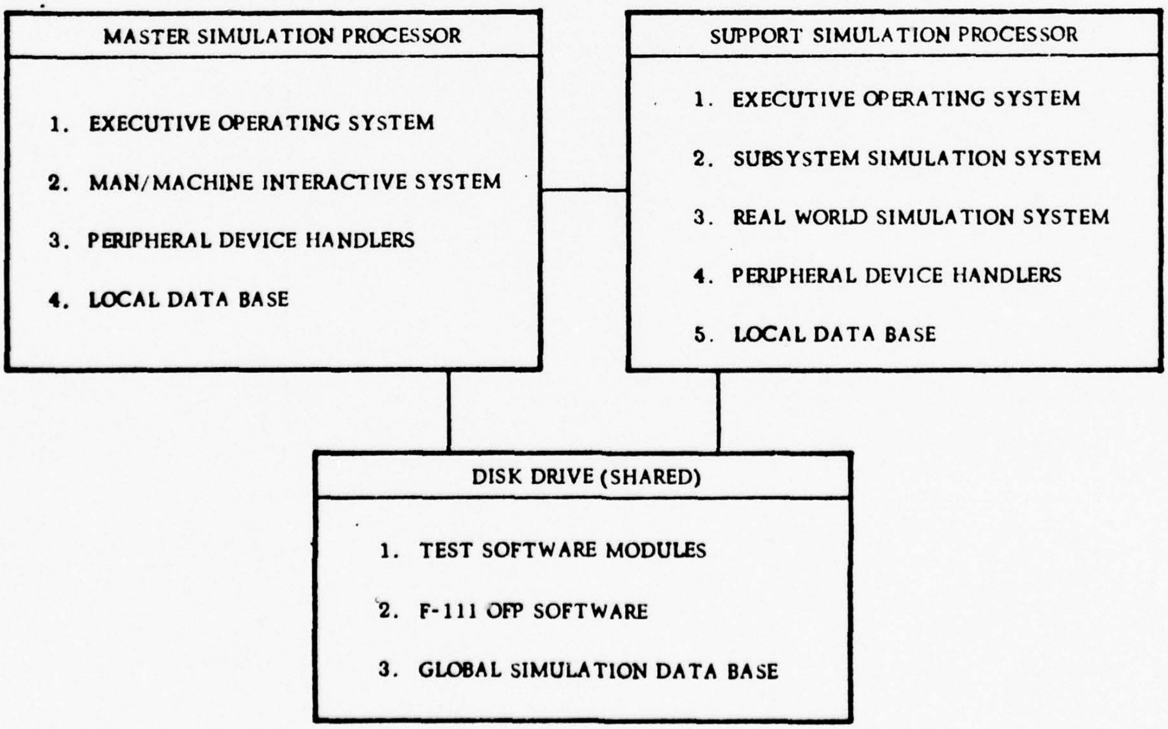


Figure 5-4. Software Partitioning for the Baseline Simulation System

is to minimize roll in/roll out of modules. This uses processor duty cycle which is at a premium. However, due to resident memory capacity, certain modules, such as periodic status report generators, background-type modules, and other nonreal time tasks, will of necessity be stored on the disk. It is the responsibility of the EOS software to control this interchange in order to have optimum duty cycle utilization for test module execution.

5.2.2.1.1 PDP Turn-on Initialization. This function will react to primary power application. Its primary purpose is to orderly transition the processors to a predictable state in order to initiate additional EOS functions. As a minimum, a gross hardware self test will be conducted. Passage of this gross test will ensure the operator that the turn-on sequence is proceeding normally.

5.2.2.1.2 Multi-PDP Handshaking. This function determines the availability of other PDP processors which must be coordinated and brought on line. The baseline approach will be to designate one PDP as the Master Simulation Processor with the other PDP providing support. The specific support would be established by the Master as directed by test operator. The multi-PDP status will be provided to the operator. There will be no automatic reconfiguration performed in the event of primary PDP system hardware failures. Some form of multi-PDP clock synchronization may be required in order to obtain repeatable and coordinated test results.

5.2.2.1.3 Scheduling of Test/Simulation Modules. The scheduling algorithm will be simple in order to minimize executive overhead. Hence, it is recommended that all modules be permanently scheduled within their particular rate group. Further, to allow for multiple contractors to generate specific test modules, a standardized interface would be established between the schedules and the modules themselves. This approach also provides a flexible structure for future changes, additions, and/or deletions.

It is envisioned that all real-time test modules will be resident in main memory at all times. Additional test modules would be brought in from bulk storage as dictated by the test operator and/or EOS. A major concern is the duty cycle to be used for each of the test modules. Hence, as part of the standardized interface, provision will be made to measure the duty cycle of each test module whenever executed.

5.2.2.1.4 PDP Simulation System Test. This function will continuously monitor the performance of the test system (hardware and software). Discrepancies will be reported to the test operator. The sole purpose of this function is to assure the operator that the test setup is operating properly. This will enable him to concentrate his efforts on the system/problem being evaluated. If, for some reason, either test processor or the disk file fail, the simulation system will be shutdown and require operator action.

5.2.2.1.5 Real Time Control and Monitoring. This function is the main "driver" of the EOS. The test modules will be scheduled in various rate groups. The specific rate group will be derived from the clock interrupts. These will be controlled either by the internal PDP clock mechanization under software management, or from an external source. The external source could be a centralized test system clock. A viable candidate would be the same clock which drives the NCU. Since the Inertial platform will be simulated, a clock, which normally is furnished to the NCU by the platform, must be mechanized. This clock will be provided in the Simulation and Switching Unit.

5.2.2.1.6 System I/O Control. All I/O including that among the test processors, test interactive devices, bulk storage, F-111 interface units, etc. will be handled by this function. The control will be partitioned such that I/O signals related to the F-111 system under test will be separated from test hardware-oriented signals. The programs for I/O operation will reside in each applicable PDP processor. Activation of any one segment of the I/O program will be initiated by the real time control and monitoring function.

5.2.2.2 Man/machine Interactive System (MMIS)

This software interprets the test operator's commands/requests and takes the appropriate action(s). For the baseline simulation system, the primary functions included herein are:

1. Data/Command entry and disposition
2. Data/Status formatting and display
3. Test setup and configuration control
4. OFP Verification and Validation

This software package will provide the operators with the tools to communicate with the F-111 system under test in order to control its operation. With this interaction, the operators can configure the test setup to reproduce a flight program problem, insert corrections to enable him to assess the problem solution, and verify flight program operation either in a segmented or full operational environment. The operation of the Computer Monitor and Control Unit, and the I/O Data Monitor Unit are controlled by the software comprising this package. Any comparisons between pre-calculated results and actual values will be handled by the software modules of this package.

5.2.2.2.1 Data/Command Entry and Disposition. During the testing of an F-111 system, all manually-entered data and/or commands destined for the system under test will be first interpreted by this function. Procedure/format errors will be assessed. Once the inputs have been processed, dissemination of the results will take place. Hard copy recording will take place if appropriate. In most cases, the results will be sent to the applicable data blocks. From here, other test modules and/or the I/O control function will use/distribute the data. The specific interactive devices with which this function will interface are the operator control keyboard/monitor and both test support monitors.

5.2.2.2.2 Data/Status Formatting and Display. The purpose of this function will be to primarily present to the test operator, data and/or status of the current test in progress. This information will be formatted according to the desires of the operator and stored in the data base for display and/or hard copy recording.

5.2.2.2.3 Test Setup and Configuration Control. It would be desirable for the operator to configure the test setup from the interactive devices. This would include establishing hardware linkages and software module linkages. Further, the setup should be stored and/or recorded for future use and/or retest setup.

In addition, all operator actions, especially those affecting the F-111 system under test (e.g., insertion of patch key-ins, initialization data for a specific test, etc.) would be recorded. The sequence of these actions can then be used to retrace the operator's steps should it be necessary to repeat tests or debug a problem. This function would maintain a log of the test setups. Some of these setups would be pre-canned and established for specific kinds of tests and/or validations. Others would be determined by the operator during the course of a particular activity. He has the option of saving this setup for future callup. The software associated with this function would maintain these test setup configurations. Upon operator request, a "menu" of the various test setup options would be presented on the CRT. The operator could then select the setup desired and the test system would establish this configuration automatically. If manual operations are necessary (such as entering data or connecting different equipments), these would be displayed to the operator.

5.2.2.2.4 OFP Verification and Validation. Because of the importance of the SITS capabilities related with this function, Para 5.2.4 is entirely allocated for its description.

5.2.2.3 Subsystem Simulation System (SSS)

This software package consists of modules which, when executed, simulate the functional operation of the applicable F-111 subsystems. Both MKII and non MKII subsystems will be simulated. There are two types of subsystem simulation modules. These are:

1. Static subsystem interface simulation
2. Functional subsystem simulation

Since the current F-111 ITE provides a good deal of static interface capability, the main emphasis will be to develop the functional subsystem models. These models would be executed in the Support Simulation Processor as shown in Figure 5-4. However, based on the subsystems to be simulated in the baseline system, certain static interface capability will result as a natural fallout.

5.2.2.3.1 Static Subsystem Interface Simulation. The primary purpose of this software is to simulate the actual "serial" interface from a subsystem to the Converter Set (CS). For example, if the Doppler radar normally transmits three serial words in a cyclic pattern, there would be a simulation of this interface. The capability to change the words individually and/or collectively by the operator will be accommodated. In addition, the ability to setup the nondata bits (i.e., control, validity, and parity) will also be provided.

In addition to simulating serial interfaces, the ability to simulate analog interfaces will be required. For example, it is envisioned that the Analog Air Data Computer would be modeled in the test processors. Hence, it is feasible to setup the output of the model to some static configuration for the purpose of testing the F-111 system. This would duplicate the capability of the current ITE, that requires a number of "pots" to be setup to achieve the same effect.

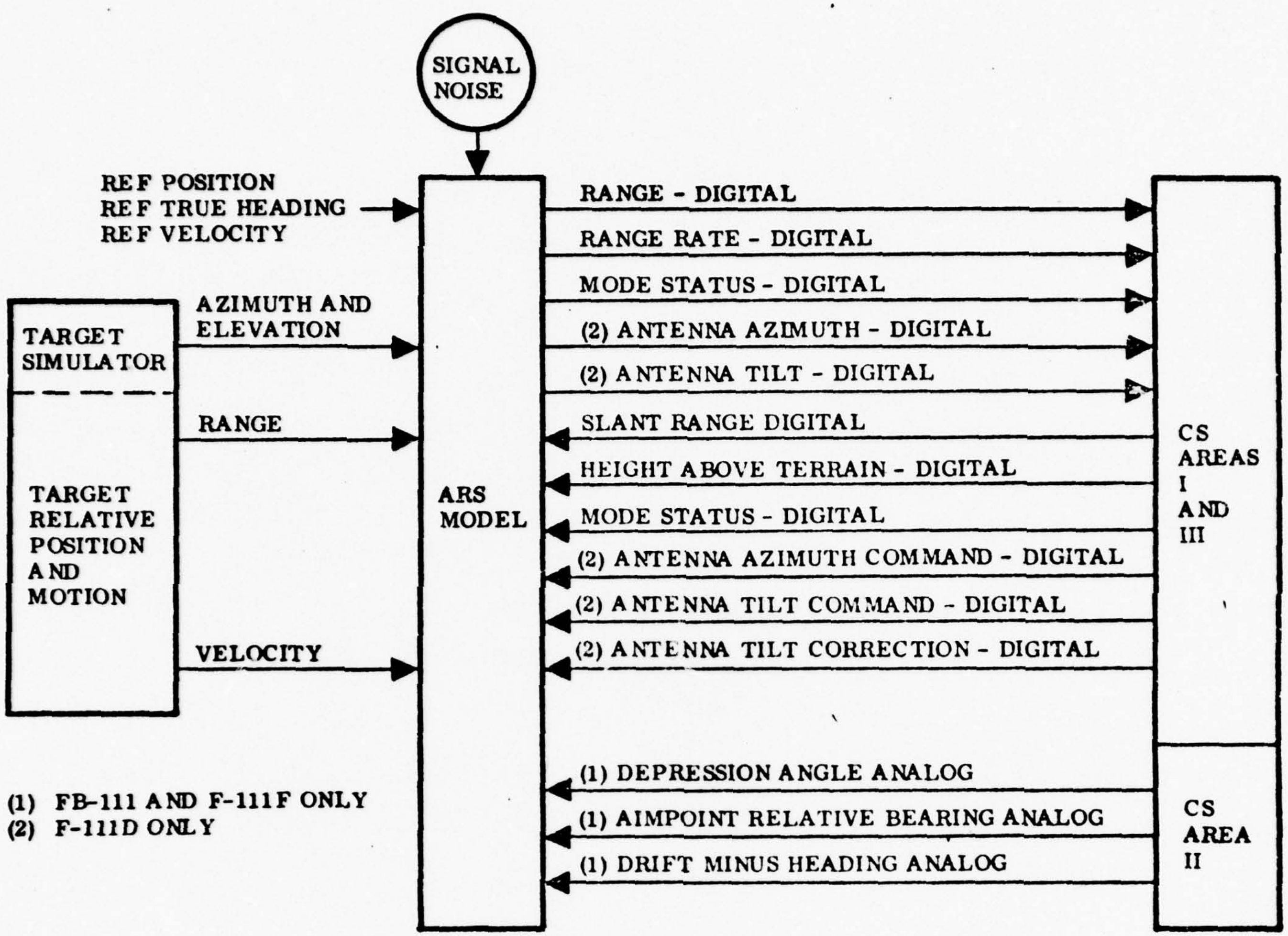
The software modules would either store pre-canned values for output or accept manual changes from the operator. These modules would be overriden whenever a functional subsystem simulation was activated by the operator.

5.2.2.3.2 Functional Subsystem Simulation. This package of software modules will be initially stored in disk storage. According to the test setup, the applicable modules will be brought into resident memory. They will be executed at the rate required to simulate subsystem functional performance. Each subsystem will be examined separately to determine the best means for simulation. The major distinction is that the models represent subsystem functional performance as opposed to hardware design. As the dynamic model computes the variables for output, the capability to control certain nondata bits (especially parity and validity) from the interactive devices would be desirable. Noise transients and/or hardware faults could then be introduced by the operator and/or at pre-canned events. The subsystem models will be capable of either open loop or closed loop operation as required by the test setup.

The functional requirements of the individual models are defined from the interface level. In all cases, the models perform two tasks. First, they transform the reference data into the coordinate system that is consistent with the actual sensors. Second, as an operator option, inputs such as bias and scalefactor errors, plus random noise, can be added to the input flow. The signal interface of each model is shown in Figures 5-5 through 5-13. The signal type (i.e., analog, serial digital, and discrete) are noted along with the differences between the FB-111, F-111F and F-111D. The figures show the signals going directly to the converter set, NCU or the J-BOX. This is simplified to show the destination within the central computer complex. Actually, the data will be collected in local data bases and sent to a main buffer in the Simulation and Switching Unit (SAS). From there it is sent to the corresponding model buffers. Up to this point all the information is digital. From these buffers, it is converted to the required signal type and sent to the avionics hardware. Similarly, the data flow from the converter set to the models is not a direct path. The loop is closed through the SAS and real world simulation system. During open loop operation, these data would be monitored to verify OFP computations but would not be fed back through the system. MK II converter set areas I, II, and III are also noted in the figures. Area I corresponds to the analog input and serial input/output for the GNC. Area III is the same for the WDC and Area II corresponds to analog output from the DCC.

5.2.2.4 Real World Simulation System (RWSS)

The purpose of this software is to generate output signals for the SSS and MMIS software as shown in Figure 5-14. From these signals, the SSS will simulate the required MK II and non-MK II subsystems identified elsewhere in this report. Also the MMIS will utilize these signals as reference data to monitor and verify the F-111 Avionics performance. Hence, the RWSS generated output signals will represent the real (or true) dynamic state and environment of the F-111 aircraft.



(1) FB-111 AND F-111F ONLY
(2) F-111D ONLY

Figure 5-5. ARS Model Signal Interface

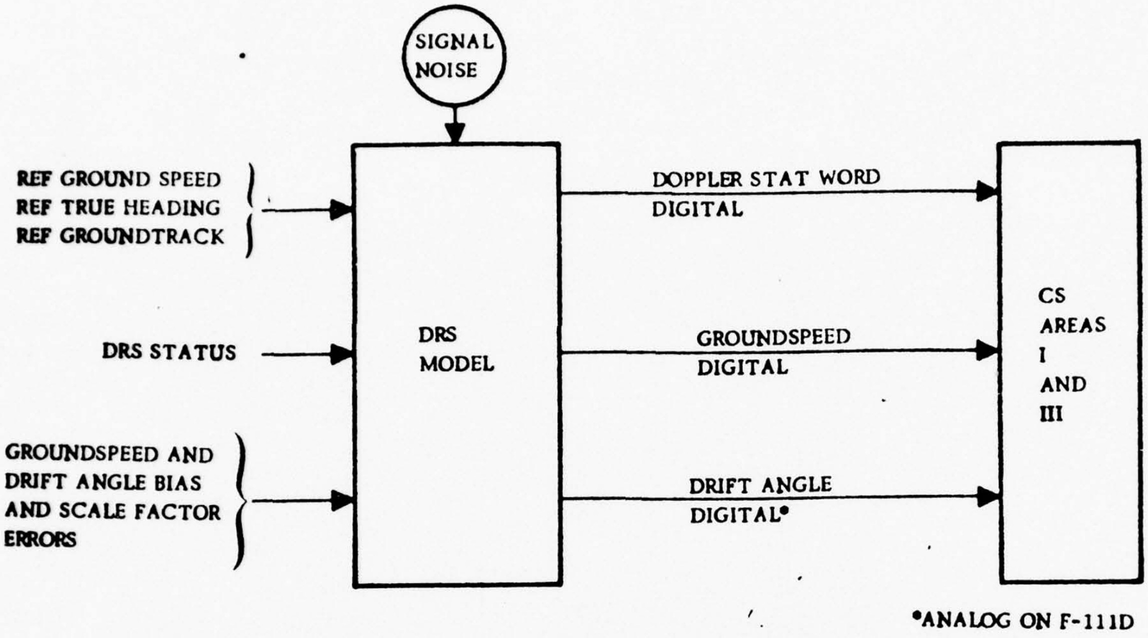


Figure 5-6. DRS Model Signal Interface

The generation of the RWSS output signals will be accomplished with the four software models:

1. F-111 Automatic Flight Control System (AFCS) Model,
2. F-111 Aircraft Dynamics Model,
3. Earth Model, and
4. Atmosphere Model.

Figure 5-14 shows a general block diagram of the four RWSS software models interfacing with (1) the SSS software, (2) the MMIS software, (3) the hardware tie-in with the F-111 Nosebay Mockup, and (4) the man shown within the F-111 Nosebay Mockup for man-in-the-loop simulations and tests.

The total and detailed functional capabilities of the baseline RWSS from the standpoint of the interface shown in Figure 5-14 and others, which are omitted for brevity, will be defined. This definition will be performed to the extent that no major changes will be necessary to the baseline RWSS during the development of the ultimate RWSS.

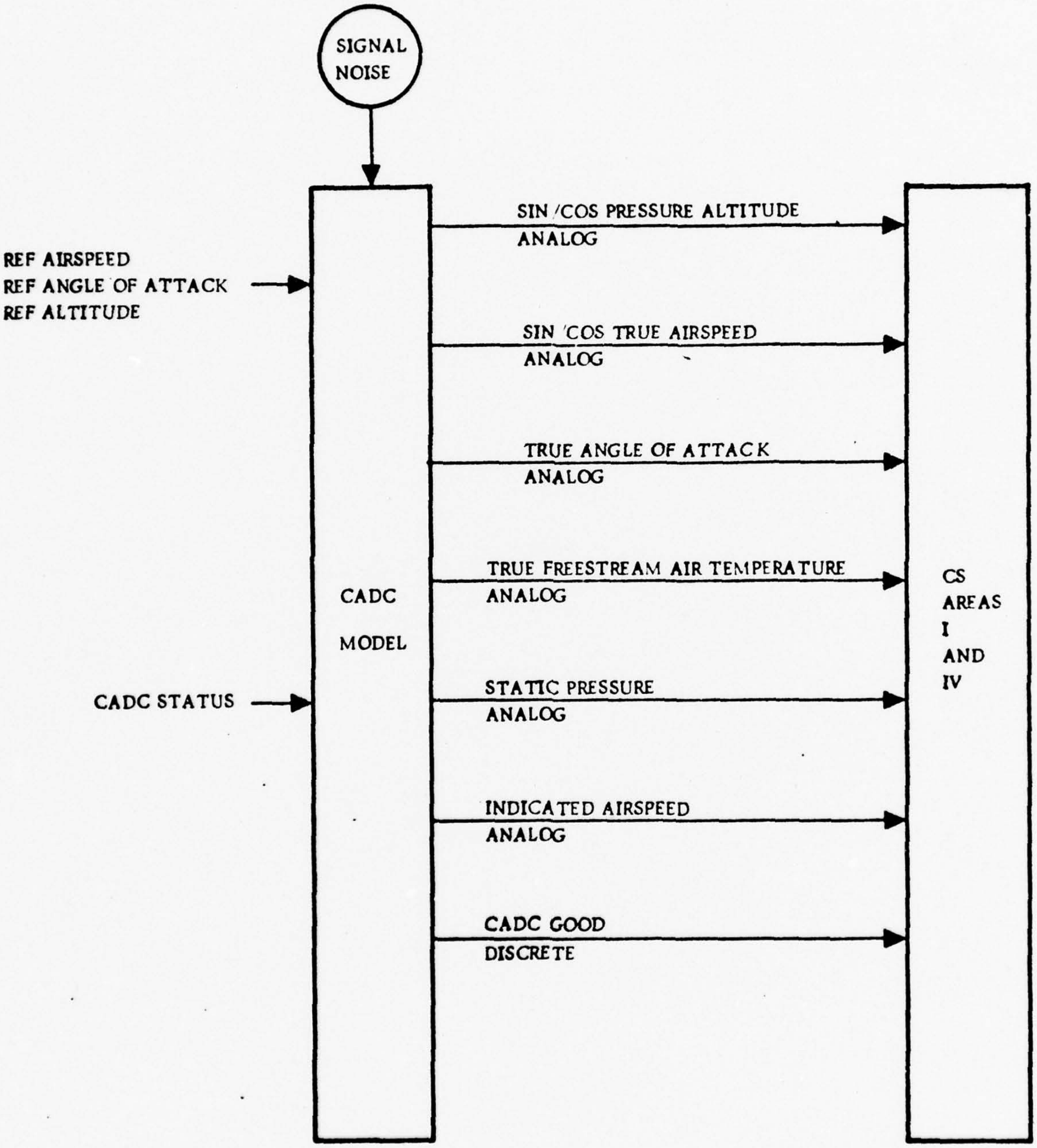


Figure 5-7. CADC Model Signal Interface

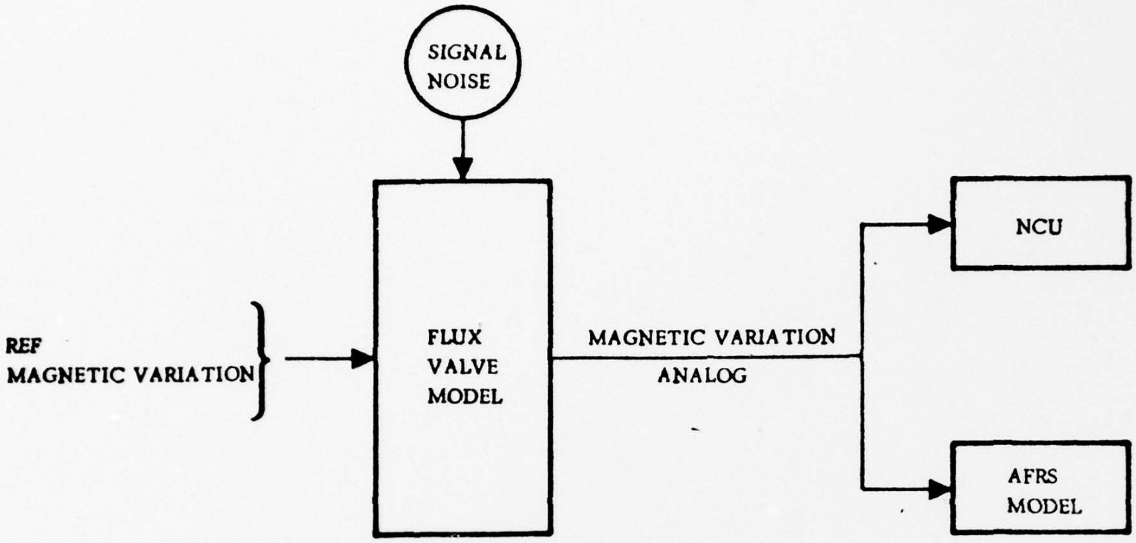


Figure 5-8. Flux Valve Model Signal Interface

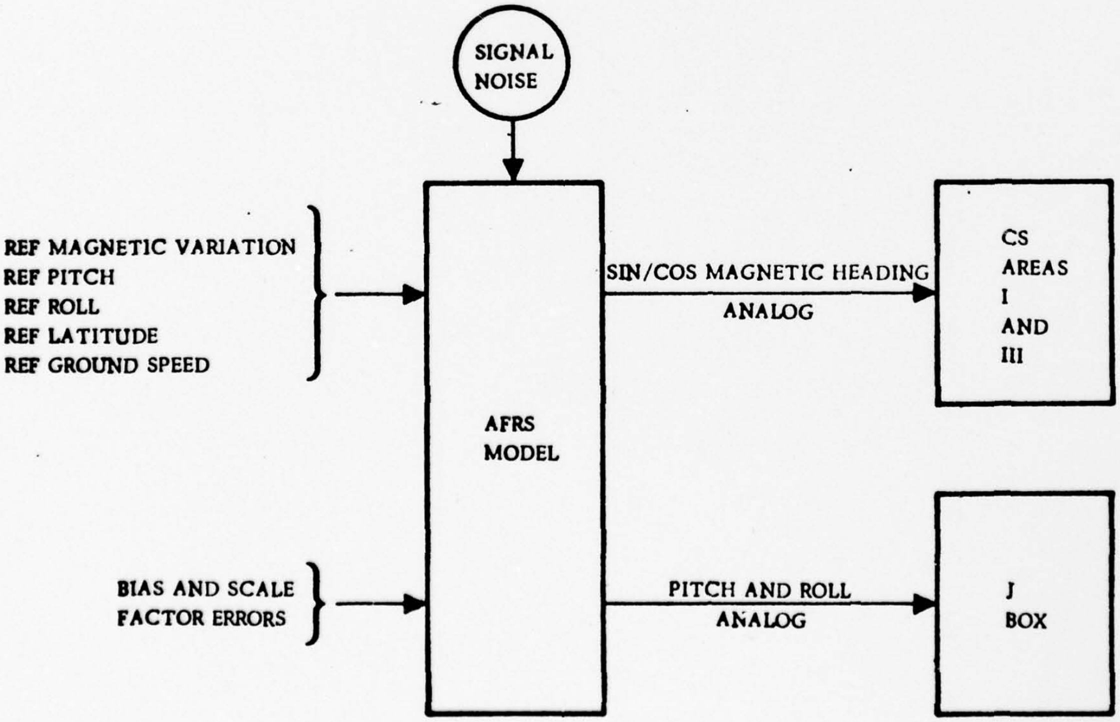


Figure 5-9. AFRS Model Signal Interface

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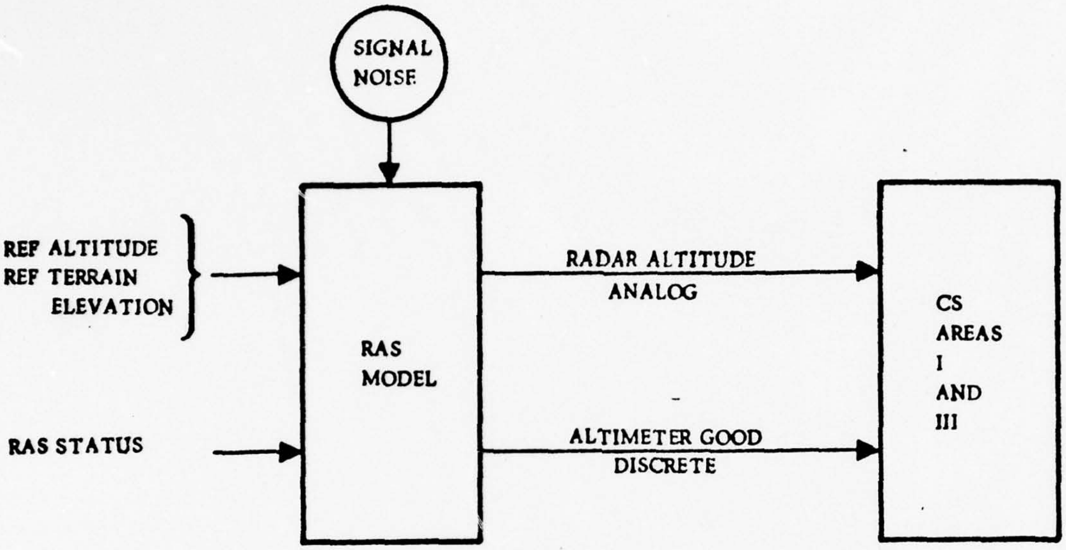

Figure 5-10. RAS Model Signal Interface

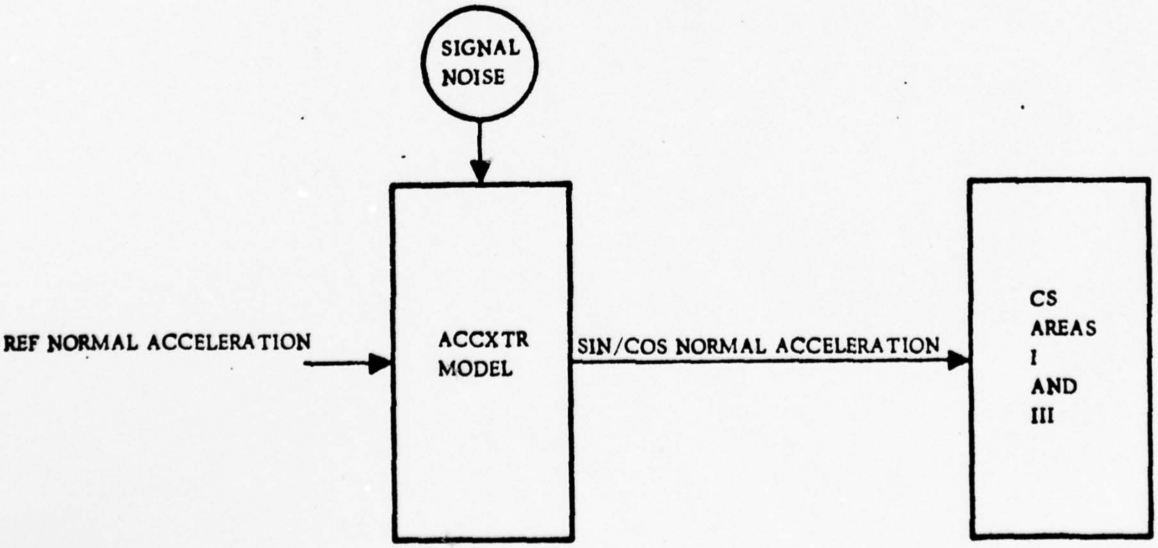

Figure 5-11. ACCXTR Model Signal Interface

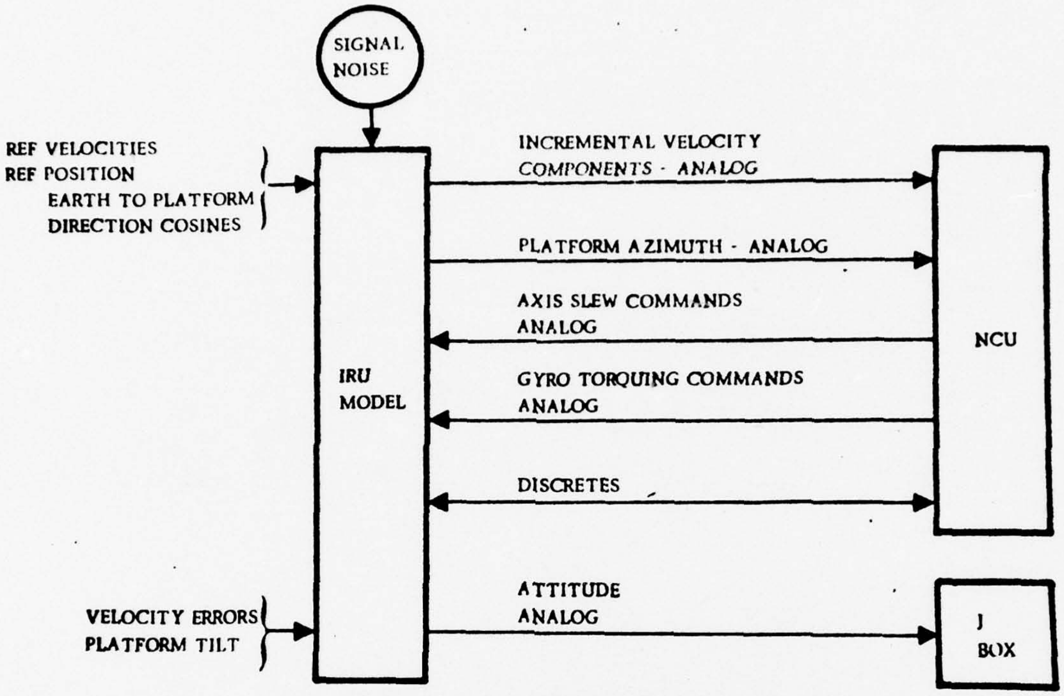

Figure 5-12. IRU Model Signal Interface

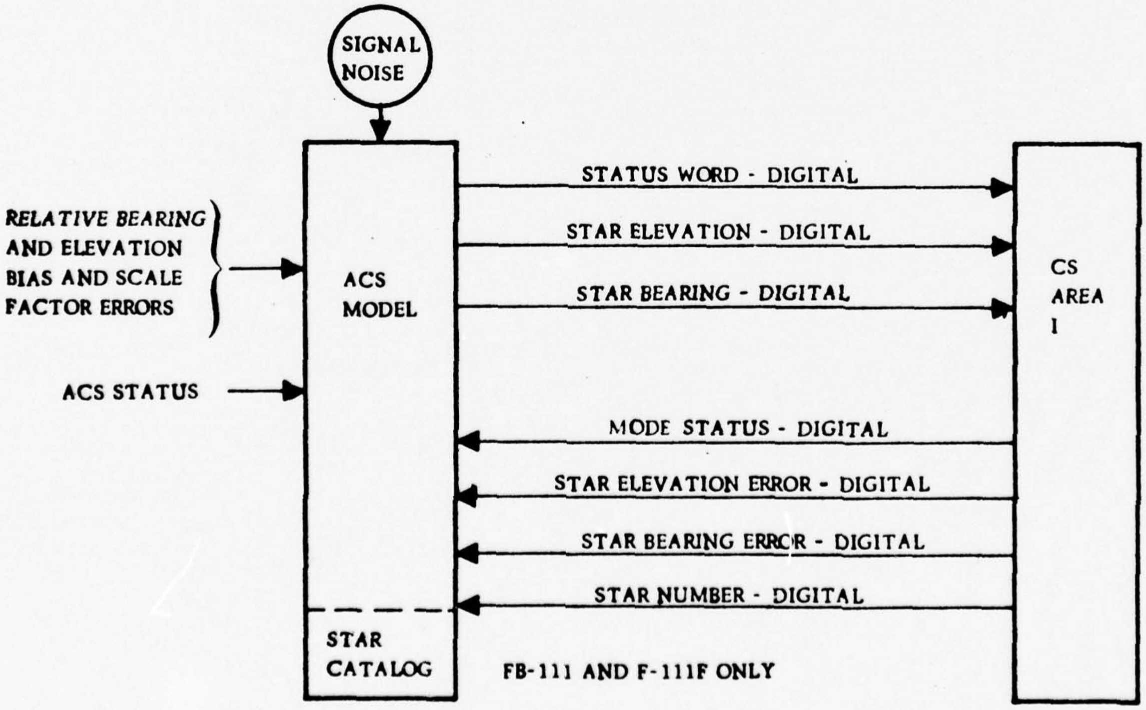

Figure 5-13. ACS Model Signal Interface

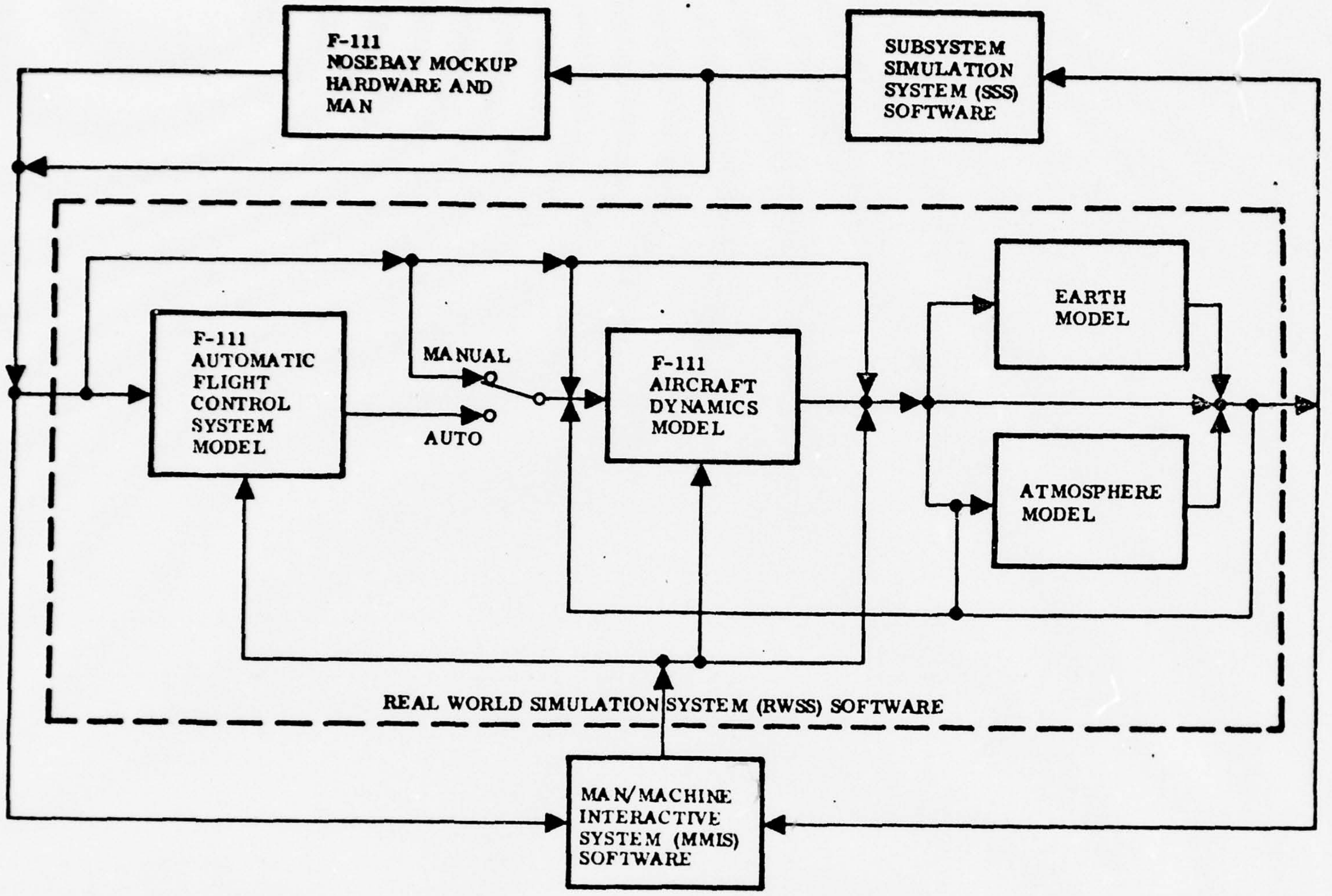

Figure 5-14. Block Diagram of the Real World Simulation System Software

The following paragraphs describe the RWSS as envisioned to be implemented in terms of its significant functional capabilities, basic input and output signals, the the recommended RWSS software models. Unless otherwise stated, the descriptions contained in the following paragraphs apply to both the baseline and ultimate RWSS.

5.2.2.4.1 Significant Functional Capabilities. The RWSS software will provide the means to simulate the complete AFCS and the six degrees-of-freedom aircraft dynamics of the F-111 aircraft. The RWSS output signals will provide true information related to the dynamic state and environment of the F-111 aircraft relative to the Earth. The accuracy level of this information will be least for the baseline and will increase to the maximum possible upon development of the ultimate RWSS software.

The baseline RWSS will be structured and implemented such that it will facilitate the selection of various complexities of the F-111 AFCS and Aircraft Dynamics models. This selection will be requested by the test operator via the MMIS software at the beginning of each simulation or test. Simple models are suggested to be implemented for the baseline RWSS for two reasons, i.e., (1) they will be the most often used models and will be adequate for most use, and (2) they require the least effort and time to implement, with negligible risk, and will be required for most of the early simulation use.

Both reasons are quite valid since general simulations and tests will be performed much sooner and more often than detailed ones. From the experiences at Autonetics and at the Naval Weapon Center, this is the case because simple models are easier to set up via the MMIS, require less computer time and the resulting data are easier to interpret. Also, the resulting data will be adequately accurate for most simulations and tests envisioned.

The following paragraphs delineate the functional capabilities of each of the four RWSS systems.

5.2.2.4.1.1 F-111 Automatic Flight Control System (AFCS) and Aircraft Dynamics Models. The F-111 AFCS augments the flight stability of the F-111 aircraft throughout its flight regime. It directs the aircraft according to the automatic steering and manual commands by means of appropriate control surface deflections. The steering commands are provided by the MK II and non-MK II avionics equipment for various steering modes. The appropriate control surface deflections are derived by the AFCS for optimum pilot comfort such as coordinated turns for lateral maneuvers.

The baseline F-111 Aircraft Dynamics Model will consist of a point mass six degrees-of-freedom (6DOF) model. That is, details related with the aerodynamic lift, drag, and side forces and the external aerodynamic roll, pitch, and yaw moments will not be simulated. The purpose of this model will be primarily to simulate the trajectory of a point mass with the body rates controlled proportionally by either the automatic steering or manual commands from the mockup. The baseline F-111 AFCS Model will simulate coordinated turns whenever lateral maneuvers are required.

The subsequent models of the F-111 AFCS and Aircraft Dynamics leading to the ultimate RWSS software are recommended to be as follows:

The ultimate RWSS software will contain two AFCS models, i.e., (1) the baseline model and (2) the full-blown model partially documented in Ref 1 in terms of

Laplace transform block diagrams. This documentation covers the F-111A aircraft instead of the specific aircraft of interest (FB-111, F-111D, and F-111F), however those, too, should be available to SMAMA. The ultimate RWSS software will contain four aircraft dynamics models, i.e., (1) the baseline point mass 6DOF, (2) the canned trajectory similar to that implemented in the Autonetics F-111 Tape Verification Tests (TVT), (3) the 6 DOF with linearized aerodynamics coefficients about specified nominal flight conditions, and (4) the full-blown 6DOF with aerodynamic coefficient function generations covering the entire flight regime of the aircraft of interest.

The purpose of the baseline point mass 6DOF aircraft dynamics model is for simplicity in frequently used test cases in which extreme accuracy of dynamic simulation is not required as explained previously.

The purpose of the canned trajectory model version is to generate exact aircraft trajectory profiles which will be repeatable bit-by-bit from one identical run to another. Such repeatable exact trajectory profiles will be useful for detail NCU, GNC, and WDC software checkout.

The purpose of the linearized 6DOF model is to study weapon delivery or other flight sensitive problems such as ILS and AILA steering modes about a nominal condition. This model will be useful to check out the basic 6DOF aircraft dynamics model against the solution of hand-performed analyses which are basically linear in order to be soluble.

The purpose of the full-blown 6DOF model is to study the entire F-111 weapon system in order to investigate detailed problems which may be encountered throughout a wide flight regime of the aircraft. Simulations of long mission time with large dynamics range concerned with minute details of the aircraft dynamics, such as stall conditions, will require such model. Ref 4 documents the full blown 6DOF equations of motion of a generalized aircraft. These equations, with minor modifications, together with data associated with the F-111 aerodynamics coefficients and engine characteristics represent the full-blown 6DOF Aircraft Dynamics Model.

Since the ultimate SITS will be utilized for simulations and tests to the finest detail, it is recommended that data related with the AFCS and aerodynamics for the specific aircraft (FB-111, F-111D, and F-111F) be obtained and used in the ultimate RWSS software.

5.2.2.4.1.2 Earth and Atmosphere Models. The Earth and Atmosphere models will be as documented in Ref 3 with some modifications related with the navigation mechanization coordinate system. In the F-111 project, the wander angle navigation mechanization coordinate system is used and implemented for world wide navigation purposes. Ref 3 uses the north oriented navigation mechanization coordinate system and is written with singularities at the Earth poles.

The Earth Model will be an oblate spheroid which rotates about its polar axis. The constants of this model will be as documented in Ref 7 in order to be consistent with the NCU, GNC, and WDC OFP's.

The Atmosphere Model will be as documented in Ref 3. The China Lake area wind profiles will be used until wind profiles of a different area of interest are identified and available.

5.2.2.4.2 Input/Output Interface. This section lists the primary input and output signals of the RWSS software. Definition of the total and detailed interface will be required during the development of the baseline RWSS. This definition will be such that no major changes will be necessary to the baseline RWSS during the development of the ultimate RWSS.

It is to be noted that this section lists the primary signals from the functional point-of-view. The detailed characteristics of the signals such as type of signal, update signal, etc., are not pertinent for the overall context of this report. However, the detailed interfaces used in the Autonetics F-111 Hybrid Simulation efforts are documented in Ref 1 and 6. Therefore, these references can be utilized as guidelines during the development of the baseline RWSS.

Also, signals related with the software functions performed by the EOS and PDH are intentionally omitted since the SITS simulation and test functions are of prime interest at this time rather than the simulation control software operation.

5.2.2.4.2.1 Input Signals. The primary input signals are from the MMIS and SSS software and the mockup hardware tie-in as shown in Figure 5-14.

These signals together with comments are listed below:

1. MMIS Software Inputs

   Simulation Configuration Options

   a. AFCS Model Options

      (1) Simple model to simulate coordinated turns, to be developed for baseline RWSS.

      (2) Full-blown model simulating adaptive gains, nonlinearities, redundancies, etc.

      (3) F-111 aircraft option to select the appropriate AFCS characteristics unique to the FB-111, F-111D, or F-111F aircraft.

   b. Aircraft Dynamics Options

      (1) Point mass 6DOF to simulate navigation and other functions which are insensitive to detail aerodynamic characteristics, to be developed for the baseline RWSS.

      (2) Canned 6DOF maneuvers for exact aircraft trajectories such as exactly +45 deg (rather than +45.01 deg) initial heading for a Great Circle Course. This option will be useful for detail bit-by-bit OFP checkout against scientific computer solutions which are easily generated under such exact trajectory conditions.

(3) Linearized 6DOF with aerodynamics coefficients linearized about a nominal point condition. This option will be useful to investigate detail aircraft characteristics such as stability during ILS/AILA Navigation Steering mode about a nominal condition of interest only.

(4) Nominal point condition for the preceding option (Mach number, altitude, wing sweep, etc.).

(5) Full blown 6DOF to simulate the entire flight regime of the specific F-111 aircraft.

(6) F-111 aircraft option to select the appropriate aerodynamics coefficients unique to the FB-111, F-111D, or F-111F aircraft.

Initial Conditions

a. True aircraft position and velocity

b. True aircraft heading, pitch, and roll Euler angles and body angular rates.

2. SSS Software Inputs

Initial Conditions

a. True platform wander angle.

AFCS Non-MK II Avionics Feedback Signals

a. Normal and Lateral Accelerometer inputs.

b. Yaw, Pitch, and Roll Rate Gyro Inputs.

c. CADC Inputs.

d. AFRS Magnetic Heading.

3. F-111 Nosebay Mockup Hardware Inputs

AFCS Related Signals

a. AFCS Auto/Manual Override Command.

b. Attitude Good Discrete.

c. J-BOX Pitch and Roll Attitudes.

5.2.2.4.2.2 Output Signals. The output signals are those generated for the SSS and MMIS software. It is to be noted that all of those output signals represent the real or true dynamic state and environment of the F-111 aircraft. The following lists are not by no means complete, however, the primary ones and those with which the baseline RWSS will be concerned are listed:

1. F-111 Aircraft Dynamics Model Outputs
    a. True normal and lateral acceleration.
    b. True yaw, pitch, and roll body angular rates.
    c. True angle of attack and side slip angles.
    d. True yaw, pitch, and roll Euler angles.
    e. True airspeed.
2. Earth Model Outputs
    a. True Latitude, Longitude, and Wander Angle,
    b. True platform components of velocity.
    c. True groundspeed, groundtrack, and drift angle.
    d. True heading relative to true north.
    e. True altitude and radii.
    f. True gravity and Coriolis acceleration components.
    g. True windspeed and wind direction.
    h. True magnetic heading.
    i. True magnetic variation.
    j. True temperature, pressure, air density, and speed of sound.

5.2.2.5 Peripheral Device Handlers

This package consists of the standard PDP-family of peripheral handlers. Included are (1) disk drive, (2) typewriter, (3) line printer, (4) keyboards, and (5) CRT monitors. It may be advantageous to merge some of these handlers with the modules of the MMIS.

5.2.2.6 Data Base Management System

The F-111 baseline simulation system data base comprises the global data blocks (on the disk dile), and the local data blocks (in each simulation processor). The local data blocks will be partitioned such that individual modules have their own dedicated areas. All data which must be routed among the modules and external to the processors will be serviced by common and I/O data blocks respectively. This partitioning will aid in maintaining the desired software modularity objective.

5.2.3 Growth Capability of the Baseline Simulation System

The baseline system proposed offers many ways to incorporate growth. For example, the UNIBUS mechanization allows many more peripherals to be connected to the processor as future requirements dictate a need. Such items as magnetic tape recorders, additional CRT monitors, more mass memory, etc. can be added directly. Further, the PDP-11/45 can be interconnected with other PDP's to form different architectures including multiprocessors and multicomputers with shared memory. The UNIBUS concept also permits each interface, at the Simulator and Switching Unit, to have a unique control address. This flexibility provides an additional modularity level for growth. The only restriction on the number of devices connected to the UNIBUS is throughput. The maximum transfer rate, based on the memory selected, is in excess of 1 million (16-bit) words-per-second.

From a software viewpoint, there are three factors which contribute most to growth. These are (1) function partitioning to promote modularity, (2) standard executive interface with test modules and (3) use of a common programming language (such as FORTRAN). Furthermore, the DEC executive real-time system has the option to interleave batch jobs if desired. One possible use would be to assemble corrections to the F-111 OFP while testing was proceeding. Updates could then be made directly to the OFP modules stored on the disk file.

It is desirable, from a cost viewpoint, to purchase the PDP-11/45 peripherals anticipated for later phases during the initial order. Hence, three additional peripherals are defined for inclusion. Peripheral handlers will also be furnished. However, application software to interface with these handlers will not be generated until Phase 2.

1. Two 800 bpi, 9 track magnetic tape units (includes controller)
2. One 300 lpm card reader
3. One paper tape reader/punch

5.2.4 OFP Verification and Validation (V and V)

The baseline SITS hardware as described in Para 5.2.1 with adequate memory and appropriate software will allow the performance of the OFP verification and validation (V and V) function autonomously and with a high degree of automation. That is, once the ultimate SITS software is developed, it is envisioned that such function will be performed without the aid of scientific computers and with a minimum of manual operations. Thus, the degree of completeness and efficiency in performing this function with the SITS will be much greater than those which can be achieved with the ITE and TVT combined.

The related software that will allow the OFP V and V capabilities as envisioned to be implemented in the ultimate MMIS software is described in the following paragraphs. Those portions of the baseline MMIS are identified in the description.

The primary objectives of the OFP V and V function are: (1) to verify the OFP coding (and other "debugging" goals) relative to the program requirements and, (2) to validate the OFP related avionics system performance relative to the avionics system specification or other "performance requirement" documents. These objectives or primary capabilities will be implemented through optimal combinations of on-line and off-line processing within the available SITS memory and processing duty cycle. Primary source of data for satisfaction of objective (1) above is the CMAC with the IODM unit as the primary data source for objective (2).

The primary task of the on-line processing will be to retrieve designated data for the off-line processing. The retrieved data will require some processing, primarily to reduce the amount of data to be stored in the Disk File. The major portion of the software which performs the OFP V and V function will be for the off-line processing of the retrieved data.

Some of the major tasks which the off-line processing will perform related to the OFP coding verification and performance validations are:

5.2.4.1 Air-to-Ground Weapon Delivery Evaluation.

As part of the OFP performance validation, this task will be performed based upon the retrieved instantaneous true condition (from the RWSS) at weapon release. By means of much more complex ballistic computations than those implemented in the OFP, the CEP of the weapon delivery to the designated target will be determined. These computations will also include separation effects and wind profiles to a degree of accuracy higher than that implemented in the OFP.

5.2.4.2 Generation of Reference Solutions for the OFP Coding Verification

The extent of this task will of course be dependent upon the extent of the OFP coding verification desired. That is the total OFP coding verification will require generation of the total reference solutions. These reference solutions can only be generated by implementing the total OFP program requirements within the SITS processors in FORTRAN IV language.

Such extent of OFP coding verification will be useful during the OFP optimization efforts which is apparantly evident. Since bit-by-bit comparison between the retrieved data and the corresponding reference solutions are of interest to detect coding errors, static test problems similar to those generated during the FB-111 and F-111D OFP developments at Autonetics will be required. Such test problems will be required for the generations of variable parameters as well as discrete information such as the state of a "flag". Initially, the application of the OFP coding verification capability of the SITS can be oriented at verifying only those OFP codings associated with the implementation of flight tape problem solutions into the OFP.

5.2.4.3 Automatic Test Sequencing for the OFP Coding Verification.

This task will be intimately associated Para 5.2.4.2. The purpose of this task is to automate the entire sequence of the OFP coding verification once initiated by the test operator. The pre-determined sequence will consist of: (1) SITS and DCC set-up for a static test problem, (2) initiation of the on-line processing for the data retrieval of the static test results, (3) initiation of the off-line processing to perform the task of Para 5.2.4.2, and (3) coding error evaluation based upon a prestored criterion for the specified test.

5.2.4.4 Memory Tracing of Executed Instructions.

This task, in conjunction with the corresponding on-line processing, will process the retrieved data and will map the entire memory of the DCC under test, i.e., the GNC or WDC. This memory map will be formatted and output on the Line Printer in a matrix of appropriate dimension (e.g., 2^7 by 2^9). Each element of that matrix will correspond to a specific memory location of the DCC computer under test. An element with a zero will indicate a memory location which was not accessed by the CPU of the DCC computer under test.

Therefore, for a specific test mode, the resulting memory map will show all of the instructions executed at least once during that test as well as the handled variables. The handled variables can be eliminated from this matrix with appropriate decisions based upon the instruction/variable OFP architecture knowledge that can be stored in the software associated with this task.

The usage of the resulting memory map matrix will be in detecting unexecuted instructions for all possible system modes which are possible to be configured by inputs to the DCC computer under test. The existance of unexecuted instructions will, in general, indicate invalid program requirements or mis-coding.

5.2.4.5 Data Reduction for OFP Performance Validation.

This task will process and reduce the retrieved data in appropriate and predetermined formats for the purpose of OFP performance validation. For example, related to navigation performance validation, this task will determine the time RMS errors of radial velocity, attitude, and heading; the maximum CEP rate; and the CEP rate as a result of a least square fit to a straight line of the time history of CEP.

The software development to accomplish all of the above five major task will not be considered for the baseline MMIS because of the time and effort required for the development of such software. However, the baseline MMIS will contain the on-line and off-line processing software to perform the navigation-related OFP performance validation as described briefly in Para 5.2.4.5.

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5.3 ALTERNATE USES OF SIMULATOR

The baseline simulation capability described previously allows the system software to be exercised in real-time. It also pr[illegible]es the capability to grow, in sophistication of simulation, or in overall progra[illegible]entation, as needs evolve. Par. 5.5 identifies the growth elements that wil[illegible]end the baseline capability. These growth phases incorporate expanded OFP evaluation techniques in an orderly manner.

Alternates to the approach discussed in other sections consist of variations in primary use of the simulation facility and possible variations in flight hardware simulation.

5.3.1 Flight Hardware Simulation – Attack Radar Set (ARS)

Inclusion of the ARS as an operating element can be accommodated to various degrees, depending on user desires. The AN/APQ-130 radar in the F-111D contains digital, software influencing system interfaces not previously attempted with airborne radar. Therefore, some degree of airborne hardware use would be justified later in the program.

At the end of the spectrum opposite complete simulation would be the use of an anechoic chamber with a positionable and otherwise controllable radio frequency target. This approach would not seem reasonable except when end-to-end checkout of the Air-to-Ground (A/G) modes is necessary. In the event that this becomes necessary, the only way to thoroughly verify the modes is by making dynamic use of the radar set. In lieu of this approach, Autonetics would recommend that final A/G mode verification be reserved for flight test.

A more reasonable alternate to be considered would use the radar as an operating element except that RF radiation would not be implemented. This configuration would exercise all of the normal ARS/System interfaces and would simulate a target only. The simulator would calculate range-to-checkpoint (from present position/checkpoint position information) and angle-to-checkpoint. This information, with ARS antenna position, would be used to trigger and gate a radar target generator (video pulse generator included in baseline simulation approach) and provide a dynamic ground map target that could be used for navigation position update. The simulated target could be inserted directly into the Integrated Display Set (IDS) where it would be combined with radar generated range marks and cursors.

During the APQ-130 development and system integration, techniques and special test equipment were used to provide a remote target for the radar. This approach used a pickoff from the Master Frequency Generator (MFG) that was amplified, routed through waveguide to a tower-mounted horn. This RF energy was then radiated back to the radar, providing a target that was controllable in range, but not in azimuth or elevation without actual physical motion of either the ARS or the tower-mounted horn.

During the study, the possibility of remotely monitoring the system displays was considered. The only approach that could be taken with the F-111D head-up display would be to mount a camera at the pilot's normal eye position. The curved combiner is actually the collimating lens and thus can not be monitored from the rear or above.

This should not be a problem with the Optical Display Sight in F-111F. The Multisensor Display could be remotely monitored by replacing the existing display camera with a television camera and a suitable lens adapter. During system development, a collimated light source was used for projection onto the combiner of the head-up display for accuracy and stability checks. This source is assumed to be available at SMAMA to be used accordingly.

5.3.2 Extensions of Intended Use

During the period that the simulator would be available there are a number of potential uses beyond the initial software checkout application.

A possibly very important use would/will be as a training device for Air Force software engineers. As more use is made of programmable airborne computers, the need for these engineers will become acute throughout the Air Force. Training that could be accomplished using the critically programmed F-111 computers in conjunction with the dynamic simulator as a tool will provide an excellent base of experience.

Essentially every aircraft in the inventory has experienced a changing role and/or mission through its service life. As this happens with the F-111, the simulator would become an invaluable tool in evaluating the capability to perform extended or modified mission roles. In this same vein, changing roles would likely be accompanied by airborne avionics hardware replacement or substantial revision. These changes can be quantitatively evaluated, prior to incorporation, rather easily using an existing dynamic simulator.

A potentially important variation in intended use of the simulator would allow test similar to the TVT testing described in Para. 3.2. The simulator would provide the same type of total software simulation of hardware with the advantage that programs within both the GNC and WDC could be tested simultaneously. This would eliminate one of the major disadvantages of the TVT approach.

5.4 TRADEOFF RESULTS

During the conduct of the study, there were four areas of major concern. These areas dominated the activity of the study team. The four areas were:

1. The role of the current F-111 Integration Test Equipment (ITE) in the baseline simulation system
2. What test simulation processing hardware to consider
3. How to test and verify the F-111 OFP's dynamically without resorting to software contamination to the programs being tested
4. What subsystems should be simulated vs those to be retained.

It is noted that these factors were considered within the constraint that a digitally controlled simulator was justifiable.

5.4.1 Role of ITE

The ITE was designed to statically test MKII equipments and interfaces and non-MKII interfaces. In addition, it provided the physical space to contain the avionics equipments themselves. It was not intended to be used for dynamic testing and operational performance evaluation. During the early portion of this study, it was learned that SMAMA would have available for its use the F-111 nosebay mockups. The use of these mockups plus the fact that SMAMA already has a static test capability (the ITE) led to the following reasons why the ITE would not be integrated into the baseline simulation system:

1. Extensive rearrangement of MKII hardware mounted in the ITE would have to be made to optimally interface (physically) with the dynamic simulation equipment and concept.

2. Serial word simulators are not representative of the actual serial channel operation and would require major modifications of the ITE to make them useable in a dynamic simulation environment.

3. Rewiring the ITE for the changes necessary to interface with the dynamic simulation equipment would mean it would be unavailable for several months as a static test console to check current problems.

4. The non-MKII simulators in the ITE are not adaptable for use by the test simulation processors without extensive rework.

The ITE served its initial goals; namely, checking interfaces and performing static functional testing of hardware. Piecemeal software testing was also performed on the ITE using the computer console portion. However, the means to achieve collective dynamic testing and validation of OFP's and/or system performance cannot be justified by modifying the ITE. The ITE should remain intact in order to test new equipments as they are introduced into the system as growth (such as LORAN and data link).

Should the nosebay mockups not be available to SMAMA for use in this facility, two alternate approaches should be considered. The ITE could be modified to provide interface with the simulator, or a special set of holding fixtures and harness could be fabricated that would replace the nosebay mockups.

The ITE modification would entail a substantial amount of electrical modification that would bring all of the MKII and non-MKII signal interfaces to a common location. In addition to the electrical changes, physical relocation of the controls and displays would be desirable in order to provide more convenient system control by a single operator. Starting with up-to-date drawings of the present configuration, it is estimated that resources on the order of 10 man months and $1K could accomplish this modification.

A rather austere approach toward providing engineering lab type of installation provisions for the flight hardware is the second alternative. It is conceived that a commercial bench or cart would be obtained and modified to house the airborne hardware. The modification would entail fabrication and installation, on the bench, of connector plates, wiring racks, cooling ducts and equipment tie-down provisions. Wiring would essentially reproduce the existing nosebay harness, with changes required due to the physical layout differences. Again, a cockpit station would provide test operator interface. Again, with up-to-date drawings of the existing installation (including wiring), resources on the order of 17 man months and $4K would be required to obtain such a set of fixtures.

It is recommended that the second approach be considered in the event the nosebay mockups should not be available. This recommendation is made primarily to keep the present ITE configuration intact. The second approach would in essence provide an additional facility, functionally similar to the nosebay, rather than changing the existing ITE.

5.4.2 Choice of Test Simulation Processors

With the wide variety of commercial mini and medium size computer systems on the market, the selection of one might seem awesome. However, the choices quickly converged on the PDP-11 family for the following reasons:

1. SMAMA has access to most government facility software packages. Hence, it seems logical to select a computer system upon which this software could be executed. An examination of the Digital Avionics Information System (DAIS) from WPAFB, Dayton, Ohio indicated that they were using the PDP family in their hot bench concept. The software planned for DAIS includes air vehicle dynamic simulators, avionic hardware simulators, etc. Some of these software packages as well as some interactive test tools could be valuable to SMAMA. If nothing else, it can become a library source. WPAFB (specifically, the AFAL) has subcontracted with industry to prepare much of the software simulations to be run on the PDP facilities. An example of one such simulator would be for the analog air data computer. An examination of the simulators being prepared for WPAFB may greatly reduce the initial development effort, at least for the SSS and RWSS software packages.

   Additional software has been developed for use in similar A-7 simulation by the Naval Weapons Center, China Lake, California. This simulation software as well as data processing routines and software needed to interface with CMAC would have direct application to SMAMA with a PDP-11 configuration.

2. A brief comparison was made between the PDP-11 system and another potentially viable candidate. While an exact duplicate configuration could not be established, sufficient similarity was obtained for comparitive purposes. The following conclusions were made:

   a. Acquisition cost was approximately the same with DEC support cost slightly lower.

b. Data transfer between multiple computers would likely be a problem with the alternate candidate because neither a programmable switch nor the equivalent of the "Unibus Window" is available. With the alternate candidate, computer to computer communication is possible only through a DMA channel and the only peripheral that could support both CPU's is the disk.

For these reasons and the PDP's flexible growth capability, the choice has been made to recommend the PDP-11/45 as the computer for the baseline simulation system.

5.4.3 Collective OFP Test and Evaluation

During the study, two factors dominated any discussion regarding the testing of the OFP's. First, any digital test facility had to be capable of testing the OFP's collectively. Second, no test and/or debug software was to be loaded into the OFP's. This no contamination requirement of the software led to the approach of using the Computer Monitor and Control Unit and the I/O Data Monitor Unit. These units will be capable of "listening" to the activity on the external and interal buses of the 4PI computers.

An examination of the presently available methods for verifying operation of the flight programs was made. First, each program (GNC, WDC, NCU) is tested in a stand-alone configuration called Tape Verification Test (TVT). Next, the three programs are integrated in a static compatibility demonstration test using the ITE. In this test the three programs are integrated once during a free inertial run. For subsequent demonstration tests, the NCU does not participate. Hence, neither method ever integrates the three OFP's such that they approach the operational environment. The baseline simulation system described in Para. 5.2 would alleviate this situation. It is noted that the NCU has not been treated (test-wise) as has the GNC and WDC. This has been done because of the dedicated function of the NCU. Since the Inertial Reference Unit (IRU) will be digitally simulated and the NCU outputs will be accessible to the test simulation processors, a complete closed loop check can be performed on the navigation computer flight program.

5.4.4 F-111 Subsystems – Simulation vs Actual

There are three basic categories of F-111 subsystems. These are computers, interactive devices (controls and displays), and sensors. Since it is the goal to test and validate the OFP's being executed in their natural habitat, all digital computers will be retained. These include the GNC, WDC and NCU. For the FB-111A system only, the SRAM computer would also be retained. Besides these digital computers, there are also analog computers. Of these, only two, the Air Data and flight director computers, have any real significance to the problem at hand. Since the flight director computer interfaces with analog-type controls and displays (such as HSI and ADI), and these man-machine devices will not be simulated, the flight director will be retained also. A major reason is the complexity of the nonlinear filters and association of these filters with air vehicle characteristics. However, the air data computer is different. It processes sensor data such as is obtained from temperature probes and pitot tubes. Since an atmospheric model will be mechanized digitally, it follows that this analog computer should be simulated. The outputs would be routed over the UNIBUS to the Simulator and Switching Unit. Here, they will be conditioned and then

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transferred to the same interfaces in the nosebay mockup as the actual analog computer. Further, this mechanization can be used for all three F-111 systems' with little or no changes.

The interactive devices are separated into controls and displays. All display devices (analog or digital) will be retained. The control devices (e.g., entry panels, SMS panels, etc.) will be retained also. However, these devices are used by the operator to control modes and function selection. Therefore, during simulation runs (whether pre-canned or manual control using the stick and throttle), the capability to simulate these panel functions and interfaces is required.

In general, all major sensors will be simulated. Moreover, the intent is to achieve functional and interface compatibility. Of all the sensors, the Inertial Reference Unit (IRU) and the Attack Radar Set (ARS) pose the biggest efforts. It is recommended that an IRU model be developed which initially simulates a perfect sensor. However, provision to incorporate errors/noise of various types would be a growth item. The model will be capable of closed loop operation. On one side, acceleration stimuli will come from the air vehicle six degree-of-freedom model. On the other side, the NCU will provide the applicable gyro torquing signals to maintain a "level simulated platform" in inertial space. This will become the primary position, velocity and attitude sensor of the simulation system during dynamic test and evaluation.

The ARS will include two kinds of mechanizations. First, the ARS will be simulated to provide the capability to display a synthetic target on the applicable displays. At least the radar cursor mechanization will be simulated such that cursor laying is possible using the tracking handle. Second, it will be possible to use the actual ARS hardware and inject RF stimulations under test simulation processor control. The former mechanization will be used for dynamic system simulations.

A unique situation exists with Radar Homing and Warning (RH and W) equipment. The equipment will not be included in Phase I nor will the equipment be simulated per se. It is desired, however, to have a visual air-to-ground capability in the baseline system and this capability can be provided by using the normal RH and W threat warning symbol on the HUD and the ODSS to represent a visual target. This symbol will be enabled by simulating the input discretes that normally would be generated in the RH and W equipment. The azimuth and elevation inputs that would normally come to the avionics from the RH and W equipment will simulate the location of a visual target. This will allow simulation of visual modes using the normal visual displays.

5.5 F-111 SIMULATION SYSTEM DEVELOPMENT

The buildup of the F-111 simulation system has been partitioned into phases. The items to be developed and delivered for Phase 1 will form the baseline simulation system described in Para. 5.2. This section summarizes the development task for Phase 1. In addition, hardware/software for use in later development phases are enumerated. Order of magnitude cost and schedule data are presented for Phase 1. An assumed go-ahead for estimating purposes is 1 January, 1974.

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5.5.1 Phase 1 – Baseline System Simulation Development

The primary goal for Phase 1 is F-111 test and evaluation using dynamic simulation techniques. There are four areas to be covered. These are:

1. Actual hardware vs simulation for each F-111 system
2. Software to support the testing of F-111 systems
3. Unique F-111-to-test simulation processor interfacing hardware to be developed
4. The test simulation computer system to be procured by SMAMA.

Before pursuing each of these areas, basic assumptions are listed.

1. All models initially developed will assume a perfect environment. Error and noise source injections will be considered a growth item.
2. Existing models, where available, will be used in the development cycle. This is especially true where the models are currently in use at other government facilities where the PDP – family of computers is used.
3. Dynamic simulation capability will take precedence over static testing.
4. Initial simulation system buildup will emphasize MK II problem solving and system evaluation over non-MK II avionics and aircraft problems.
5. Two simulation systems will be developed. One will handle the F-111D while the other will handle both the FB-111A and F-111F systems.
6. No restrictions in physical size, weight, power and cooling are anticipated. The emphasis for new interface hardware will be on reliability and modularity to accommodate growth.

5.5.1.1 Actual vs Simulated Hardware

Tables 5-1 and 5-2 list the major hardware items associated with each of the three F-111 systems. The tables indicate which hardware will be simulated and/or not simulated. An indication of Phase 1 applicability is shown. The meaning of the notes indicated are defined below.

Note (1) – The J-BOX primarily routes attitude signals from the IRU and AFRS to multiple users. Since these two sensors will be simulated, the interface into the J-BOX will come from the simulation and switching unit defined in the baseline system discussion. (See Figure 5-3.)

Note (2) – These items must be capable of being switched in the simulation and switching unit. The status of all switches, buttons, etc. will be alterable either from pre-canned mission setups or via the operator control keyboard/monitor unit. When not being controlled from the test simulation system, the actual hardware item will interface directly as normal.

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Table 5-1. F-111 D Major Hardware Items

Hardware Item	Abbreviation	Simulated		Actual Hardware	Phase I
		Interface	Functional		
1. General Navigation Computer	GNC			X	X
2. Weapon Delivery Computer	WDC			X	X
3. Navigation Computer Unit	NCU			X	X
4. Converter Set	CS			X	X
5. Junction Box	J-BOX	X(1)		X	X
6. Integrated Display Set	IDS			X	X
7. Horizontal Situation Display	HSD			X	X
8. Head up Display	HUD			X	X
9. Horizontal Situation Indicator	HSI			X	X
10. Navigation Data Entry Panel	NDEP	X(2)		X	X
11. Navigation Data Display Panel	NDDP	X(2)		X	X
12. Stores Management Set	SMS	X(2)		X	X
13. Autopilot Damper Panel	ADP	X(2)		X	X
14. Instrument Set Coupler	ISC	X(2)		X	X
15. Avionics Test Panel	ATP			X	X
16. Maintenance Control Unit	MCU			X	X
17. Mode Select Coupler	MSC	X(2)		X	X
18. Tracking Handle (2)	TH			X	X
19. Flight Line Tape Reader	FLTR			X	X
20. Throttle	THROT	X(3)			X
21. Flight Control Stick	FCS	X(3)			X
22. Automatic Flight Control System	AFCS			X	
23. Inertial Reference Unit	IRU	X	X		X
24. Auxiliary Flight Reference System	AFRS	X	X		X
25. Flux Valve	FXVE	X	X		X
26. Doppler Radar Set	DRS	X	X		X
27. Central Air Data Computer	CADC	X	X	X(4)	X
28. Attack Radar Set	ARS	X	X	X(4)	X
29. Radar Homing and Warning	RHAW			X	
30. Accelerometer Transmitter	ACC STR	X	X		X
31. Radar Altimeter Set	RAS	X	X		X
32. Terrain Following Radar	TFR	X	X	X(4)	
33. Fuel Totalizer	FT	X	X		
34. Tactical Airborne Navigation	TACAN	X	X		
35. Instrument Landing System	ILS	X	X		
36. Flight Director Computer	FDC			X	X

Table 5-2. FB-111A/F-111F Major Hardware Items

Hardware Item	Abbreviation	Simulated		Actual Hardware	System		Phase I
		Interface	Functional		FB	F	
1. General Navigation Computer	GNC			X	X	X	X
2. Weapon Delivery Computer	WDC			X	X	X	X
3. Navigation Computer Unit	NCU			X	X	X	X
4. Converter Set	CS			X	X	X	X
5. Junction Box	J-BOX	X(1)		X	X	X	X
6. Attitude Director Indicator	ADI			X	X	X	X
7. Horizontal Situation Display	HSD			X	X	X	X
8. Optical Display Sight Set	ODSS			X	X	X	X
9. Horizontal Situation Indicator	HSI			X	X	X	X
10. Computer Control Unit	CCU	X(2)		X	X	X	X
11. Navigation Data Unit	NDU	X(2)		X	X	X	X
12. Stores Management Set	SMS	X(2)		X	X	X	X
13. Autopilot Damper Panel	ADP	X(2)		X	X	X	X
14. Instrument Set Coupler	ISC	X(2)		X	X	X	X
15. Short Range Attack Missile Computer	SRAM-C			X	X		
16. Short Range Attack Missile	SRAM	X(5)			X		
17. Astrocompass Set	ACS	X	X		X		
18. Tracking Handle (1)	TH			X	X	X	X
19. Flight Line Tape Reader	FLTR			X	X	X	X
20. Throttle	THROT	X(3)			X	X	X
21. Flight Control Stick	FCS	X(3)			X	X	X
22. Automatic Flight Control System	AFCS			X	X	X	
23. Inertial Reference Unit	IRU	X	X		X	X	X
24. Auxiliary Flight Reference System	AFRS	X	X		X	X	X
25. Flux Valve	FXVE	X	X		X	X	X
26. Doppler Radar Set	DRS	X	X		X		X
27. Central Air Data Computer	CADC	X	X	X(4)	X	X	X
28. Attack Radar Set	ARS	X	X	X(4)	X	X	X
29. Radar Homing and Warning	RHAW			X	X	X	
30. Accelerometer Transmitter	ACC XTR	X	X		X	X	X
31. Radar Altimeter Set	RAS	X	X		X	X	X
32. Terrain Following Radar	TFR	X	X	X(4)	X	X	
33. Flight Director Computer	FDC			X	X	X	X

Note (3) – These two air vehicle controls will be included in the simulation facility. They are a reasonable facsimile of the actual controls and interface (with force or position transducers) directly with the simulation and switching unit for input to the support simulation processor.

Note (4) – Both the ARS and TFR will, in certain tests, require the actual hardware to be used. In these cases, stimulations, under test simulation processor control, will be used. This capability is a growth item for later phases.

Note (5) – It is not the intention to simulate the entire SRAM weapon. However, certain functions such as targeting and platform alignment may be desirable for future phases.

From Tables 5-1 and 5-2, two immediate conclusions are drawn. First, there is great commonality of hardware among the three systems. Hence, interfaces and software can be prepared once and used across the board with little or no modification. Second, the Phase 1 baseline system will comprise about 90 percent of the full F-111 dynamic simulation capability. Hence, one should not view the multiphased approach as starting small and building accordingly.

5.5.1.2 Simulation System Software

The software falls generally into three categories, namely, that to be (1) purchased, (2) developed and/or modified from existing software, and (3) acquired from other government agencies. Even though actual program modules will not be directly useable, (except for those purchased), the functional requirements, logic, and mathematical algorithms will be of immediate value.

5.5.1.2.1 Purchased Software. These software packages will include peripheral handlers and computer/peripheral self test modules for the PDP-11/45 test simulation system. In addition, the real time system executive (RSX-11D) will be purchased. An assessment will then be made as to its ability to fulfill the Executive Operating System requirements discussed in Para. 5.2.2. A hybrid is anticipated with some RSX-11D features merged with requirements unique to the simulation system tasks to be performed. For example, memory management does not appear to offer significant advantages for the simulation system. On the other hand, a good deal of inter-PDP traffic will be necessary. This implies a synchronization between the two test computers to ensure timely and repeatable results.

5.5.1.2.2 Developed/Modified Software. The primary software items to be developed are:

1. Man/Machine Interactive System
2. Canned Mission Profiles with Breakpoints for Recycling
3. F-111 Subsystem Interface Simulators

The Man/Machine Interactive System includes modules to communicate with the Computer Control and Monitor Unit and the I/O Data Monitor Unit among others. The canned mission profiles will interface with the Real World Simulation System as the

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main driving function. The subsystem interface simulators will provide the linkage between the subsystem model outputs and the Simulator and Switching Unit which interfaces directly with the Nosebay Mockup.

It is anticipated that all other software modules will be modifications of existing packages. These modifications either entail coding changes to make the module compatible to run on the Executive Operating System or using the existing requirements, logic and/or algorithms in order to "re-code" the module for the new computer/environment. The following items fall into the software modification category:

1. IRU Closed Loop Model (with J-BOX interface)
2. Doppler Radar Model (functionally compatible to the F-111D and FB-111A systems)
3. F-111D Attack Radar Model (provide simulated Air-to-Ground target capability with no Doppler processing modes initially)
4. FB-111A/F-111F Attack Radar Model (same capability as F-111D)
5. Central Air Data Computer and Angle-of-Attack Models
6. Radar Altimeter Set Model
7. Auxiliary Flight Reference System Model (with J-BOX interface)
8. Flux Valve Model (provides heading for IRU ground alignment)
9. Accelerometer Transmitter Model (provides normal acceleration)
10. Throttle and Control Stick Interface Model
11. Real World-to-Sensor Model Interfaces
12. Sensor Model-to-Simulation and Switching Unit Interfaces

Acquisition of some of these models (e.g., Air Data Computer, and Radar Altimeter Set) would probably come from other government agencies and/or government contractors. Still others would be available in some form from Autonetics (such as IRU model). Those items listed which indicate interfaces, will, in general be developed.

5.5.1.2.3 Government-Furnished Software. Assessment of the Navy A-7 simulation facility at China Lake indicates that the following software could be used as the design baseline for the F-111 simulation facility:

1. 6 degree-of-freedom air vehicle model
2. 3 axis autopilot model
3. Atmospheric Model

Actually, the Navy has three different air vehicle models with varied levels of simulation realism (and complexity). The most complex, of these, along with the atmospheric and autopilot models are currently programmed on the SIGMA 5 computer and utilize about 50 percent of the CPU duty cycle.

5.5.1.3 F-111-to-Test Computer Interface Units

From Para. 5.2, three pieces of hardware have been identified for specific development. These are necessary to enable the test operators and/or the simulation test system to communicate with the F-111 system under test. These hardware are:

1. Computer Monitor and Control (CMAC) Unit
2. I/O Data Monitor (IODM) Unit
3. Simulator and Switching (SAS) Unit.

The CMAC unit interfaces with the 4PI AGE connector and is based on a design by Naval Weapon Center engineers. The IODM unit interfaces with the 4PI parallel channels (both PCO and ECI). The SAS unit interfaces with the CS, 4 PIs, nosebay mockup, and control stick and throttle. Figure 5-3 provides some insight into the hookup of the SAS unit with the F-111 nosebay mockup. Data to/from the support simulation processor will be stored in a general SAS buffer and distributed to the specific interface buffers shown. Here, the applicable conversion, and/or conditioning will occur followed by the appropriate drivers or receivers. Cable length compensation will be provided as necessary. It is anticipated that the NCU, J-BOX, TROT and CTL STICK, CADC, RAS, and ACC XMTR interfaces will be similar if not identical for each of the three F-111 systems.

5.5.1.4 Test Simulation Computer System

The computer system recommended for the F-111 Test Simulation is presented in Figure 5-15. This configuration represents a modification to the Baseline System discussed in Para. 5.2. The primary difference is that the communication between the processors is established through a DA11-F unibus window. This interprocessor communication link and shared peripherals are depicted in the figure. This configuration will permit the Support Processor to run as a task under the real-time executive (RSX-11D) in the Master Processor. The recommended technique eliminates the requirement for the Support Processor to have all the memory and peripherals that would be needed to support another real-time executive. This approach will not only reduce hardware cost by the elimination of expensive switches but will also increase the Support Processor throughput due to the reduced overhead of the Support Software. The window extends the concept of using the basic PDP-11 dual-port memory by allowing memories to be made shareable or nonshareable dynamically and on-line as well as sharing the control of peripherals.

5.5.2 F-111 Simulation System Schedules and Cost

This section summarizes the preliminary cost and schedule estimates required to implement the Phase 1 baseline Simulation System. Costs will be estimated for design, development, and test. Figure 5-16 is a summary of the schedule for Phase 1

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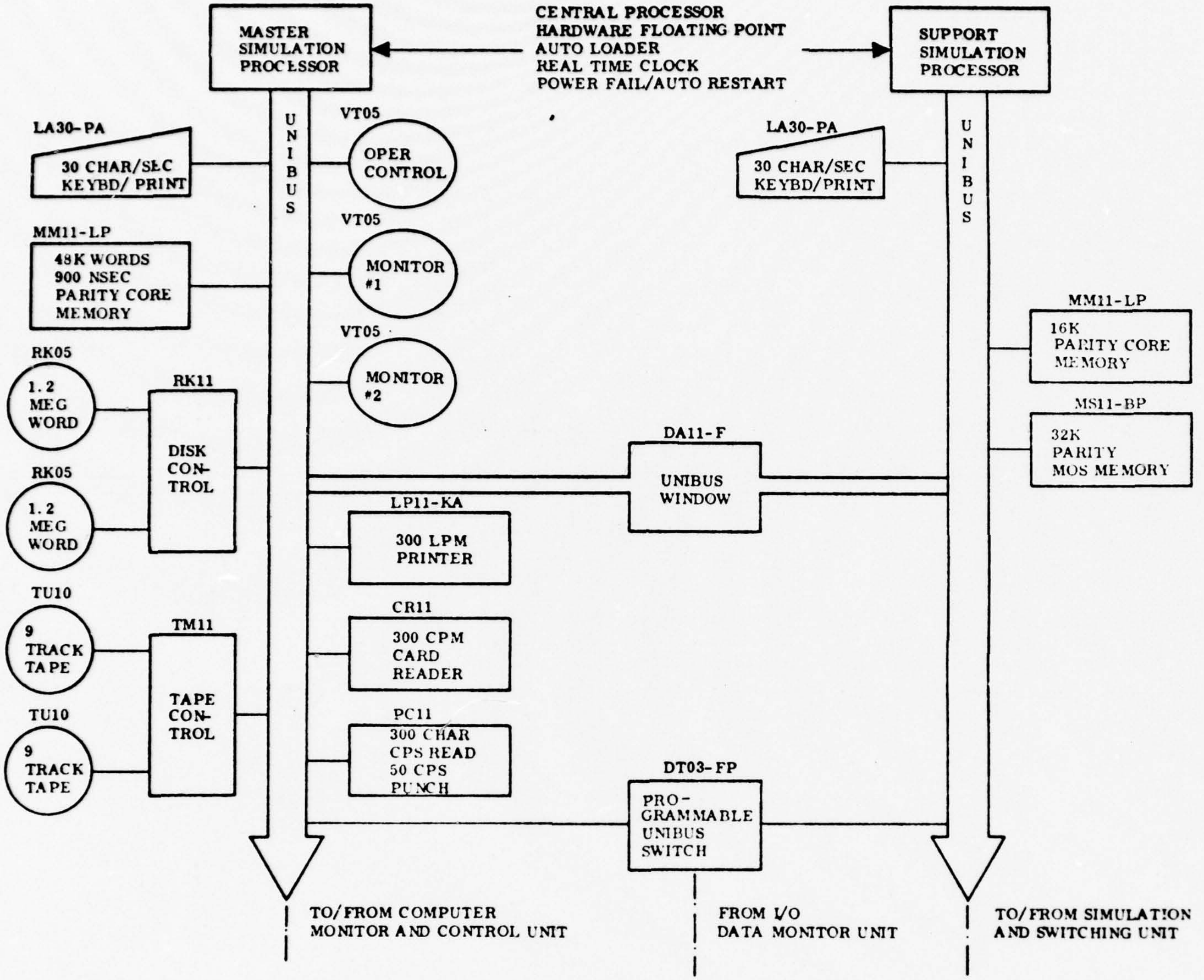

Figure 5-15. Test Simulation Computer System

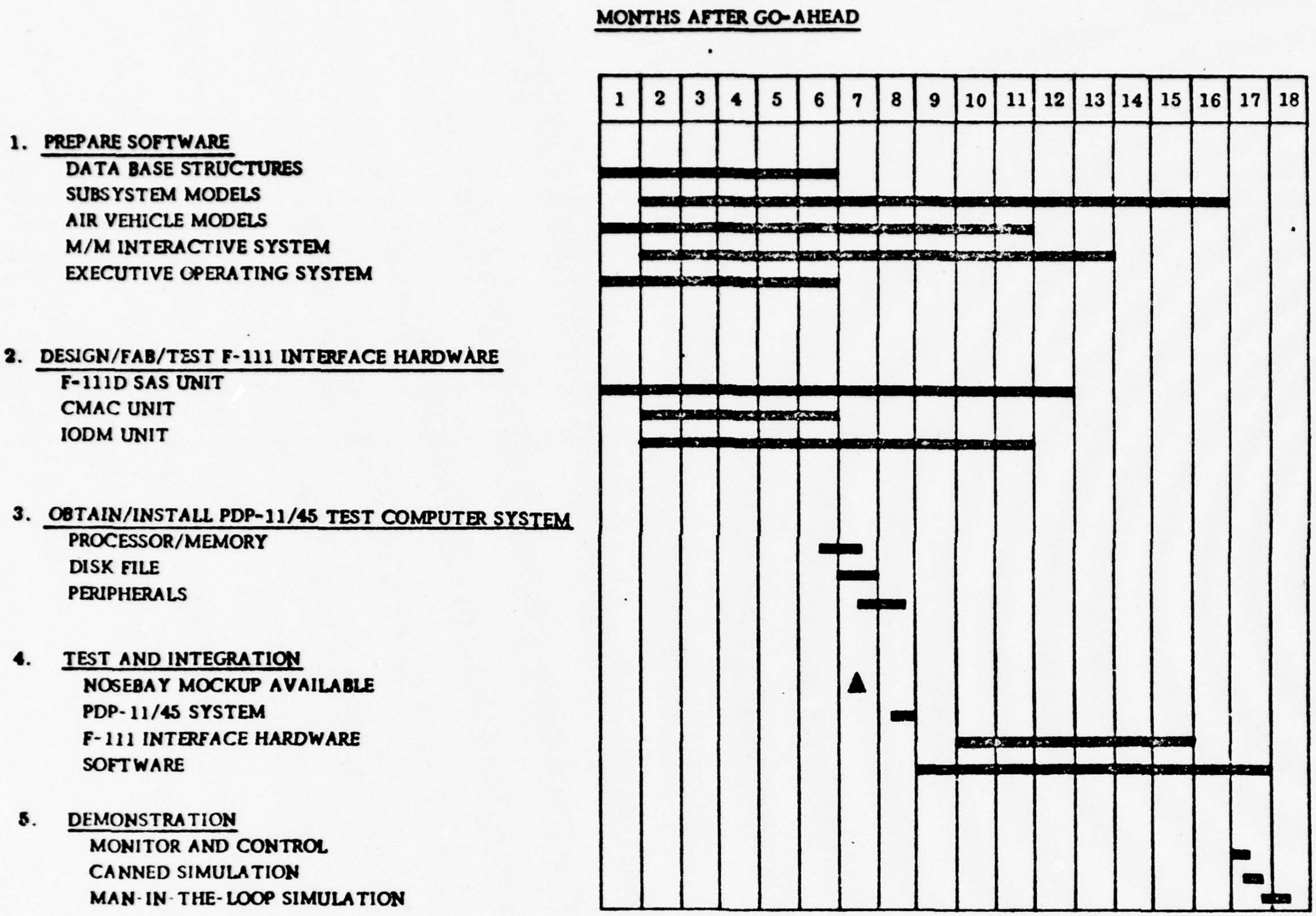

Figure 5-16. F-111D Development Schedule

for the F-111D System. Using as much commonality as possible, the schedule for the FB-111A/F-111F development is shown in Figure 5-17. The schedule indicates that the baseline F-111 simulation system for all three F-111 systems can be demonstrated and made operational (Phase 1) about 18 months after go-ahead. The cost estimates are discussed below according to the categories shown in Figures 5-16 and 5-17.

5.5.2.1 Software Costs

The estimate for the software effort will be based on the tasks to be performed for each category. These categories are (1) data base structure, (2) subsystem models, (3) air vehicle models, (4) man/machine interactive system, and (5) executive operating system. The tasks will be estimated for these five categories for the F-111D first. Then, using as much commonality as possible, the effort for the FB-111A/F-111F will be estimated.

5.5.2.1.1 <u>F-111D Software.</u> The first category is data base structure. The tasks involved include:

1. Organizing the disk pack into records which will accommodate, as a minimum, test modules, F-111D flight programs for the GNC and WDC, canned mission profiles, formats for displays and hardcopy devices of the test computer system, and tables related to parameter conversions, test setup menus, etc.
2. Organizing the local data bases within each simulation computer to include input/output data, intermediate data, test module/executive interfacing tables and mission-related data.
3. Document the resulting structure.

The structure selected will be applied to the FB-111A/F-111F design requirements. The manpower estimate is 5 MM and is spread as follows:

Mo. after go-ahead	1	2	3	4	5	6
Manpower:	1/2	1	1	1	1	1/2

The second category is subsystem models. The eight models noted below for Phase 1 for digital functional simulation are included in this effort. It is assumed that all subsystem models already exist in some form. That is, requirements, algorithms, and logic can be used along with some subsets of specific code to develop the subsystem test modules to run on the PDP-11/45. The tasks include:

1. Evaluating the usefulness of existing models
2. Reworking models as necessary to be compatible with F-111 simulation system requirements and air vehicle interfaces

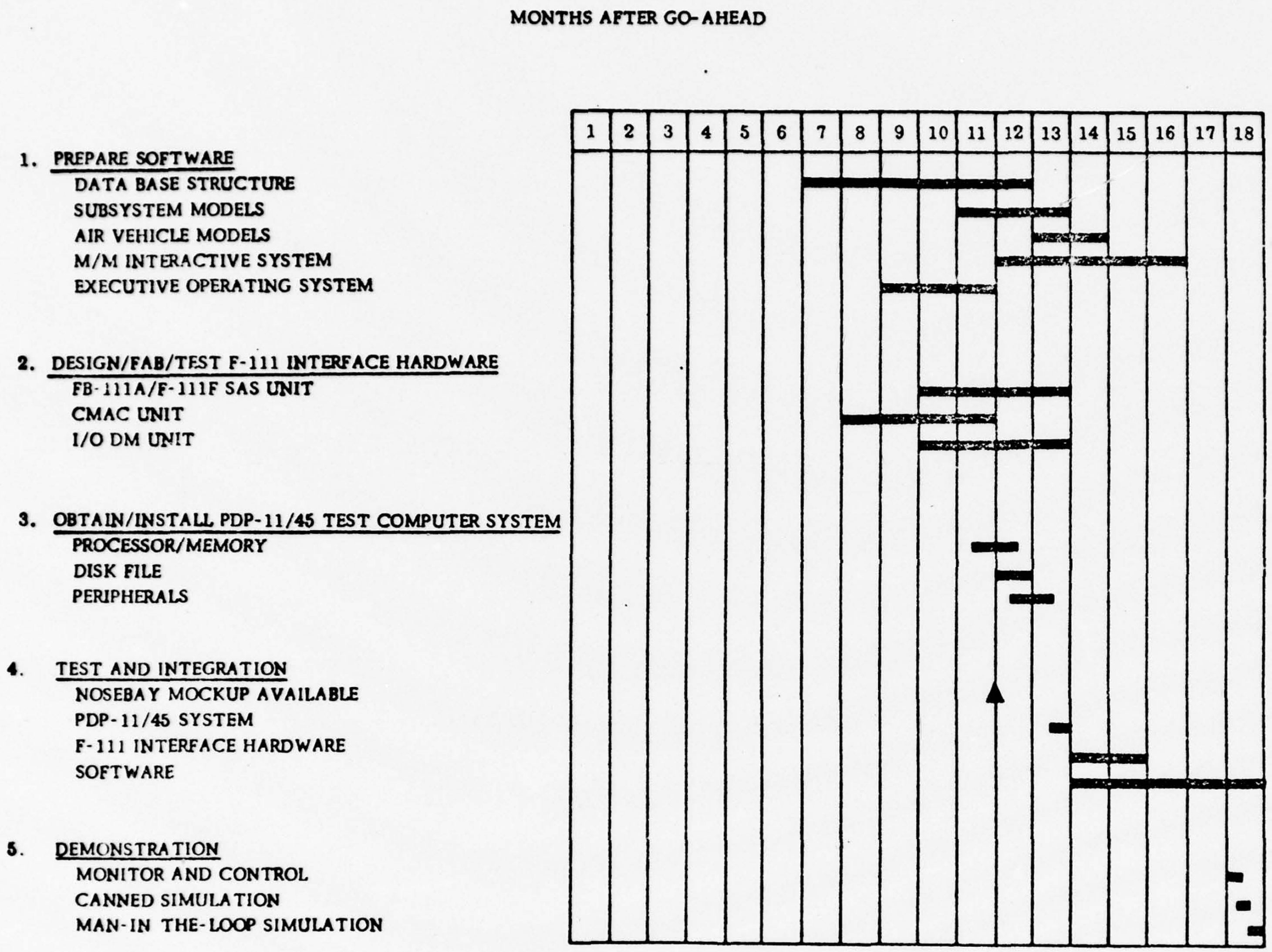

Figure 5-17. FB-111A/F-111F Development Schedule

3. Flow chart, code and checkout the resulting modules short of hardware integration

4. Document the resulting structure.

The matrix below summarizes the estimates to perform the tasks.

Subsystem Model	MM	Comments
1. IRU	8.0	Closed Loop Provision to Later Add Noise/Errors
2. AFRS	4.0	Simple Model
3. Flux Valve	1.5	Simple to Interface With IRU
4. DRS	3.0	Simple Model
5. CADC	3.0	Compatible with Atmospheric Model
6. ARS	5.0	Simple with Simulated Ground Target
7. ACC. XMTR	0.5	Provide Normal Acceleration
8. RAS	1.0	Simple Model
Total	26.0MM	

The spread for these 26 MM is shown below:

Months after go-ahead:	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Manpower:	3	3	3	3	3	2	2	2	1	1	1	1	1/2	1/2

The third category is air vehicle models. As mentioned in previous paragraphs, the software estimating baseline for the dynamic 6 deg.-of-freedom, 3-axis autopilot, and atmospheric model will be that currently mechanized at the Naval Weapons Center, China Lake, California. The major tasks include tailoring the package to operate within the executive operating system in the PDP-11/45 test computer system. As many FORTRAN statements as possible will be carried over. Specific adjustments will be made for conversion of SIGMA-5 assembly code to PDP-11/45 assembly code. The primary emphasis will be to minimize the duty cycle of this package. Hence, extra effort is estimated to perform analyses for this effort is 22 MM. The manpower spread is 2 men per month from month 1 through month 11 (See Figure 5-16).

The fourth category, namely man/machine interactive system, represents the single biggest new software development effort. It is this software package with which the SMAMA engineers will communicate with and control the test simulation system. The tasks will include as a minimum:

1. Keyboard options for control of the test setups stored on Disk File

2. Keyboard options for control of the F-111 interfacing hardware (i.e., CMAC, IODM, and SAS units)

3. CRT display formats for all test setups established

4. Control options for turning the test system on and initializing

5. Line Printer data formats

6. Keyboard options for controlling the operation of the Support Simulation Computer.

For these tasks to be fully responsive, SMAMA must participate in the requirements generation. The estimate for this task is 42 MM. The spread is shown below:

Months after go-ahead:	2	3	4	5	6	7	8	9	10	11	12	13
Manpower:	3	3	3	3	3	4	4	4	4	4	4	4

The final software category is the executive operating system. This effort will primarily be to examine the PDP-11/45 real time system executive and determine its adequacy against the EOS requirements. The effort will require consultation with DEC software system personnel. A support contract with DEC to cover this activity appears feasible. Assuming this DEC support and that about 50 percent of the software currently used in the PDP-11/45 executive is useable, the estimate for this task is 12 MM. The spread is 2 men per month for months 1 through 6 inclusive.

5.5.2.1.2 <u>FB-111A/F-111F Software</u>. Using common software requirements, modules, data, etc. generated from F-111D efforts, this estimate is considered to be 25 percent of the total F-111D effort. This amounts to 27 MM's. The spread is shown below:

Months after go-ahead:	7	8	9	10	11	12	13	14	15	16
Manpower:										
Data Base Structure	1	2	2	2	1					
Subsystem Models					1	2	1			
Air Vehicles Models							2	1		
M/M Interactive Sys						2	2	2	2	1
Executive Operating Sys			1	1	1					

5.5.2.1.3 <u>Summary of Software Costs.</u> The spread and total manpower estimate for both F-111D and FB-111A/F-111F software design and development is shown below. Note that more software manpower will be required in Para. 5.5.2.4 of this section (namely "test and integration").

Months after go-ahead:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Total
Manpower:																			
F-111D	4-1/2	8	11	11	11	10-1/2	9	8	8	8	7	5	4	1	1/2	1/2			107
FB-111A/F-111F							1	2	3	3	3	4	5	3	2	1			27
																			134 MM

5.5.2.2 F-111 Interface Hardware Costs

Hardware that will provide the direct simulator interface with the F-111 airborne hardware and the monitoring and control of the OFP evaluation has been discussed previously. This hardware consists of: (1) Simulation and Switching (SAS) Unit (including partial analog simulation of the ARS), (2) I/O Data Monitoring (I/O DM) Unit, and (3) Computer Monitor and Control (CMAC) Unit. Estimated cost of these units to provide the baseline capability consists of design, fabrication and test of a first (F-111D) unit and fabrication and test of a second (FB-111A/F-111F) unit. The I/O DM and CMAC designs will not change between the first and second units. Additionally, no design cost is associated with the CMAC since the government has an existing design (NWC, China Lake). Summarized cost for these units are presented in Table 5-3.

Table 5-3. Estimate of F-111 Interface Equipment Cost

Equipment	1st Unit (F-111D)		2nd Unit (FB-111A/F-111F)	
	Labor (Manmonths)	Parts, Material, Etc. ($)	Labor (Manmonths)	Parts, Material, Etc. ($)
SAS	42.0	87,500	16.0	77,000
I/O DMU	10.5	14,400	3.0	6,400
CMAC	5.0	3,300	3.5	3,300
Total	57.5	105,200	22.5	86,700

Development of these equipments is compatible with the schedule presented as Figures 5-16 and 5-17.

5.5.2.3 PDP - 11/45 Test Computer System Cost

Estimated cost for each element of the Test Computer System is presented as Table 5-4. List price for each of the F-111D and FB-111A/F-111F Test Computer system is $239,355. Original Equipment Manufacturer's Discount available to Rockwell International would reduce that price by $38,381. A maintenance contract for the listed equipment would total $1,794 per month.

It is noted that this price would include real-time computer software and computer/peripheral system integration. Software to be provided would include background/foreground resident executive, FORTRAN IV compiler, MACRO assembler, batch background monitor and utility programs. The unibus window handler is not supported under the supplied software and must be written as part of the specific operating system software.

5.5.2.4 Test and Integration Costs

There are three tasks related to test and integration. These are to demonstrate the operation of the PDP-11/45 test computer system, to integrate the F-111 interface hardware between the PDP-11/45 and the nosebay mockup, and to integrate the simulation software.

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Table 5-4. Test Computer System Cost Breakdown

Item	Qty	Description	Unit Price	Price	Monthly Maint. Extended
		MASTER SIMULATION PROCESSOR			
1	1	11/45-MW 40K 11/45-based Real-time System with foreground and background processing. Hardware floating point and dual cartridge disk storage. Includes: • 11/45-CP Processor with 32K parity (CR) core memory, memory management, processor and extension mounting cabinets, auto loader, real-time clock and serial 30 CPS DECwriter • MM11-LP 8K parity core memory • FP11-B Floating point processor • RK11-D 1.2 million word DECpack disk unit • RK05 1.2 million word DECpack disk drive • QJ580-AE Real-time system software license	$77,260	$77,260	580
2	1	MM11-LP, 8K words 900 n/sec parity memory	5,400	5,400	35
3	3	DL11-A 20MA Asynchronous Line Interface	430	1,290	18
4	3	VT05B-AA Alpha/numeric Keyboard CRT Terminal	2,795	8,385	66
5	1	TM11-EA 9 channel Industrial Compatible Tape, 800 bpi, 45 ips with controller and cabinet	10,745	10,745	95
6	1	TU10-EE 9 channel Industrial Compatible Tape, 800 bpi, 45 ips, includes cabinet	7,505	7,505	70
7	1	PC11, High Speed Paper Tape Reader/Punch	3,900	3,900	36
8	1	LP11-KA, 300 LPM Line Printer, 132 column	19,000	19,000	80
9	1	CR11, 300 CPM Card Reader	4,860	4,860	50
10	2	DD11-B, System Units	185	370	-
11	1	DB11-A, Unibus Repeater	1,080	1,080	5
		SUPPORT SIMULATION PROCESSOR			
12	1	11/50-CP Central Processor with 16K parity MOS memory plus 16K parity core memory and hardware memory management. Includes power supply, cabinet, line frequency clock, multi-device auto loader, power fail/restart, serial 30 CPS DECwriter terminal and control, and five training credits	51,070	51,070	430
13	1	FP11-B Floating Point Processor. Performs hardware operations on 32-bit and 64-bit floating point numbers as well as integer to floating conversions.	5,290	5,290	42
14	1	MS11-BD Second MOS Memory Control. Controls up to four additional MS11-BM or MS11-BP memories.	1,500	1,500	12
15	4	MS11-BP, 4K MOS memory with byte parity	5,200	20,800	160
		COMMON DEVICES			
16	1	DA11-F Unibus Window, High Speed Interbus Channel	6,500	6,500	40
17	1	DT03-FP, Programmable Unibus Switch	8,400	8,400	75
18	1	System Integration Charge	6,000	6,000	-

5.5.2.4.1 Simulation Equipment Demonstration. After the PDP-11/45 system has been assembled, tested and integrated by DEC personnel, this effort would demonstrate final operation of this purchased hardware/software system to SMAMA. As a minimum, all peripherals, including the disk file, will be exercised to demonstrate proper operation. Compilation and execution of a typical FORTRAN program will be demonstrated. An intercomputer data transfer demonstration will also be accomplished. The cost for this demonstration is included in the purchase price of the total PDP-11/45 system discussed in Para 5.5.2.3.

5.5.2.4.2 Interface Hardware Integration. Each F-111 Interface Hardware Unit will be integrated. The CMAC and IODM units will be integrated first on the F-111D system. Once checked and debugged on the F-111D system, the second units (for the FB-111A/F-111D system) will be checked primarily for fabrication problems. The major integration effort occurs with the SAS units (both systems). The estimated manpower to test and integrate these units is:

F-111D - Months After Go-ahead:	10	11	12	13	14	15	Totals
CMAC unit	2	1					3
IODM unit		2	1				3
SAS unit			2	2	2	1	7
							13 MM
FB-111A/F-111F							
CMAC unit					1/2		1/2
IODM unit					1/2		1/2
SAS unit					2	2	4
							5 MM

5.5.2.4.3 Checkout and Integration. The checkout and integration of the unique test simulation software modules comprises this cost. From similar experience on other programs (F-111, Polaris, Minuteman), it is estimated that one fourth of the total programming effort supports software/hardware integration. Hence, the estimate is 27 MM. The spread is 3 men per month from month 9 through month 17 (See Figure 5-16). The estimate for the FB-111A/F-111F is based on similar activity with F-111D. This estimate is 10 MM. The spread is 2 men per month from month 14 through 18.

5.5.2.4.4 Summary. A summary of the test and integration task is shown below.

Months after go-ahead:	9	10	11	12	13	14	15	16	17	18	Totals
F-111D	3	5	6	6	5	5	4	3	3		40
FB-111A/F-111F						5	4	2	2	2	15
											55 MM

5.5.2.5 Demonstration Costs

During months 17 and 18, a demonstration of all basic functions would be performed. This demonstration will certify that the hardware and software perform the operations dictated by the test operators. The estimate is 3 MM for each month for the F-111D and FB-111A/F-111F respectively.

5.5.2.6 General Comments

While not specifically enumerated as a cost item, the documentation of hardware descriptions (including operation), and software modules is included in the previous costs. However, it is desirable to provide an overall users manual for F-111 simulation system operation. This manual is assumed to be written by SMAMA personnel with assistance as required from the applicable contractors. It is estimated that there would be at least 60 percent commonality between the F-111D manual and the FB-111A/F-111F manual.

5.5.3 F-111 Simulation System Growth (Phase II and III)

It is envisioned that all software modules developed will be modular. The capability to introduce noise, errors, etc. into simulated subsystem, airframe, etc. will be provided without software redesign. Also, the SAS unit will be designed to accommodate growth for additional analog, serial and parallel interfaces with the DCC and nosebay mockup.

5.5.3.1 Phase II Growth (Minimum)

1. Astrocompass Model
2. Error/Noise Injection into Models
3. Static Simulation of all F-111 Panel Interfaces
4. Attack Radar Doppler Processing Modes (F-111D only)
5. Magnetic Tape Recorders (for data recording of simulated system activity during a test. Data reduction would be accomplished using PDP's or other large computer complex
6. Card Reader (for continuous program maintenance)
7. Paper Tape Reader/Punch (Making addendum tapes for F-111 field use)
8. Takeoff and Landing Capability in Mission Profiles

5.5.3.2 Phase III Growth (Minimum)

1. SRAM Missile Model
2. HUD/ODSS stability and accuracy hardware/software mechanization
3. Automatic F-111 Problem/Tape Configuration Control maintenance

5.6 BASIC SIMULATION REQUIREMENT RATIONALE

There is a basic shortcoming in the F-111 avionics software capability at SMAMA. This shortcoming is the lack of a capability to dynamically evaluate new or revised operational flight software and the solutions to software/hardware problems. This lack makes it very difficult for SMAMA to thoroughly evaluate software prior to

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release to operating commands. With a dynamic simulation capability, significant benefits will be derived in the areas discussed below.

5.6.1 Improvements in Completeness of Checkout

The simulation facility proposed in this study will provide AFLC/SMAMA the necessary test capability for FB-111, F-111D and F-111F system and software maintenance. This equipment overcomes the test limitations imposed by the static capability of the existing ITE facilities. Improvements in completeness of checkout that will result from the recommended facility are attained because dynamic simulation:

1. Allows dynamic evaluation of all modes on ground
2. Allows interactive use of all three computers in dynamic situations -- not possible statically
3. Allows both man-in-the-loop search for anomalies and preprogrammed flight profile accuracy evaluation
4. Allows detailed examination of conditions causing anomalies
5. Eliminates aircraft scheduling/availability problems
6. Allows exact (if known) and repeatable reproduction of conditions in which flight problems are experienced.

The requirement for an increased test capability resulting in improvements in the completeness of checkout was established by examining: (1) the F-111 weapon system maintenance problem, (2) the integration test equipment (ITE) inadequacies, (3) need for improved test facilities, and (4) required test facility.

5.6.1.1 The F-111 Weapon System Maintenance Problem

F-111 systems are composed of numerous advanced subsystems which are integrated into the most sophisticated avionic equipment available today. The complexity of the FB-111A, F-111D and F-111F avionics systems required that numerous functions within the airborne systems be automated and removed from continuous operator control, manipulation and even observation and access. This automation was provided by the incorporation of three separate digital computers. The computer control of the various subsystems and functions is provided in the GNC and WDC by executing permanently stored programs. In order to perform the required control with the available memory and computing capability, extremely efficient programs were developed. The natural result is that the computer flight programs are generally inflexible. Any changes desired to the program require detailed analysis and usually major program modifications to provide required memory space for the addition or change. The high degree of computer utilization combined with extremely efficient flight programs requires that a systematic and timely solution to problems be developed. Figure 5-18 outlines steps taken in the past in solving a typical field problem involving a flight program change. This flow is not unique and is presented to indicate areas in which ground test facility use is either required or would be useful. Steps 4 through 8 represent those areas within the OFP revision cycle. The type of

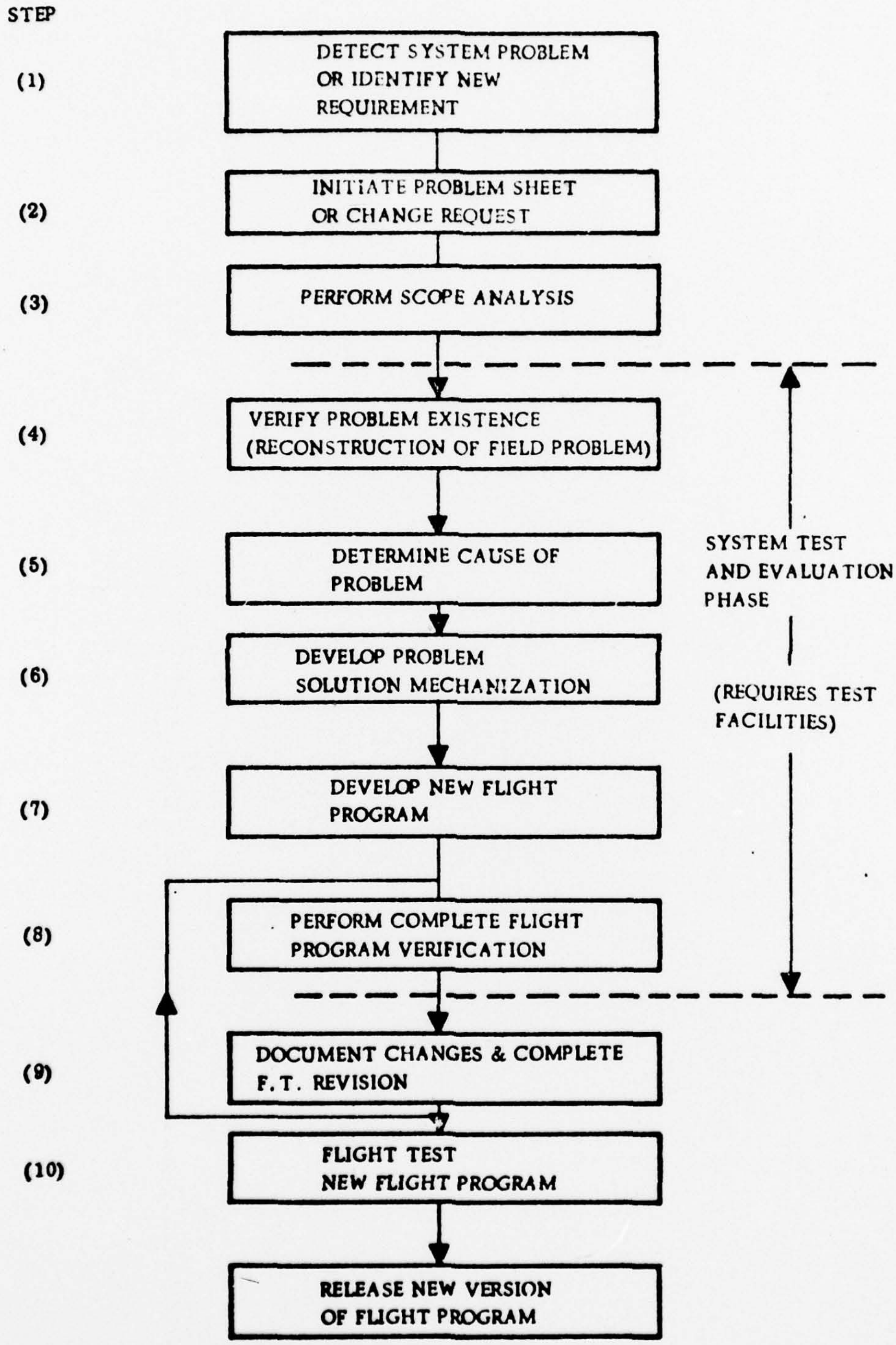

Figure 5-18. Typical F-111 Problem Solution Sequence

facilities and the degree of automation are indicated in following sections by reviewing in detail what test functions must be provided to enable a timely solution to typical expected system engineering problems.

5.6.1.2 Integration Test Equipment (ITE) Inadequacies

Capabilities of the ITE were examined to determine its usefulness in a long term software maintenance/development program. The Integration Test Equipment (ITE) is special test equipment which was initially designed to accomplish the overall functional checkout including development and verification of operational computer programs. In general, this equipment statically simulates all external interface signals required for avionic system operation, provides the capability to monitor digital and analog signals as tests are performed, and control, fill, and readout the digital computers in each system. The ITE performs no automatic testing. Flight program inputs are initialized by manually setting sensor inputs and switch position on avionic subsystem hardware and simulators. Verification of system test response is obtained by observing static ITE displays and outputs of the avionic subsystem hardware. In spite of the ITE inadequacies presented here, the capabilities within the ITE are valuable and useful. It must be kept in mind that the ITE is the tool that has been used since the beginning of the F-111 program to integrate and test both hardware and software. Many, many problems were identified and solved using this equipment with techniques and approaches still available. Of primary concern in the discussion of inadequacies are the subtle problems that elude detection on the ITE and result in operational shortcomings and nagging problems.

Specific limitations of the existing F-111 avionic test equipment (ITE) are listed in Table 5-5. These limitations can be segregated into the following general categories:

1. Limited input signal control – only one serial data word can be set up and transferred at any one time. No real-time data entry can be performed.
2. Lack of monitoring or data gathering capability.
3. Inability to create realistic dynamic flight conditions.

Testing of the complex F-111 avionic system requires continuous positive control over the F-111 flight hardware. This control includes the capability to stimulate the hardware to a degree sufficient to create an actual system environment. The present ITE equipment provides a limited input capability which results in an artificial "static" test situation. This capability is inadequate to create test situations necessary to precipitate solutions to the majority of existing or expected problems.

5.6.1.3 Need for Improved F-111 Test Facilities

The high degree of automation in the F-111 weapon systems combined with the large number of sophisticated subsystems makes system problem solutions difficult. This difficulty results from the extensive interaction of individual subsystems through the digital computer complex via the extremely efficient flight programs. A review of existing and expected hardware and software problems has revealed that a dynamic test capability must be provided. This dynamic test capability is required to provide (1) rapid reconstruction of field problems, (2) isolation of problem sources,

Table 5-5. Specific ITE Inadequacies

ITE Test Element/Function	Inadequacies
1) Serial Word Simulator (SWS)	1) a. Serial word simulators are limited to simulation of valid data for only one word at a time. This results in time consuming operations to input multiple data and in a number of cases does not provide valid testing since actual data transfer rates are not being met. b. Data entry is in difficult-to-use bit patterns instead of desirable engineering units.
2) Serial Word Monitors (SWS)	2) a. Serial word monitors, (SWM), are limited to monitoring only one word at a time. Only three SWMs are available per ITE. Data words are in binary bit patterns. b. SWM can only be put in freeze mode manually to retain and display the last input received. It is desirable to monitor the fast changing data at critical times which can only be indicated by a discrete or strobe signal.
3) Computer/ Converter Set Interface Monitoring	3) Visual monitoring equipment is not available at computer/ converter set interface. Visual and perhaps hard copy recording should be provided at all subsystem interfaces. Controls to freeze data at critical times should be included.
4) Computer Data Entry	4) Programmers key-in data in the wrong memory locations. Correcting the data in these locations might only be accomplished by a new memory load. A hard copy print-out should be provided for all memory key-ins.
5) Simulated External Input Signals (Velocity, Altitude, Heading, Pitch, etc.)	5) Manual entry results in step data changes instead of the smoothly varying real world. Signals cannot be coordinated to simulate the actual aircraft dynamics.
6) INS, ARS, Doppler Radar and Astro Compass Static Test Set-up	6) ITE provides only static operation of these subsystems. Static operation greatly limits overall system testing and evaluation. Critical system modes such as designation, target tracking and navigation cannot be tested.
7) Computer Monitoring	7) The ITE test set-up does not allow the use of peripherals (printers, tape units, etc.) for data/program monitoring without the introduction of contaminating data monitoring programs to the actual flight program.

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(3) development and evaluation of problem solutions, and (4) the on-line and real-time dynamic verification of flight tape changes prior to and/or in lieu of flight testing.

An examination of over 300 past and present problems in the "SMAMA F-111 Problem Book" was made. Two major conclusions were reached. First, between 25 and 40 percent of the problems for all three F-111 systems will require some form of dynamic test configuration in order to develop and/or validate a solution. If simulation is not available, flight testing will be extensively required. Second, about 80 percent of the problems require the alteration of the operational flight programs. Moreover, these alterations will primarily add words to computers that are 98 percent filled in order to effect the solution.

AFLC/SMAMA presently does not have the capability to provide the required dynamic weapon system testing necessary for timely solutions to field problems and flight program revisions. Failure to obtain these dynamic test facilities will result in excessively high maintenance costs, slow response times to field problems and, in general, will result in F-111 weapon systems operating in the field below designed levels.

AFLC/SMAMA F-111 system engineering responsibilities will include flight computer program maintenance, investigation of mechanization problems (both hardware and software) and implementation of new modes and hardware. To meet these responsibilities, SMAMA must have facilities, test equipment and a team of skilled personnel who are capable of performing all the functions necessary to define, develop, verify and implement change to flight programs and perform rapid system mechanization changes. Key to this effort is the basic system test and evaluation facilities. The degree of automation and sophistication in the test and evaluation facilities will determine the timeliness of problem solutions, cost in manpower, the cost of flight test support required, and will ultimately determine the operational quality (capability, accuracy, etc.) of the FB-111A, F-111D and F-111F weapon systems. A study into the total F-111 system maintenance problem indicates the need for a degree of test equipment automation above that presently available with the static ITE test stations. To understand the need for a simulation/computer aided test facility, one must first review the tasks involved in performing system level maintenance on the FB-111A, F-111D and F-111F weapon systems.

5.6.1.4 Required Test Facility

As the F-111 weapon system matures, the problems encountered become more complex, difficult to solve, and time consuming. For example, problems in weapon trajectory computations almost always involve several analysis/test/evaluate iteration cycles before satisfactory, accurate solutions are obtained. Large amounts of data must be collected for problem identification. Also, F-111 problems involving navigational accuracy require statistical processing of large amounts of test data. Solution of navigation steering and weapon delivery steering type problems requires a dynamic man-in-the-loop simulation of the F-111 aircrafts. In order to solve these problems, test facilities must provide continuous positive control over the F-111 flight hardware under test. This control includes stimulation or input data generation, monitoring or data gathering, and evaluation of data analysis. An F-111 digital simulation facility would provide the direct control necessary to develop and/or verify solutions to operational problems. This facility would provide the dynamic system environment necessary for investigation and evaluation of problem solutions and would be capable of automatic data generation, data gathering, and data analysis. Some of the features of this F-111 digital simulation facility necessary for rapid problem solutions are as follows:

5.6.1.4.1 Stimulation or Input Data Generation. An important aspect of the F-111 problem solution is the measurement of the weapon systems response to stimulation. Important factors in the stimulation phase are the choice of the points of data injection into the system and the approach to data generation. The presently available F-111 ITE equipment has limited data stimulation capability. This shortcoming is overcome by using digital simulation equipment involving a test computer. Real-time data and dynamic flight profiles would be supplied as input stimulations. This capability would provide for the creation of a realistic system operational environment instead of the artificial "static" situation now provided with the existing test equipment.

5.6.1.4.2 Monitoring or Data Gathering. The digital test or simulation facilities would allow data gathering in real-time. Test computer control would enable direct control of the F-111 weapon system. During problem analysis and debugging, flight programs could be halted and examined at predetermined or sensed program states. This capability would greatly facilitate problem isolation and is not now available with the existing ITE test equipment.

5.6.1.4.3 Creation of Unique Problem States. It is possible under digital simulation to create computer program and flight situations that are unlikely (low probability of occurrence), dangerous, or expensive to duplicate under live flight conditions. The digital simulation facility can be used to create artificial program states to check the flight programs and flight hardware responses to error conditions. This capability is not available with the existing F-111 test facilities.

Two important test problem areas that require a dynamic system environment are discussed below:

5.6.1.4.4 Collective Evaluation of Flight Programs. Each program (GNC, WDC and NCU) can be tested in a stand-alone configuration. The three programs can also be integrated in a static compatibility demonstration test using the ITE. In this latter test the three programs are integrated only during a "free inertial" run. For subsequent demonstration tests, the NCU does not participate. Hence, neither method ever integrates the three flight programs such that they approach the operational environment. The F-111 dual computer mechanization has a number of areas of flight program interaction. This interaction includes GNC program inputs to the WDC computer for weapon delivery computations; dual computer operation is required for self-test and backup mode operation. The dual computer synchronization and timing can only be verified by simultaneous operation of both computers. The requirements for dual computer operation during an operational environment requires a source of external control and monitoring. This capability can best be provided with a digitally controlled test setup or simulation facility.

5.6.1.4.5 Man-in-the-Loop Sequential Testing. A large number of the F-111 system modes require that the crew sequence through a number of operating conditions or steps in response to a dynamic or changing set of system parameters. In general, these steps must be exercised in a systematic sequence, usually within a given time period. Some of the system modes requiring this crew/hardware interaction include target recognition, designation, weapon delivery and manual steering.

The evaluation of changes and optimization to the crew/mechanization parameters cannot be simulated or evaluated with a static test facility. A means must be provided for real-time queuing of the crew and the measurement or evaluation of the resultant crew response. This requires dynamic displays and other hardware responses capable of simulating the actual dynamic environment. Failure to provide dynamic test facilities for man-in-the-loop type testing will necessitate problem solution by extensive flight testing.

5.6.2 Cost Ramifications

In order to quantize the direct cost saving potential with an F-111 dynamic simulator, costs, schedule, and performance confidence factors of a recent effort in developing an updated operational flight program (OFP) for the F-111D were examined. These factors were then compared with their expected equivalents, had the proposed dynamic simulator approach been available.

The task that was examined is the contractor/Air Force effort in converting the PID-4 operational flight program, with its identified operational and specification problems, into an updated PID-5 version (subsequently identified as OFP 112/212) designed to resolve the PID-4 problems. The task had been preceded by a number of previous similar OFP updates and thus the examined effort is felt to represent a typical update of a mature operational flight program by experienced personnel.

The subtasks to be performed were identified as follows:

<u>Task</u>

(A) Problem Analysis
    Fact Finding
    Problem reconstruction on available test equipment and hardware
    Problem solution

(B) Mechanization Change Requirements Analysis
    Program optimization
    Definition of mechanization requirements

(C) Software/Program Change Analysis
    Definition

(D) Lab Evaluation on Available Test Equipment

(E) Initial Software/Program Changes

(F) Prepare Test and Evaluation Tapes

(G) System Compatibility Demonstration and TVT

(H) Finalize Software/Program Tapes
    Sell-off

(I) Configuration Control

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(J) ECS/ECP Documentation

(K) Flight Test

The above subtasks may be grouped into the following phases:

Phase 1	Tasks A and B	Problem/Solution Definition
Phase 2	Tasks C, D, E and F	Implement Changes
Phase 3	Tasks G, H, I and J	Static Test Verification
Phase 4	Task K	Flight Test Verification

An examination of the in-house (contractor) effort in completing Phases 1 through 3 indicates the following:

Cost:	Average 12 men/month
Schedule:	Seven months
Performance Confidence:	Fair confidence that new OFP will meet all requirements for operational use

An estimate of the flight test effort, i.e., Phase 4, can be made based on the presently planned F-111D OFP DO7 115/215 validation at Cannon AFB (TAC Project 73 Alpha 136F). In this validation effort, 40 sorties are planned requiring the commitment of six aircraft, four crews, the necessary supporting maintenance and other services and spanning one to two months calendar time. It has been previously estimated that an average sortie costs $14K. Thus, it can be estimated that the DO7 115/215 validation flight test costs will be approximately $560K (sustained by the operational command).

With a detailed knowledge of the tasks involved in developing an updated operational flight program utilizing the existing methodology and test equipment, it is possible to make a reasonable comparison to an approach utilizing the proposed dynamic simulator. This comparison is summarized in Table 5-6.

It is is assumed that each of the F-111 models, i.e., the D, F and FB, will require one OFP update per year, it is thus apparent that F-111 OFP maintenance effort savings of approximately $3[(83-55)\ (\$/MM) + (490K)] \cong \$1,700,000$ could be realized each year. Additionally, the schedule improvement to four months per aircraft model OFP would permit a continuous noninterference full-time approach to the programming update effort for the three models of the F-111. Finally, and most significant, is the overall high performance confidence factor that the updated OFP will meet the system requirements.

In addition to the F-111 OFP maintenance savings, certain indirect savings will result from use of a dynamic simulator. These savings will result from a reduced number of anomalies experienced in flight that are not identifiable in static ground test. This type of problem results in "retest OK" and "cannot duplicate" maintenance actions.

Table 5-6. F-111D Operational Flight Program Update Comparison

Without Simulator				With Simulator		
Task	Cost (Man-Months)	Schedule	OFP Performance Confidence Factor	Cost (Man-Months)	Schedule	OFP Performance Confidence Factor
A B	33 MM	Phase 1 2 Months	Low	23 MM	1 Month	High
C D E F	17 MM	Phase 2 3 Months	Medium	15 MM	1-1/2 Month	Medium
G H I J	33 MM	Phase 3 2 Months	Low	17 MM	1 Month	High
K	40 Sorties $560K	Phase 4 2 Months	Medium	5 Sorties $70K	1/2 Month	High
Total	83 MM & $560K	9 Months	Medium	55 MM & $70K	4 Months	High

Valid cost comparisons are difficult to make because the results are very dependent upon the accuracy of the assumptions. Autonetics has made a comparison of potential flight test cost, with and without a simulator, using the following assumptions:

1. Ground test cost will not change except for the simulator acquisition cost, estimated to be $1.0 million.
2. Average cost of a test flight is $14,000.

3. Both SMAMA and the operating commands would be conducting flight test. This condition is similar to the existing situation wherein both GD-FW and TAC/SAC are flight testing tapes.

Figure 5-19 presents flight test cost through a 10-year program with the number of flights required for verification as a parameter. The base condition (no simulator) considers that SMAMA will require six flights to verify each tape and that TAC/SAC will require 30 for the F-111D and ten each for the F-111F and FB-111A. As noted previously, 40 flights are presently being conducted at Cannon AFB for the current F-111D tape verification. The alternate conditions with a simulator assume the reduced number of verification flights shown on the Figure and represent what are felt to be realistic extremes. It should be noted that the annual operating cost with simulator is the same as the base condition until the simulator becomes operational. The simulator acquisition cost is additive and results in a cost "break-even" point between the third and fourth years dependent upon number of flights required.

5.6.3 Personnel/Equipment Use

Simulation/dynamic testing will provide for a more efficient use of Air Force personnel and equipment. AFLC/SMAMA personnel can concentrate on the development of F-111 software and system level expertise that presently does not exist in the Air Force. Operational commands will be left free to concentrate on normal hardware support and operational readiness efforts. The more efficient use of personnel and equipment will result from deletion of extensive software development flight tests by operational commands. The need for an extensive weapon delivery flight test program, with live ordnances and the associated support personnel and equipment, will be eliminated. The present iterative process of software problem solving using existing static test facilities and operational flight tests results in increased program costs and reduced operational effectiveness for the FB-111A, F-111D and F-111F weapon systems.

Little knowledge presently exists within SMAMA or the operational commands into the details of the individual subprograms and the rationale behind their development. Incorporation of changes to F-111 computer flight programs requires an intimate knowledge of system mechanization requirements and the methods of software implementation. Problem solution development, even when performed by contractor personnel who have intimate knowledge of the requirements and past development history, is difficult and time consuming in the complex areas of weapon delivery, navigation and filter computations. In addition, the task of changing F-111 flight programs is being greatly aggravated by the high degree of computer program optimizations necessary to meet the constraints imposed by computer memory size and available cycle times. The recommended F-111 avionic simulator/dynamic test facility will provide the required degree of F-111 software visibility necessary for AFLC/SMAMA to become proficient in the software maintenance. Failure to obtain these facilities will result in a long and costly learning cycle with F-111 software maintenance being performed by a trial and error type procedure using static test equipment and extensive flight testing.

Deletion of the requirements for extensive flight testing by the operational commands will greatly reduce the required personnel and equipment. A current example of the required flight program validation effort can be seen by the aforementioned F-111D flight test efforts at Cannon AFB. Air Force planning for the

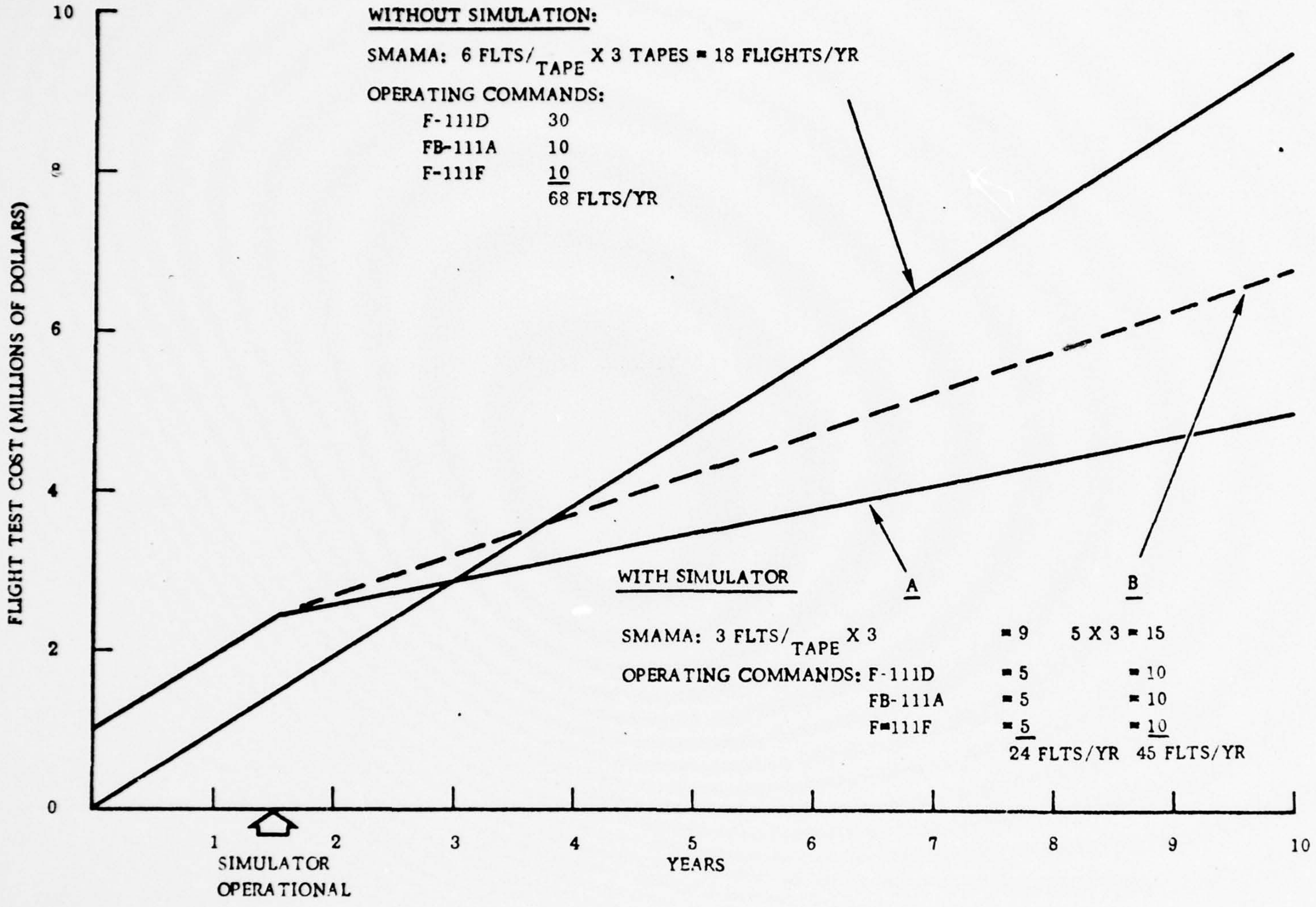

Figure 5-19. Flight Test Cost – With and Without Simulation

validation of the recently received "final" F-111D operational flight program (tape DO7 115/215) includes 40 sorties, the use of three aircraft from the operational wing, the tie-up of three operational test and evaluation (OT&E) aircraft, three wing crews, one OT&E crew and is expected to span one to two months calendar time. Experience indicates that when this effort is complete, however thoroughly it is performed, numerous uncertainties in the readiness of the weapon system will still remain. The flight test crew in an uncontrolled environment can do no more than identify the top of "problem iceberg, " so to speak. Testing under controlled conditions with extensive program sequence visibility and data recording is necessary to isolate subtle programming and system problems. The dynamic simulator approach as outlined in this study is the most practical and cost effective means of meeting the FB-111A, F-111D and F-111F system maintenance requirements.

5.6.4 Operational Capability

Perhaps the most important advantage offered by a simulation/dynamic test facility is the improvement in operational readiness and weapon system accuracy. Many people fail to realize that the F-111 computer software system must be evaluated, tested and maintained just as thoroughly as the actual system hardware. The complexity of the F-111 avionic system necessitates the need for a critical and quantitative evaluation of its software performance. With the existing static test facilities, validation of software accuracy and operational effectiveness cannot be obtained even with an inordinate amount of operational flight testing. During flight tests, the software program inputs cannot be controlled. Interpretation of relevant results is complicated by stochastic environmental variables. The proposed simulation facility would enable control of input signals and test conditions. Weapon delivery and navigational program sensitivities to individual error factors could be observed and analyzed. Complex weapon delivery and navigational flight programs could be optimized by repeated simulated flights under controlled conditions. However, the degree of operational improvements obtainable with this facility is difficult to quantify. Considering the severe test limitations imposed by the present facilities, the uncontrolled nature of flight tests and the present iterative process of problem solving, the expected improvements in F-111 operational capabilities would be significant.

6. RECOMMENDATIONS AND CONCLUSIONS

6.1 GENERAL

Based upon the areas investigated and the results obtained, it is concluded that SMAMA has a real need for a digital simulation and integration test facility of the type defined in this report. It is noted, however, that this capability of and by itself is not the complete answer to SMAMA's problem. Along with the described facility and the ITE, a cadre of competent, dedicated personnel who have detailed F-111 software problem solving experience should be developed as soon as possible to round-out this capability.

As time passes, knowledgeable F-111 contractor support is becoming increasingly difficult to obtain. SMAMA should consider this factor in planning future areas of contractor involvement and the efficiency expected from that involvement.

Autonetics recommends that SMAMA:

1. Complete the upgrading/calibration of the ITE and get qualified software personnel actively involved, full time, in detailed examination of F-111 OFP status, problems and optimization. This effort will serve the immediate purpose of on-going system support as well as being a training ground that will enable future, more comprehensive OFP work on all three F-111 systems.

2. Partition the work required to obtain the improved capability described herein and set out to implement that work through combined SMAMA and contractor efforts as soon as possible. Such effort will include:

    a. Concentrated search throughout the government agencies for applicable base software models; acquisition of those models and examination of their applicability to the F-111 use. These models would encompass off-line data reduction and analysis capability in addition to the simulation models.

    b. Acquisition of CMAC design details from NWC, China Lake, and fabrication of initial unit.

    c. Search for possible alternate test/simultaion processor and peripheral supplier, and trade-off these alternates against the baseline presented herein. Place orders for selected equipment. (Processor equipment delivery could constitute the limiting schedule factor).

    d. Conduct of detailed design requirements study/definition for the F-111 unique interface equipment (IODM Unit and SAS Unit) followed by initiation of design/fabrication of these units.

    e. Firmly bounding all of the software models/submodels based upon this study and the results of "a" and "c" above, and initiation of software preparation/acquisition and/or modification.

7. REFERENCES

Copies of the following documents, used in this study, are either held by SMAMA or available to SMAMA on request.

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