



National Aeronautics and  
Space Administration

JAN 14 1982  
JSC-17859

**Lyndon B. Johnson Space Center**  
Houston, Texas 77058

NASA-CR-167579

AVIONICS TEST BED DEVELOPMENT PLAN

Job Order 39-429



Prepared By

Lockheed Engineering and Management Services Company, Inc.

Avionics Systems Department

Engineering Development and Integration Branch

Houston, Texas

Contract NAS 9-15800

For

AVIONICS SYSTEMS DIVISION

ENGINEERING AND DEVELOPMENT DIRECTORATE

December 1981

LEMSCO-17155A

(NASA-CR-167579) AVIONICS TEST BED  
DEVELOPMENT PLAN (Lockheed Engineering and  
Management) 89 p HC A05/MF A01 CSCI 22B

N82-21250

Unclas  
G3/19 17839

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LYNDON B. JOHNSON SPACE CENTER  
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November 1981

LEMSCO-17155A

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1. Report No. JSC-17859		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle  Avionics Test Bed Development Plan				5. Report Date December 1981	
				6. Performing Organization Code	
7. Author(s) L. H. Harris, J. Mac Parks, and C. R. Murdock Lockheed Engineering and Management Services Company, Inc.				8. Performing Organization Report No. LEMSCO-17155A	
				10. Work Unit No.	
9. Performing Organization Name and Address Lockheed Engineering and Management Services Company, Inc. 1830 NASA Road 1 Houston, Texas 77058				11. Contract or Grant No. NAS 9-15800	
				13. Type of Report and Period Covered Development Plan/Orbiter	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Lyndon B. Johnson Space Center Houston, Texas 77058 JSC Technical Monitor: E.S. Chevers				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract <p>This document presents a development plan for a proposed Avionics Test Bed facility for the early investigation and evaluation of new concepts for the control of Large Space Structures, Orbiter attached flex body experiments, and Orbiter enhancements. This plan outlines a distributed data processing facility that will utilize the current JSC laboratory resources for the test bed development. This document defines the future studies required for implementation, the management system for project control, and the baseline system configuration.</p> <p>The attached appendix provides a background analysis of the specific hardware system for the preliminary baseline Avionics Test Bed system.</p>					
17. Key Words (Suggested by Author(s))  Avionics Test Bed Large Space Structures Orbiter			18. Distribution Statement  Unclassified - unlimited		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 85	
				22. Price*	

\*For sale by the National Technical Information Service, Springfield, Virginia 22161

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## ACRONYMS

AC	- Alternating Current
Ada	- DOD Programming Language
ADO	- ATB Development Operation
AMIA	- Autonomous Multiplexed Interface Adapter
AMS	- ATB Management System
ANA	- Analysis
APD	- ATB Project Office
ASD	- Avionics System Division
ASEO	- Avionics Systems Engineering Operation
ATB	- Avionics Test Bed
AUO	- ATB Utilization Operation
BC	- Bus Controller
BCA	- Bus Controller A
BCB	- Bus Controller B
Bit	- Binary digit
BMR	- Byte Message Request
BT	- Bit Time
BWW	- Bus Word Width
CADAM	- Computer Aided Design and Management
CDC	- Control Data Corp.
CATV	- Cable Television
CMDS	- Commands
CLK	- Clock
COAS	- Crewman Optical Alignment Sight
CPU	- Central Processing Unit
CRT	- Cathode Ray Tube
D&C	- Displays and Controls
DAP	- Digital Autopilot
DARPA	- Defense Advanced Research Projects Agency
DC	- Direct Current

DCL	- DEC Command Line
DEC	- Digital Equipment Corp.
DEV	- Development
DM	- Data Management
DMA	- Direct Memory Access
DMN	- Data Management Network
DMS	- Data Management System
DMT	- Data Management Terminal
DOD	- Department of Defense
DOF	- Degree of Freedom
EAS	- Engineering Analysis Simulation System
EAU	- Ethernet Access Unit
ECC	- Error Correction Coding
EDP	- Electronic Data Processing
EIA	- Electronics Industries Association
EM	- Electro-mechanical
EPD&C or	- Electrical Power Distribution and Control System
EPDC, or	
EPDCS	
EPRM	- Erasable Programmable Read Only Memory
Ethernet	- Serial Data Transmission Protocol
FC	- Flight Control
FPU	- Floating Point Unit
FCS	- Flight Control System
FDC	- Floppy Disk Controller
FRC	- Functional Redundancy Checking
FY	- Fiscal Year
GDP	- General Data Processor
GNC	- Guidance Navigation and Control
GO	- General Order
GPC	- General Purpose Computer
GPS	- Global Positioning System

GSA	- Government Service Agency
GTS	- GNC Test Station
HOL	- High Order Language
HIS	- Hardware Testing System
HV	- High Voltage
HW or	- Hardware
H/W	
I/F	- Interface
IBM	- International Business Machine Corp.
ICD	- Interface Control Document
IEEE	- Institute of Electrical and Electronic Engineers
IMU	- Inertial Measurement Unit
IP	- Input Processor
IUS	- Interior Upper Stage
ICE	- In-circuit emulator
JPL	- Jet Propulsion Laboratory
JSC	- Johnson Space Center
LACN	- Local Area Computer Network
LCD	- Liquid Crystal Display
LCN	- Loosely Coupled Network
LDEF	- Long Duration Exposure Facility
LDMS	- Laboratory Data Management System
LEMSCO	- Lockheed Engineering and Management Services Company
LEO	- Low Earth Orbit
LSI	- Large Scale Integration
LSS	- Large Space Structures
MAX	- Maximum
MBIC	- Microprogrammed Bus Interface Controller
MCR	- Monitor Console Routine
MFOPS	- Million Floating Point Operations per Second



MIL	- Man-In-the-Loop
MIL	- Military
MIM	- Minimum Message
MIMR	- Minimum Message Rate
MIMT	- Minimum Message Time
MOS	- Metal Oxide Semiconductor
MSBLS	- Microwave Scan Beam Landing System
MTT	- Message Transaction Time
MT D/M	- Master Time Display/Monitor
MTU	- Master Timing Unit
MUX	- Multiplexer
MVS	- Multi Variable Storage
MXM	- Maximum Message
MXMR	- Maximum Message Rate
MXMT	- Maximum Message Time
NA	- Not Applicable
NAD	- Network Access Device
NASA	- National Aeronautics and Space Administration
NAV	- Navigation
NOS	- Network Operating System
NRT	- Non-Real Time
OEM	- Original Equipment Manufacture
OEX	- Orbiter Experiments
OS	- Operating System
OPS	- Operational Sequence
PEP	- Power Extension Package
PERT	- Program Evaluation Review Technique
PFS	- Primary Flight System
PUP	- Power Utilization Platform
RCS	- Reaction Control System
RDZ	- Rendezvous

RG	- Rate Gyro
RHF	- Remote Host Facility
RM	- Redundancy Management
RMS	- Redundancy Management System
RMS	- Remote Manipulator System
ROM	- Read Only Memory
ROM	- Reasonable Order of Magnitude
RPC	- Remote Power Controller
RTC	- Real Time Clock
SAIL	- Shuttle Avionics Integration Laboratory
SEL	- Systems Engineering Laboratory Corp.
SEPS	- Shuttle Electrical Power System
SIMS	- Simulations
SM	- System Management
SMCN	- Subsystem Managers Console Network
SMMS	- Solar Max Mission Satellite
SMN	- System Management Network
SN	- Simulation Network
SUC	- Space Operations Center
SOP	- Subsystem Operation Procedure
SPAS	- Shuttle Payload Applications Satellite
SSGIF	- SAIL STS and GTS Interface Function
SSM	- Subsystem Management
STD	- Standard
STS	- Shuttle Test Station
STS	- Shuttle Transportation System
SW or S/W	- Software
TACAN	- Tactical Air Navigation Set
TBD	- To Be Determined
TBS	- To Be Supplied
TMIA	- Time Multiplexed Interface Adapter
T/R	- Transmit/Receive

UBIC     - Universal Bus Interface Controller  
UNIBUS   - Trade Name for DEC Computer Bus

VAX       - Virtual Address Extension  
VLSI      - Very Large Scale Integrated

XMTR      - Transmitter

$\mu$          - Micro

$\mu$ P        - Microprocessor

$\mu$ S        - Microsecond

2BMR      - Two Byte Message Request

## 1. INTRODUCTION

This document describes a development plan for the NASA Avionics Systems Division (ASD) Avionics Test Bed (ATB) to be located in building 16 of the Johnson Space Center (JSC). The ATB will be a ground based flight avionics systems development facility for testing and evaluation of advance technology and new concepts. The ATB is designed to facilitate early investigation of Orbiter attached flex body experiments, the Space Operations Center (SOC) avionics systems, adaptive control systems for Large Space Structures (LSS) and a pallet mounted microprocessor flight control system to support Orbiter/LSS flight experiments. The ATB will also support evaluation of concepts such as Orbiter enhancements and the all electric aircraft avionics control systems.

### 1.1 BACKGROUND

Avionics for coming flight programs will employ sophisticated sensor and effector systems with integral microprocessors, linked by distributed data networks. Redundancy will be employed to enhance reliability. Adaptive control systems will provide damping and stability for large lightweight flexible structures. Ground-based facilities must measure up to the needs of these programs for development and early demonstration of concepts and technologies. As programs mature, these facilities must support the orderly development with engineering data, design trade-offs, and system-level integration studies.

In the past NASA has not established a dedicated integrated avionics development facility to provide early evaluations of new concepts prior to the release of design requirements for bids. Presently there are independent component and subsystem level evaluations conducted in NASA laboratories. System level evaluations have been conducted by integration contractors at their facilities. Many new concepts will require sufficient empirical information for NASA decisions on state-of-the-art technologies. It is the goal of the ATB to fill these needs.

## 1.2 PURPOSE

The purpose of the ATB is to provide a versatile facility to test and evaluate new flight avionics technology and concepts from their inception through the design and testing of prototype hardware. Two near term expected major users of the ATB will be the Space Operations Center (SOC) program and the Orbiter with attached LSS. The ATB will be a major contributor in the partitioning and configuration of the SOC avionics system in preparation of design requirements. The ATB will be capable of large scale adaptation to, as yet unknown, SOC avionics concepts and technologies. For LSS the ATB will support design, development and verification of a pallet mounted control system which would compliment the Orbiter flight control subsystem for LSS attached unique requirements. The ATB is projected to provide the following benefits for NASA:

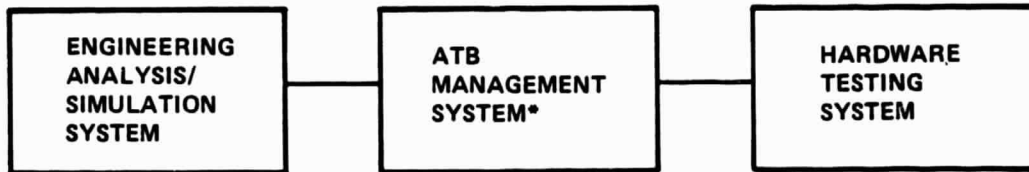
- Produces confidence very early in the concept development.
- Provides hands-on experience in new technology issues for personnel who are responsible for development of design requirements.
- Facilitates a systems level evaluation of subsystem functional elements and concepts long before commitment to final design and hardware fabrication.
- Provides a reconfigurable/flexible facility for early integration of design concepts with previously developed new hardware.
- Accommodates relatively fast test and evaluation of new technologies and concepts in a development atmosphere.

## 1.3 DOCUMENT OBJECTIVE

The objective of the ATB Development Plan is to define a set of candidate missions, describe their ATB requirements and define major tasks required for the ATB implementation. This plan will also offer alternative system configurations and suggest a phased approach to the ATB development.

#### 1.4 DEVELOPMENT PLAN APPROACH

In the first phase of implementation, the ATB is viewed as two separate systems that will be developed in parallel. They are (reference figure 1-1) the Engineering Analysis/Simulation (EAS) System and Hardware Testing System (HTS) further described in subsequent sections. In the second phase of implementation an ATB Management System (AMS) Function is proposed to coordinate the parallel development of EAS and HTS and to eventually provide system level planning and computerized control functions between the areas for hardware evaluations. The ATB Management System Function also includes hardware that is necessary to manage a distributed processing test facility. Distributed processing is a data management technique that permits geographically separated interactive or independent operations.



\*Initially this will be a Management function only with hardware to implement system as requirements evolve.

Figure 1-1.- Avionics Test Bed overall block diagram.

#### 1.5 ATB UTILIZATION SUMMARY

Table 1-1 reflects a forecast of potential ATB uses in the coming decades. The tasks or programs listed are based on a sampling of future space, commercial and defense programs and their potential needs for avionics systems development. Predicted activity within the ATB areas is marked with an X. A dash or hyphen in a column indicates an area of uncertainty to be clarified at a later date. NA means the program activity is not applicable to the ATB as currently predicted. An analysis of the ATB uses is in section 2.

TABLE 1-1.- ATB UTILIZATION SUMMARY

Program/task	EAS activities		HTS activities	ATB joint activities
	Non-realtime math model sim	Realtime man-in-the-loop		
1. SHUTTLE AVIONICS ENHANCEMENTS				
1.1 HARDWARE ENHANCEMENTS				
1.1.1 ELECTROMECHANICAL ACTUATORS	X	X	X	X
1.1.2 IMU UPGRADE	X	X	X	X
1.1.3 GPC UPGRADE	NA	NA	X	NA
1.1.4 BUBBLE MEMORY	NA	NA	X	NA
1.1.5 ORBITER ENHANCED AIR DATA SYSTEM	X	X	X	X
1.1.6 STAR TRACKER	X	X	X	X
1.1.7 IMPROVED CREWMAN OPTICAL ALIGNMENT SIGHT	NA	X	NA	NA
1.1.8 PAYLOAD ASSEMBLY CARGO ELEMENT	NA	NA	X	NA
1.1.9 FIBER OPTIC DATA BUS	NA	NA	X	NA
1.2 SYSTEM ENHANCEMENTS				
1.2.1 RCS RM UPGRADE	X	X	X	X
1.2.2 AUTO DOCKING/STATION KEEPING	X	X	X	X
1.2.3 SIMPLIFIED D&C UPGRADE	NA	X	X	X
1.2.4 AUTO BRAKING/LANDING	X	X	NA	NA
1.2.5 DISTRIBUTED DATA PROCESSING UPGRADE	X	X	X	X
1.2.6 ADVANCED RCS DAP (OEX)	X	X	X	X
1.2.7 GLOBAL POSITIONING SYSTEM	X	X	X	X.

X = Predicted Activity. NA = Predicted as Not Applicable to ATB. - = Uncertainty, to be clarified at later date.

TABLE 1-1.- ATB UTILIZATION SUMMARY (Continued)

Program/task	EAS activities		HTS activities	ATB joint activities
	Non-realtime math model sim	Realtime man-in-the-loop	Systems testing	EAS and HTS + AWS
1.3 ORBITER ENHANCEMENTS				
1.3.1 IN-FLIGHT TILE INSPECTION	X	X	NA	NA
1.3.2 EXTENDED ORBIT DURATION CAPABILITY	X	X	-	-
1.3.3 LOW POWER/LONG-TERM ORBIT FCS CAPABILITY (REDUNDANT VERNIERS)	X	X	X	X
1.3.4 ORBIT COOPERATIVE ATTITUDE CONTROL	X	X	-	-
1.3.5 ENTRY ORBITER LATERAL CONTROL AUGMENTATION	X	X	NA	NA
1.3.6 AUTOMATED ONBOARD CHECKOUT	NA	NA	X	NA
2. LSS CONTROL TECHNOLOGY DEVELOPMENT				
2.1 HARDWARE ASSESSMENT/DEMONSTRATION				
2.1.1 SENSORS	X	NA	X	X
2.1.2 EFFECTORS	X	NA	X	X
2.1.3 DATA PROCESSING	X	NA	X	X
2.1.4 HIGH-VOLTAGE EPD&C	NA	NA	X	NA
2.2 SOFTWARE	X	NA	X	X
2.3 SYSTEMS-ALGORITHMS, PARTITIONING				
3. POWER UTILIZATION PLATFORM (PUP)				
3.1 ORBITER COOPERATIVE - SAFETY & OPERATIONS				
3.1.1 ORBITER/RMS/PUP (ORBITER ATTACHED)	X	X	NA	NA

X = Predicted Activity. NA = Predicted as Not Applicable to ATB. - = Uncertainty, to be clarified at later date.



TABLE 1-1.- ATB UTILIZATION SUMMARY (Continued)

Program/task	EAS activities		HTS activities	ATB joint activities
	Non-realtime math model sim	Realtime man-in-the-loop		
3.1.2 ORBITER/RMS/PUP (FREE FLYER)	X	X	NA	NA
3.1.3 ORBITER/PUP				
3.1.3.1 DYNAMICS & CONTROL	X	X	X	X
3.1.3.2 GN&C INTERFACE	NA	NA	X	NA
3.1.3.3 POWER INTERFACE	NA	NA	X	NA
3.2 PUP AVIONICS DEVELOPMENT	X	X	X	X
4. ORBITER-ATTACHED LSS EXPERIMENTS & PAYLOADS				
4.1 RMS UTILIZATION				
4.1.1 STS-3 AND SUBSEQUENT MISSIONS	X	X	X	X
4.1.2 SHUTTLE PAYLOAD APPLICATIONS SATELLITE	X	X	X	-
4.1.3 LONG DURATION EXPOSURE FACILITY	X	X	-	-
4.1.4 SOLAR MAX MISSION SATELLITE RETRIEVAL	X	X	-	-
4.1.5 SPACE TELESCOPE	X	X	-	-
4.2 POWER EXTENSION PACKAGE	X	X	X	X
4.3 SEPS CONTROL EXPERIMENT	X	X	X	X
4.4 JSC/GO STRUCTURE	X	X	X	X
4.5 ATTACHED ANTENNAS	X	X	X	X
4.6 SATELLITE SERVICES	X	X	X	X

X = Predicted Activity. NA = Predicted Not Applicable to ATB. - = Uncertainty, to be clarified at later date.

TABLE 1-1.- ATB UTILIZATION SUMMARY (Concluded)

Program/task	EAS activities		HTS activities	ATB joint activities
	Non-realtime math model sim	Realtime man-in-the-loop		
5. FREE-FLIER LSS EXPERIMENTS & PAYLOADS*				
5.1 SOC/LEO PLATFORMS	X	X	X	X
5.2 JPL ANTENNA	X	X	X	X
5.3 ORBITAL TRANSFER VEHICLES	X	X	X	X
5.4 PLANETARY SPACECRAFT	X	X	X	X
5.5 SOLAR POWER STATION	X	X	X	X
5.6 GEOSTATIONARY ORBIT PLATFORMS	X	X	X	X
6. COMMUNICATIONS SYSTEMS	NA	NA	X	NA
7. DOD MISSIONS	X	X	X	X
8. COMMERCIAL AIRCRAFT SYSTEMS	X	X	X	X

X = Predicted Activity. NA = Predicted as Not Applicable to ATB. - = Uncertainty, to be clarified at later date.

## 2. ATB UTILIZATION ANALYSIS

### 2.1 INTRODUCTION

Utilization of the ATB is tied to avionics definition and development for space flight in the future decades. In this section a forecast of potential ATB utilization is developed based on a sampling of future space programs and their potential needs for avionics development. The utilization analysis also leads into some organization and management concepts for the ATB. These ideas are offered as they occur in this section. The integrated management plan is presented in section 7.

### 2.2 UTILIZATION OVERVIEW

The basic data for the forecast and recommendations is organized into the matrix of table 1-1 in section 1. The columns in the matrix depict the typical activity phases of laboratory utilization for avionic systems development and analysis as practiced by ASD. The rows of the matrix comprise a scenario of planned and conceivable space programs which would be served by the ATB concept. The elements of the matrix then constitute a model for ATB utilization. Entries were developed through interview and analysis with various individuals in the Division and reflect their perceptions of how the ATB would be used for the various programs. Dashes signify areas of uncertainty to be clarified at a later date. NA indicates the activity is not predicted for use.

#### 2.2.1 NON-REAL-TIME (MATH MODEL) SIMULATION

Design concepts are analyzed initially in non-real-time (NRT) simulations to assess feasibility. This phase is represented in column 1 of the matrix and by figure 2-1 in the generic example. These time-domain simulations (other software-based analytical methods, such as frequency-domain analysis, are considered outside the ATB domain) are then maintained and enhanced to track the maturing development program, or shelved if the program does not come to life. In the example scenario, as illustrated in figure 2-1, early design concepts for the control algorithm are evaluated against dynamic flight

simulations, including flexible structure dynamics. The four basic blocks shown in the figure:

- vehicle attitude stability and control
- vehicle (rigid body, traditionally) dynamics
- flex structure control algorithm (under study)
- flex structure dynamics simulation

are resident in the laboratory computer (or computers), and are executed in demand or batch (but non-real-time) mode.

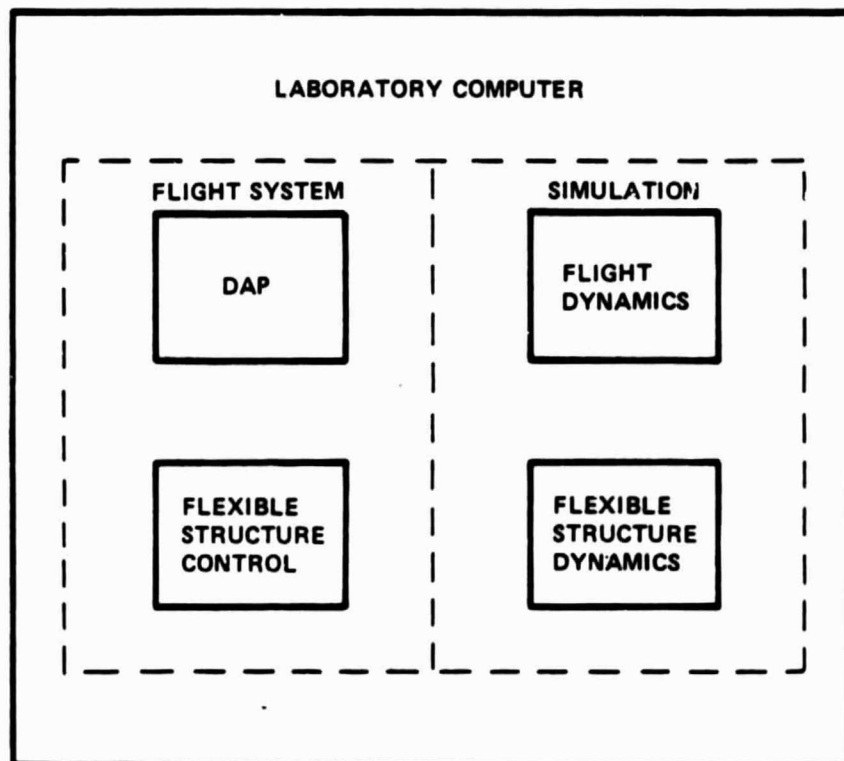


Figure 2-1.- NRT math model.

### 2.2.2 REAL-TIME (MATH MODEL) SIMULATION

For programs where manual pilot characteristics are important, a Man-In-the Loop (MIL) cockpit with appropriate scenes, displays, and control devices is added, necessitating the real-time execution of the simulation. Column 2 of the table 1-1 matrix represents this phase, and figure 2-2 illustrates the structure for the generic example. Generally the MIL cockpit at this phase is oriented toward functional fidelity with displays, controls, and scenes necessary to do the analysis and, neglecting high fidelity details of a crew station mockup, is used for layout design or procedures development in the Displays and Control Lab.

### 2.2.3 HARDWARE SYSTEMS TESTING (LOCAL LAB)

Roughly concurrent in time with the NRT simulation math model analysis, hardware evaluations are made in the appropriate hardware laboratories. This phase is represented in column 3 of the table 1-1 matrix. First, basic hardware characteristics are tested. Figure 2-3 illustrates this for the generic example where controller microprocessor speed, memory, and data interface characteristics and requirements are evaluated. These evaluations are conducted on a local basis without significant interaction with other ASD laboratories. As algorithms and system models emerge from the NRT simulation efforts and other sources, this software is utilized in more detailed testing of the hardware. Figure 2-4 illustrates this for the flex structure controller development where control algorithms are executed in the control microprocessor against some representation of the flexible structure dynamics. At this stage in the development, representations of the same hardware or software may exist in separate laboratories. Here arises the first need for the ATB Management System (AMS) function described later. Concepts of efficiency and commonality suggest that a central control and monitor of these activities would enhance the merging and integration of data and results and ease complex integration tasks later in the program. Also the possibility exists to utilize the same laboratory computer facility for the testing in the configuration of figure 2-4 as that used in the simulation activities of figure 2-1.

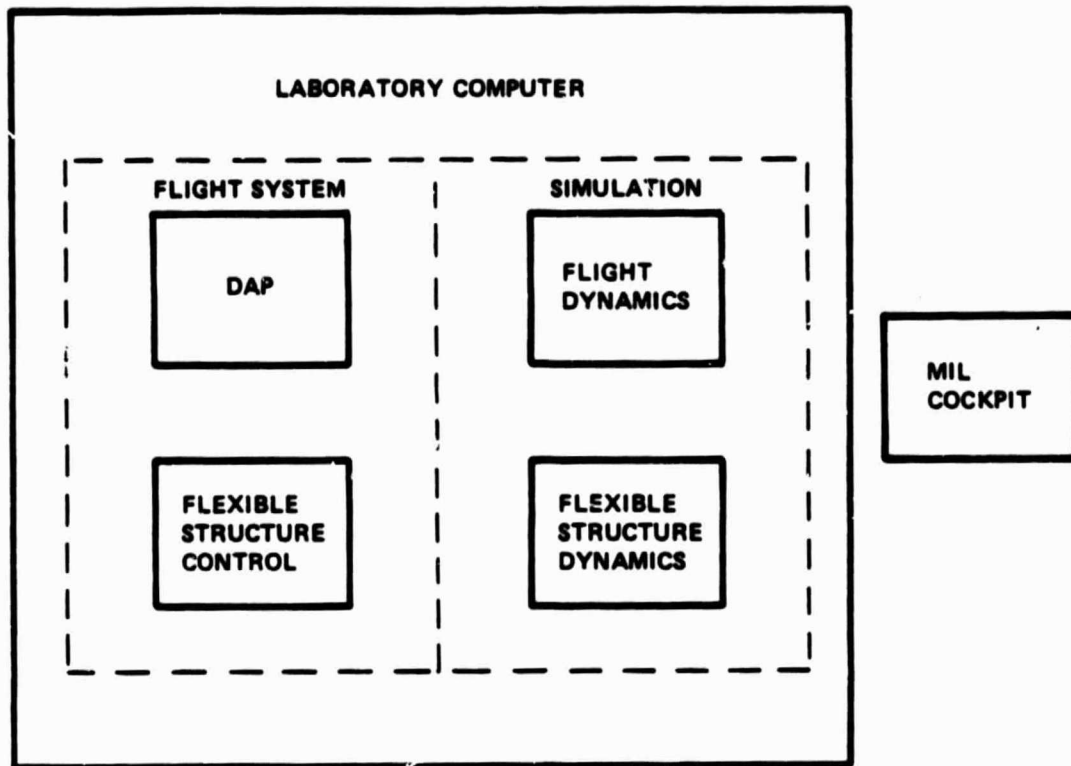


Figure 2-2.- Realtime math model (EAS).

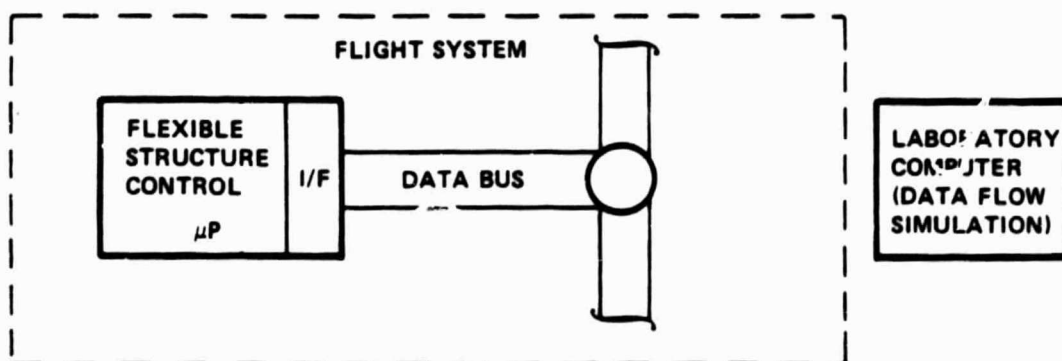


Figure 2-3.- Controller hardware evaluation.

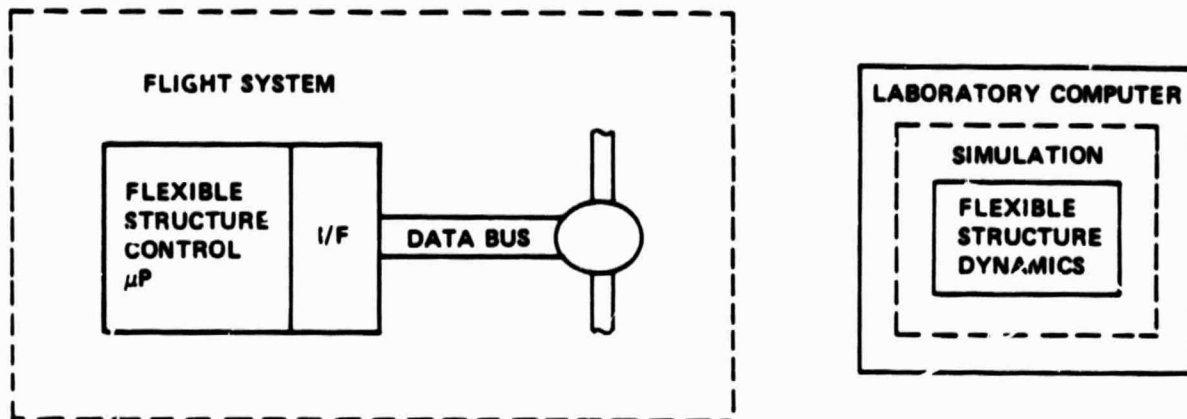


Figure 2-4.- Controller system evaluation (HTS).

#### 2.2.4 MULTI-LAB (ATB) TESTING

The ATB phase is represented by column 4 of the Table 1-1 matrix. Figure 2-5 illustrates the multi-lab configuration for the generic example. Testing involves two or more local laboratories in an integrated mode. In the generic example, the control microprocessor hardware and software are linked with the dynamics simulation, including the MIL Cockpit, in a real-time, man-in-the-loop simulation. A major goal of the ATB concept is to provide means for transfer and common utilization of major pieces of simulation software and technology among the various elements of ASD and at appropriate levels of the ATB.

#### 2.3 PROGRAM EXAMPLES

In the following program examples the concept of levels is used for clarity. The concept is illustrated in the ATB configuration diagram, Figure 2-5. For ATB purposes, there are two levels. Activities which span at least two ATB functions are defined as Level 1. All Level 1 activities are the responsibility of the AMS. Level 2 activities are confined to individual ATB functions. All Level 2 activities are accomplished in local laboratory modes.

Four programs were selected from the list in table 1-1 to provide specific examples of ATB configuration requirements and to serve as departure points for more detailed sizing and costing studies. Two Shuttle enhancements were

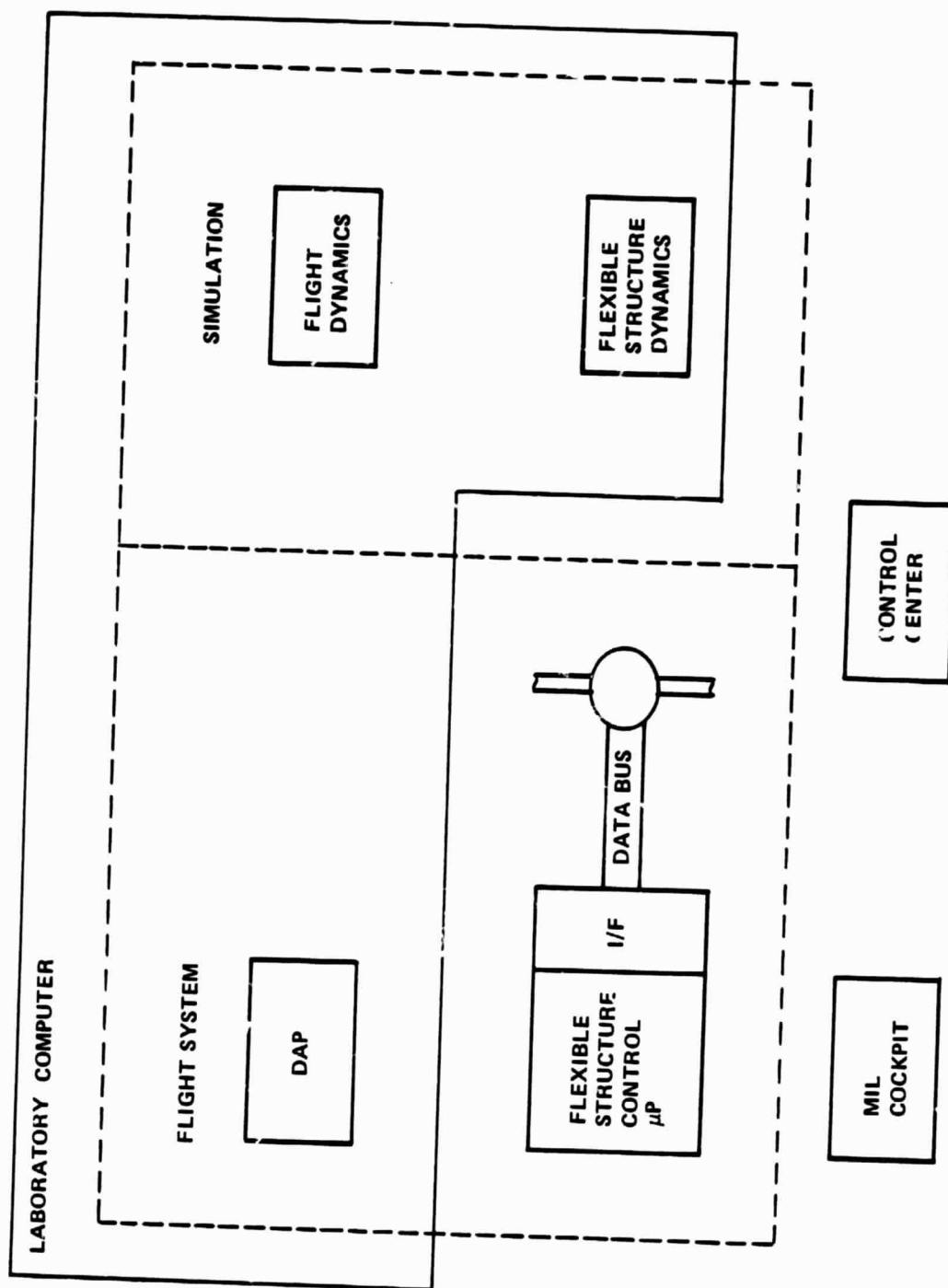


Figure 2-5.- ATB joint laboratory testing.



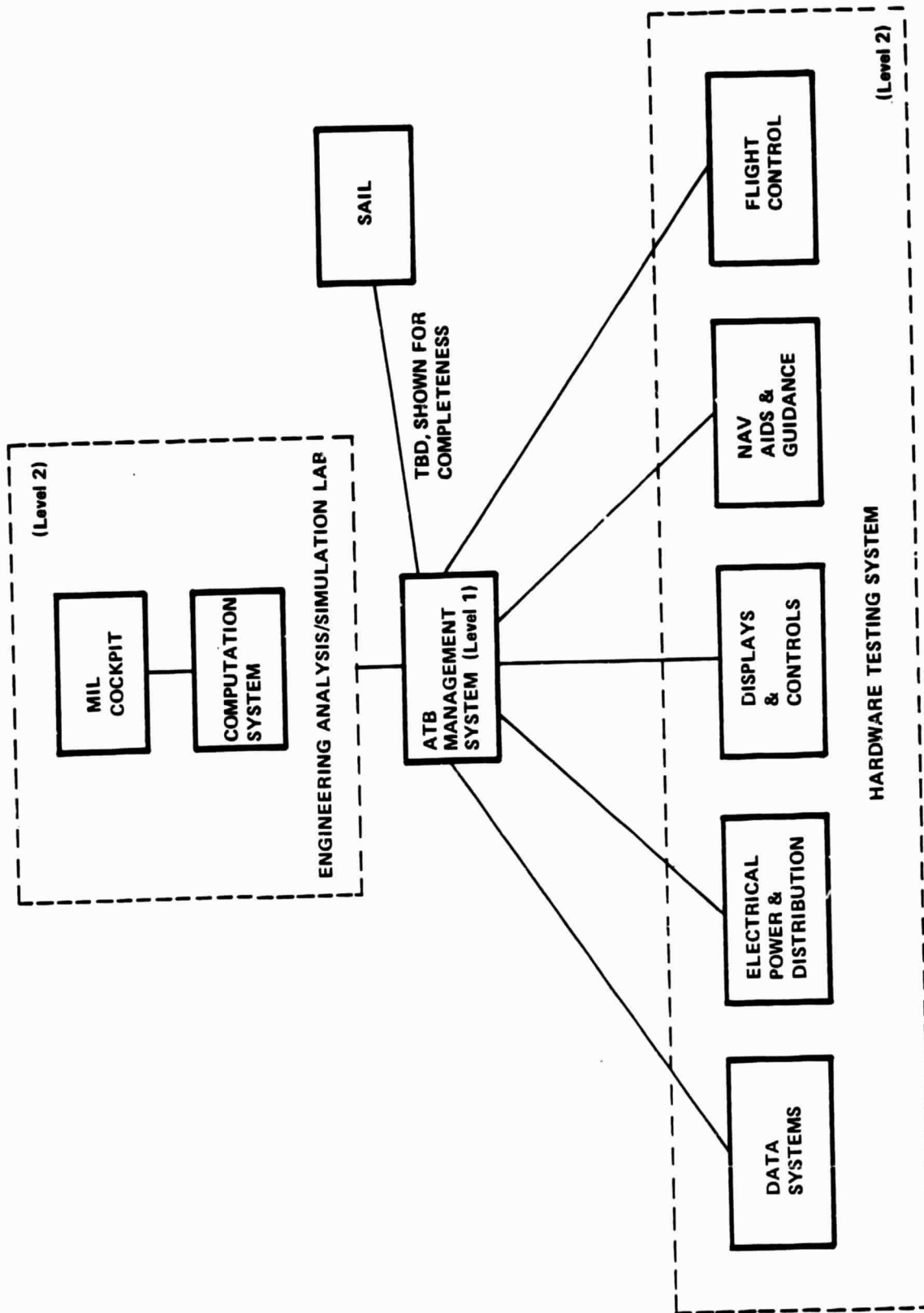


Figure 2-6.- ATB configuration.

selected, IMU upgrade (sensor development) and RCS enhancements (effector development), as typical of requirements for ongoing Shuttle work. The PEP program was selected because of the readily available reservoir of information on PEP requirements and because the activity reaches outside the more traditional GN&C laboratory configurations. SOC is a key new manned space flight program, and the ability to address SOC avionics development needs is fundamental to the ATB. A presentation of these four program examples as they relate to the ATB and ATB requirements follows.

### 2.3.1 IMU UPGRADE (SENSOR DEVELOPMENT)

The IMU upgrade program example is shown in figure 2-7. Initial analysis and development occurs at level 2 in the EAS laboratory and in the navigation and control subsystems laboratory. In the EAS laboratory, emphasis is on analysis and development of flight algorithms for inertial navigation and attitude control using IMU data, and with development of algorithms and procedures for IMU redundancy management. Non-real-time simulations are the primary mode in this example. The MIL cockpit and real-time simulation would be utilized when pilot dynamics are a key part of the system time response, primarily in the attitude control system development. In the navigation and control subsystems laboratory, testing is oriented toward development of inertial subsystem hardware and algorithms and interfaces for processing the hardware data. IMU redundancy management is also evaluated, primarily with trade studies to define partitioning requirements for data processing among remote microprocessors and the central computer. Level 2 tests are managed and conducted autonomously within the individual laboratories, but interfaces which will span multiple laboratories during level 1 are identified and managed at level 1. Also, level 2 software which has wider application during level 1 or other level 2 testing is identified and controlled by level 1. The level 2 interface across the two laboratories is made through the AMS function, illustrated in figure 2-7, and level 1 testing becomes the responsibility of the AMS organization. Level 1 testing provides high-fidelity dynamic response data on the combined IMU hardware and software.

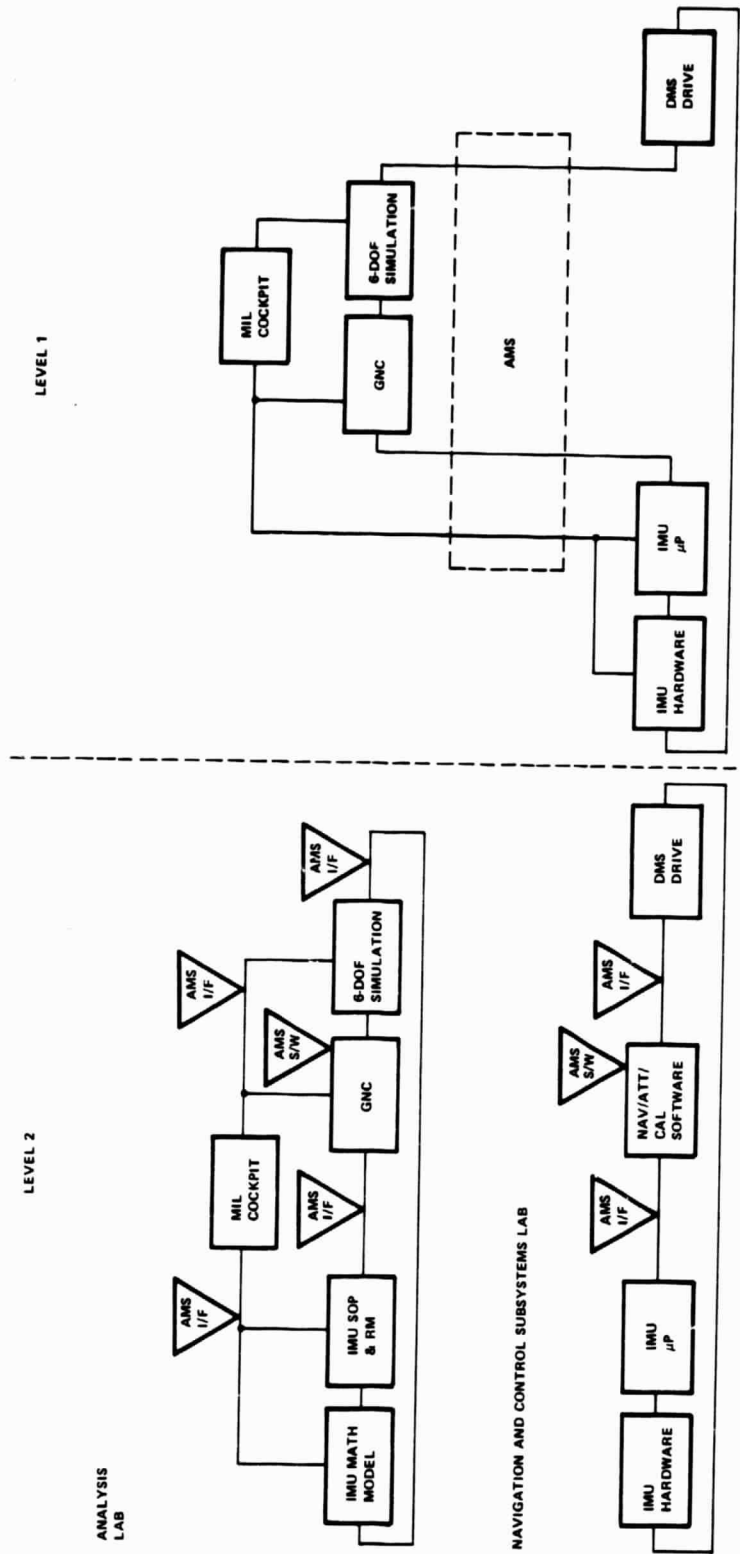


Figure 2-7.- IMU upgrade (sensor development) program example.

### 2.3.2 RCS ENHANCEMENTS (EFFECTOR DEVELOPMENT)

The RCS enhancements development is illustrated in figure 2-8. Flow from level 2 to level 1 is much like the IMU example in the previous paragraph. RCS redundancy management and jet select algorithms are developed and analyzed in the analysis laboratory against math model dynamics and the RCS digital autopilot. Microprocessor hardware, software, and data interface testing occurs in the data systems laboratory. RCS driver electronics and data interface hardware are tested in the navigation and control subsystems laboratory. Intermediate levels of testing involving two or three of the laboratories may be required. Any combined laboratory testing is the responsibility of the AMS, with the full-up level 1 configuration illustrated in figure 2-8.

### 2.3.3 PEP PROGRAM

The level 2 configuration for the PEP program is shown in figure 2-9. In the analysis laboratory, the principal effort is directed toward analysis of the interaction between the Orbiter digital autopilot and the RMS control system and the development of solutions to dynamic stability and control problems. The principal mode is non-real-time simulation, with the MIL cockpit added to study manual operations. Testing in the power distribution laboratory evaluates PEP power conversion, distribution and control, and the power interface with Orbiter systems. Testing in the flight control laboratories evaluates sun sensors, pointing and tracking controls, and control dynamics. The level 1 configuration is shown in figure 2-10. The interface between the analysis laboratory, flight controls, and the power system laboratory is made through the AMS. Closed-loop testing, including manual modes, is conducted to evaluate PEP control interactions with RMS and Orbiter control systems and to assess dynamic effects of Orbiter/RMS manual and automatic control modes on PEP power system performance.

### 2.3.4 SOC PROGRAM

SOC is a major new program which is expected to be a principal user of the ATB capability. Since the Shuttle vehicle will serve as the base for construction and resupply of SOC, Shuttle test and simulation capabilities will form the

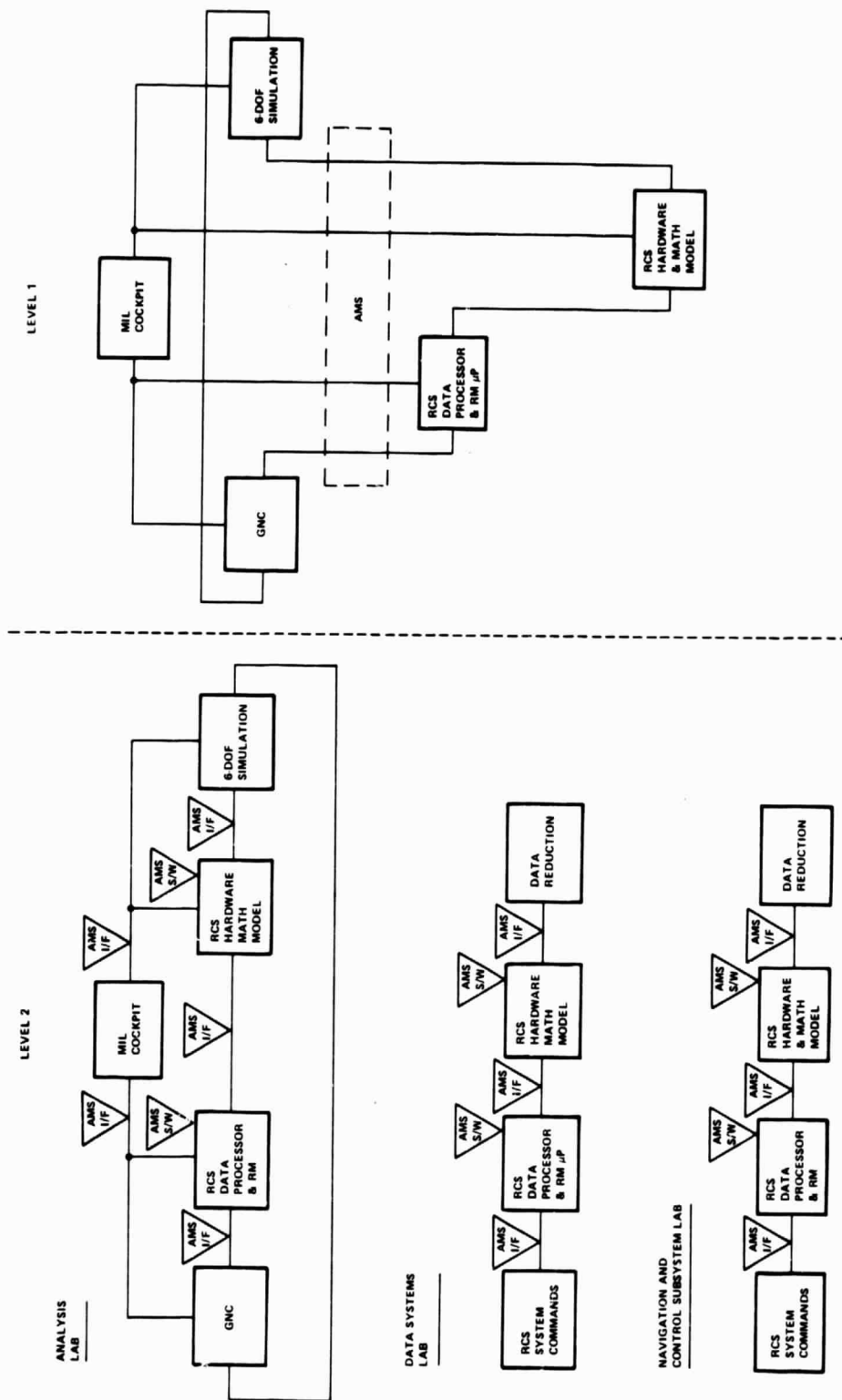


Figure 2-8.- RCS enhancements (effector development) program example.

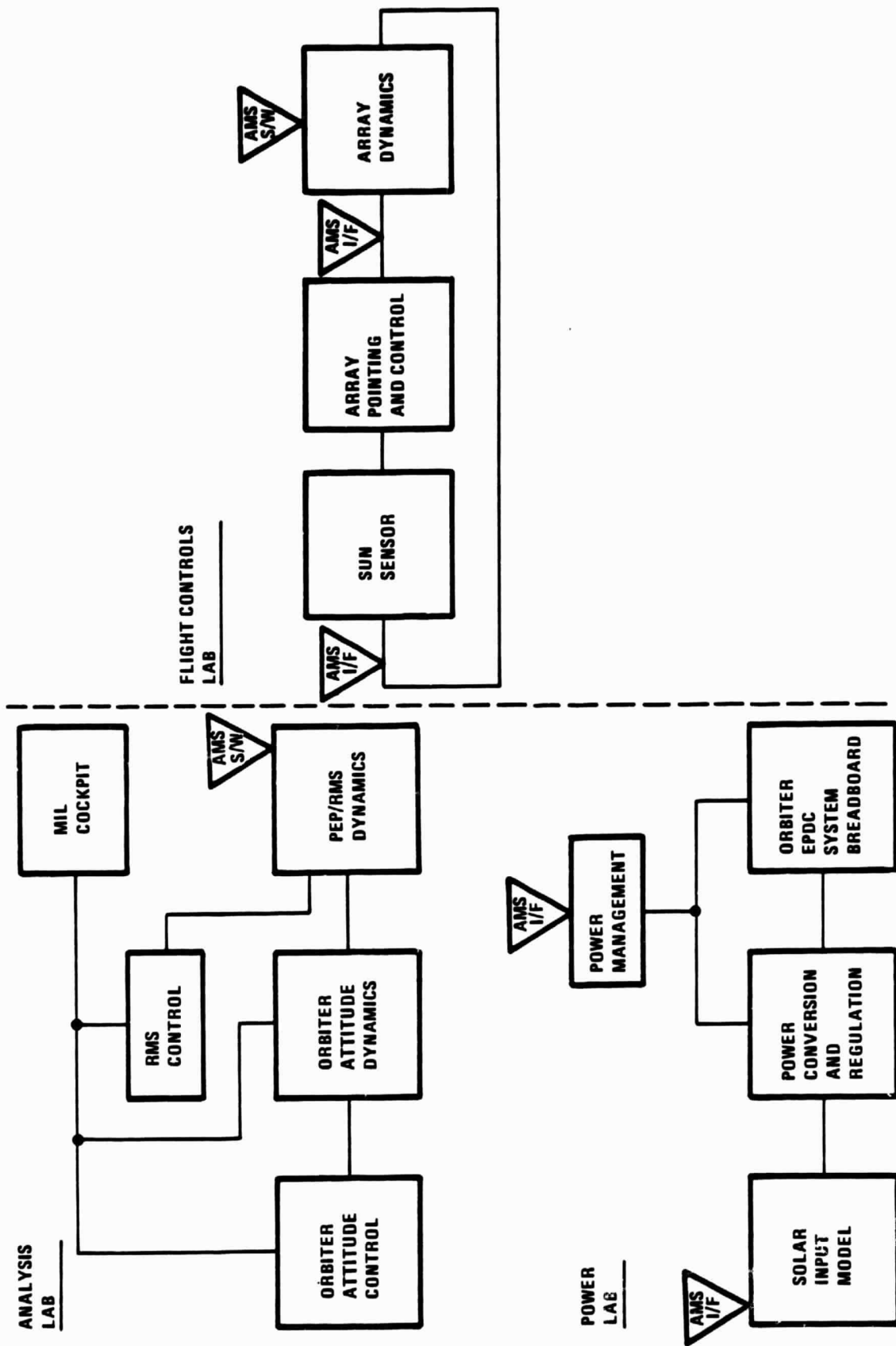


Figure 2-9.- PEP program example - level 2.

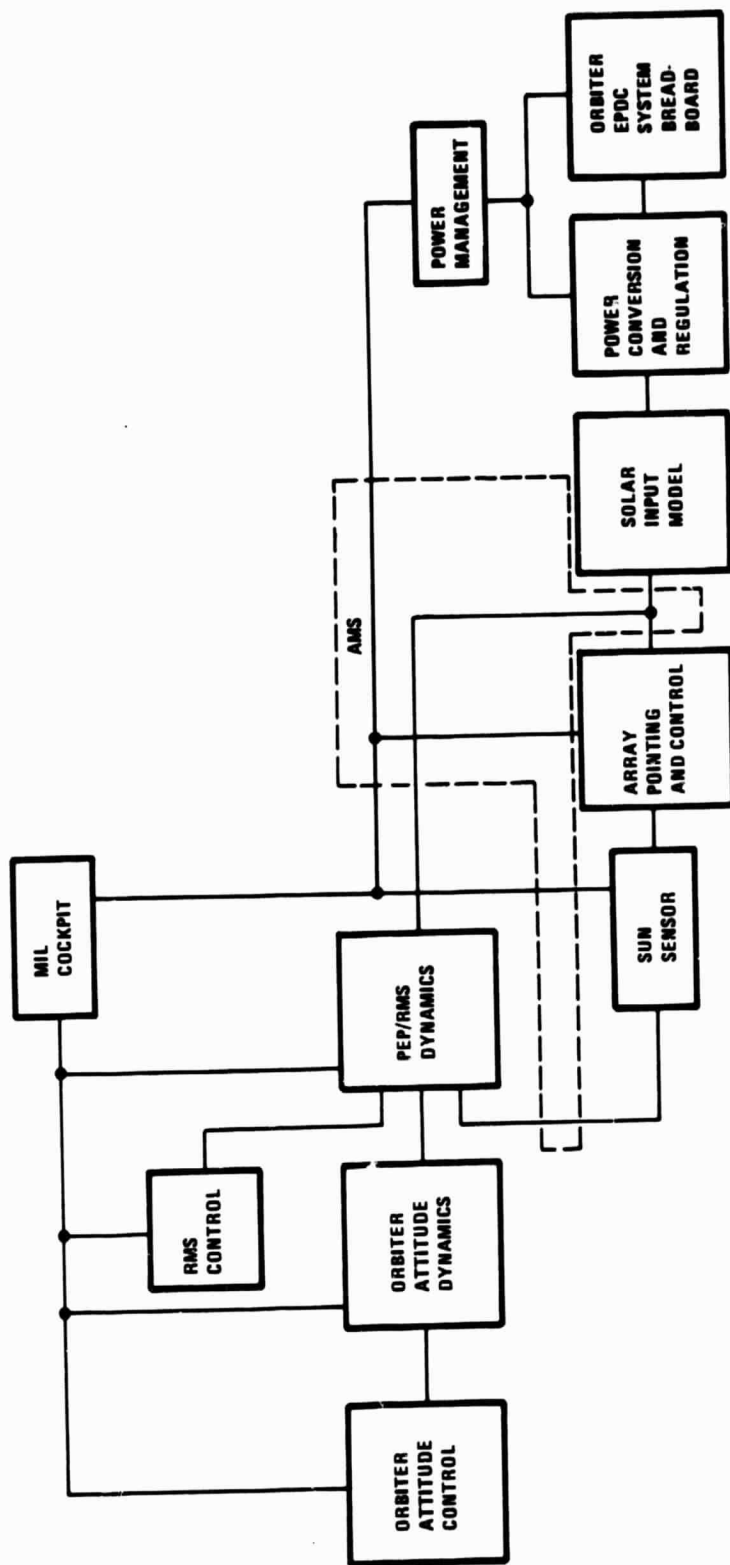


Figure 2-10.- PEP program example - level 1.

basis for initial Orbiter-centered SOC rendezvous, proximity operations, and deployment simulations. As SOC systems are defined in sufficient detail, SOC-centered simulation and test activities will evolve through the typical ATB sequence, described by the generic example of section 2.2. ATB utilization for SOC, then evolves on two primary fronts:

- 1) Orbiter-centered: utilizing primarily math model simulation of joint Orbiter/SOC operations. Hardware development laboratories are used when new or enhanced Orbiter avionics are evaluated for the SOC mission.
- 2) SOC-centered: utilizing the full ATB capability for SOC avionics development. A full complement of simulation, hardware testing, and joint hardware/simulation operations capabilities is required to support SOC development.

The ATB configuration and management concepts, as defined here and in section 7, are fully supportive of SOC development. The three program examples given in previous sections could serve equally well as SOC avionics development examples utilizing ATB. A full-up level 1 SOC avionics development configuration, using the drawing format and conventions of previous sections is shown in figure 2-11. The basic ATB configuration is intact, and organizational roles and responsibilities are easily identifiable, including the AMS. Finally, the ATB configuration as recommended, given sufficient computation and data flow capacity, can support full dynamic simulation, including hardware loops, of SOC and Orbiter jointly for rendezvous, proximity operations, docking, and cooperative control studies.



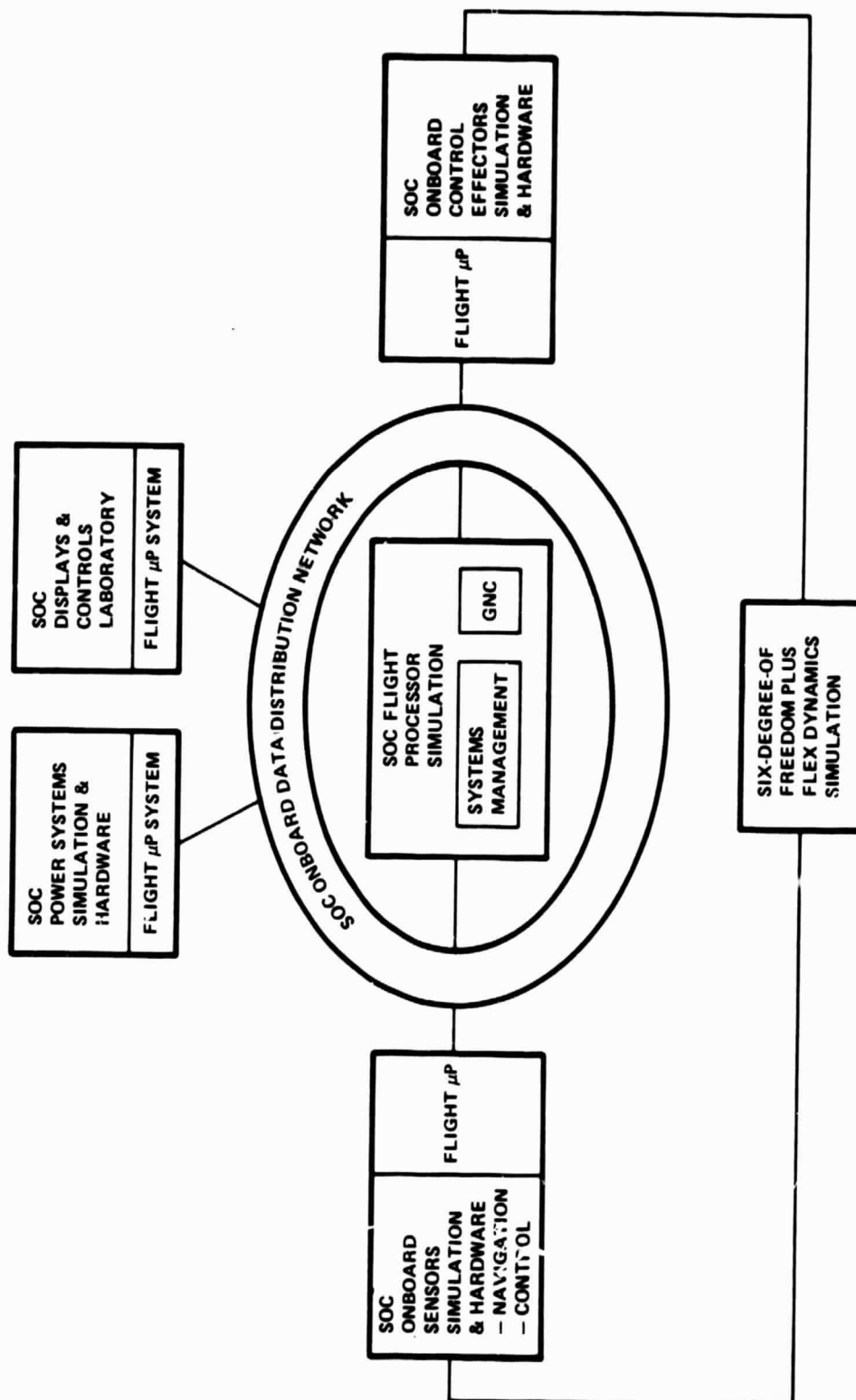


Figure 2-11.- Full up (level 1) SOC in ATB.

### 3. ATB SYSTEM OVERVIEW

As shown in figure 1-1 in section 1, the ATB may be divided into three major functional areas, EAS, AMS, and HTS with sub-functions as shown in figure 3-1. Some of the activities are listed on the figure 3-1 in each of the major functional areas and for the HTS sub-functions across the bottom of the figure. The areas and functions shown are as follows:

1. Engineering Analysis/Simulation System (EAS)
2. ATB Management System (AMS)
3. Hardware Testing System (HTS)
  - HTS Data Management Function
  - Navigation Aids and Guidance Function
  - Flight Control Function
  - Displays and Control Function
  - Electrical Power and Distribution Function
  - SAIL STS and GTS Interface Function

Early ATB development will be concentrated on the EAS and HTS with the AMS function coordinating the development effort. The AMS will be initially a management function only, but will become an actual computer based system as operational requirements evolve. The EAS and HTS can be operated independently and simultaneously.

The functional areas are linked by four major data, voice, and video communication networks. Figure 3-2, ATB Functional Block Diagram, defines the functional areas and their four communication networks. The networks are described as follows:

1. The Simulation Network (SN) is CDC's Loosely Coupled Network (LCN) - a 50 megabit/second serial link that is compatible with CYBER and DEC computers. This data link will provide a high speed bidirectional serial communications link between the EAS and HTS. This link has a large

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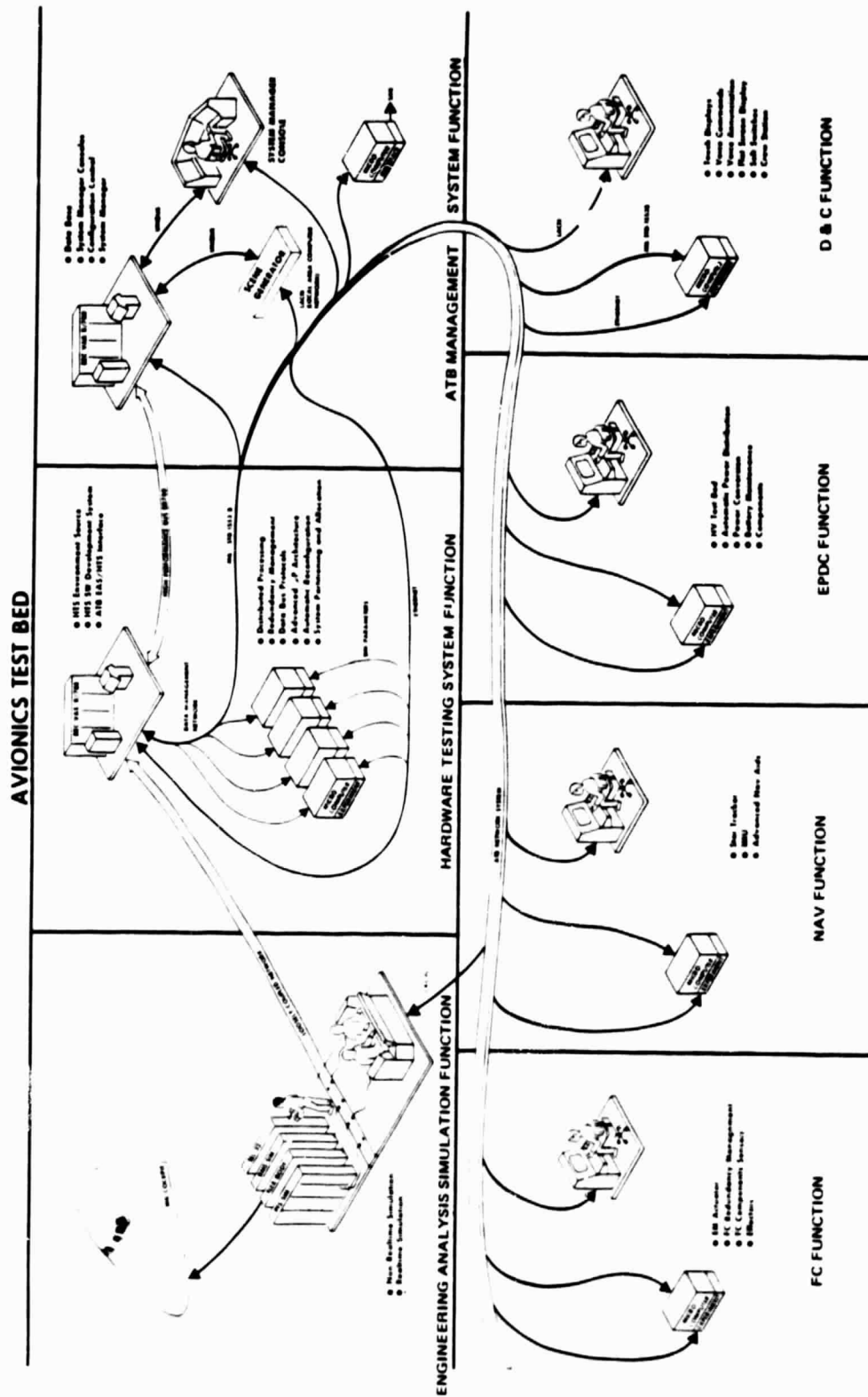


Figure 3-1.- Avionics Test Bed systems organization.

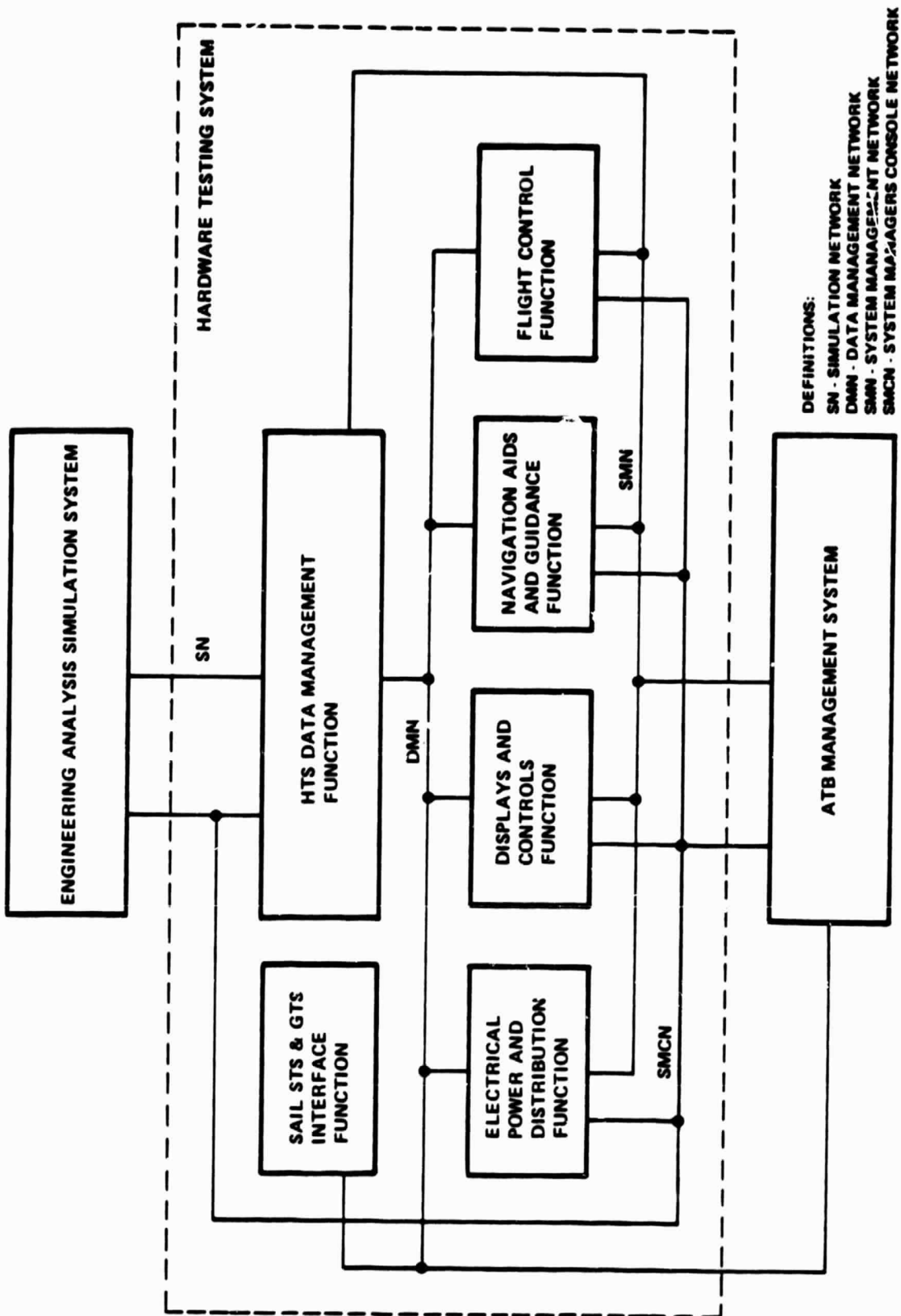


Figure 3-2.- ATB functional block diagram.

geographic separation. The purpose of this link is to transfer EAS environment parameters to the HTS for distribution to its six functional areas and to return reaction parameters to the EAS math models.

2. The Data Management Network (DMN) utilizes MIL-STD-1553B communication protocol (1 megabit/second) with an in-house designed terminal multiplexer. This is the avionics system network that will be used to investigate data bus electrical specifications, protocols, redundancy management, and system configurations. The data content for this network will be depicted by the investigation.
3. The System Management Network (SMN) is for system initial condition, configuration control, data acquisition, and environment interface, and will utilize the Ethernet protocol (10 megabit/sec.).
4. The Subsystem Managers Console Network (SMCN) is a broadband voice, video, and data (14 megabit/sec.) CATV communication link. This link will distribute scenes, test conductor's console communications, and broadband data.

The compatibility of the networks and host computers offer a high degree of reconfigurability. Each of the networks and their protocols are either IEEE, MIL-STD, or industry proven; therefore, they are supported by several computer operating systems. For example, the CDC 50 megabit/second Loosely Coupled Network is supported by the CDC Remote Host Facility (RHF), IBM OS/MVS JES2 or JES3, and by the DEC RSX11M operating systems. DEC, in turn, supports Ethernet while Local Area Computer Network (LACN) supports high performance Ethernet. MIL-STD-1553B is an avionics network protocol used by many military missile and aircraft. MIL-STD-1553B is similar to the Orbiter's data bus format; but, due to a much larger market, many special very large scale integrated (VLSI) circuits are available to support hardware development. Its data bus electrical characteristics are identical to the Orbiter's data bus.

Figure 3-3, Detailed ATB block diagram, breaks the functional areas shown in figure 3-1 into major system components. This configuration utilizes the present laboratory resources wherever possible. This ATB design allows multilevel reconfiguration, i.e., various combinations of the major functional

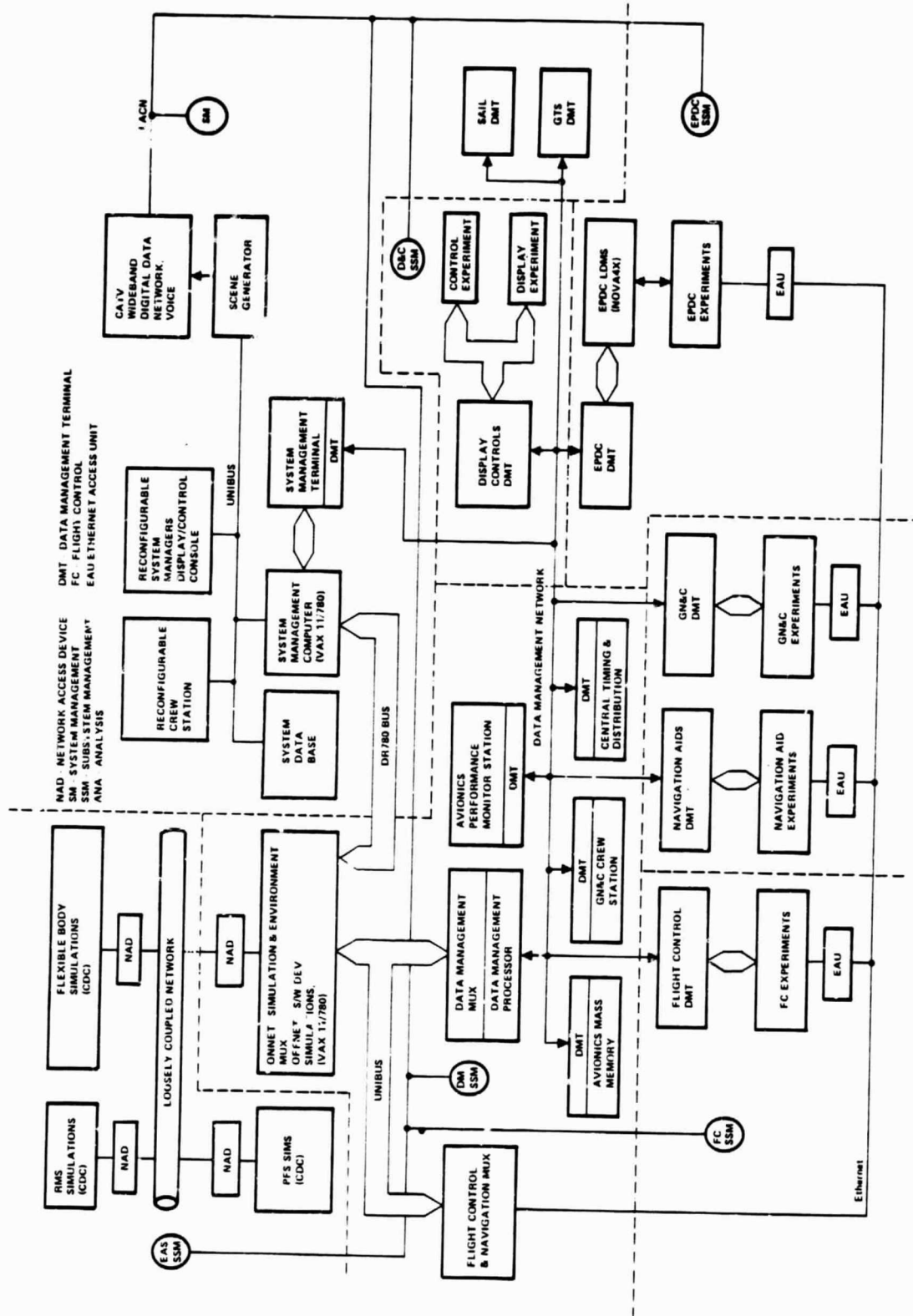


Figure 3-3.- Detailed ATB block diagram.

areas may be configured into one or more systems. In addition, the various functional blocks or laboratories can be reconfigured to either support a system test or subsystem test. One major concern in the ATB is in the system management area. A reconfigurable crew station and system managers display/control console will be required. These systems should utilize advanced touch sensitive display terminals. This allows "soft" display and control switches that can be built by software for each test configuration.

The following design goals were selected for the ATB system configuration shown in figure 3-1.

- Cost control through use of commercially available communication networks, operating systems and computers.
- Multilevel reconfigurability
- Maximum utilization of ASD laboratory resources
- Minimize new hardware and software design using commercially available equipment
- Centralized display and integration of distributed tests
- Each ASD laboratory maintains its sovereignty
- Phased design allows future expansion to LSS system studies
- ASD laboratories remain in place by geographic distribution of data processing
- Local processing at each network terminal reduces overall throughput requirements
- Reduce software rewrite through use of advanced operating systems and languages such as FORTRAN 77 and Ada
- Phased design approach supports early test capabilities
- Alternative configurations must not impact ATB objective
- Cost control through use of MIL-STD instruction set architecture such as Air Force MIL-STD-1750 16 bit and Army MIL-STD-1862 32 bit instruction sets. Instruction set architecture standardization will reduce software

cost in three ways: 1) permits a common set of support software tools, 2) transportability of operational code modules, and 3) enhanced programmer familiarity.

The following paragraphs will discuss the capabilities in each of the functional areas.

### 3.1 ENGINEERING ANALYSIS SIMULATION SYSTEM FUNCTION

EAS performs three major functions in the context of the ATB. The first two functions are stand-alone EAS (Level 2), requiring no physical interface with the remainder of the ATB. The third function supports the multi-lab ATB (Level 1).

#### 3.1.1 NON-REAL-TIME (MATH MODEL) SIMULATION

These large-scale, time domain dynamic simulations are used for analysis, development, and verification of design concepts. An example is the Space Shuttle Functional Simulator (SSFS), which simulates all Shuttle flight phases (ascent/GRTLS, orbit, entry), at varying levels of detail, depending on analysis requirements. The program comprises 50-thousand lines of FORTRAN code (negligible assembly language), with runtimes ranging from seconds to several hours on the Univac 1110, depending on the application. Study areas typically include stability and control; altitude and pointing analyses; guidance and navigation analyses; and guidance, navigation, and control software and system integration studies.

#### 3.1.2 REAL-TIME (MATH MODEL) SIMULATION

These simulations incorporate the essential element of systems for manned flight: the pilot. To simulate the dynamics of the pilot's response, they must execute in real time, and they must provide adequate realism at the pilot interface, i.e., scenes, displays, and controls. An example is the Shuttle Engineering Simulation (SES), which performs MIL simulation studies of Shuttle ascent/GRTLS, orbit (including remote manipulator system), and entry.



### 3.1.3 MULTI-LAB (ATB) TESTING

In the performance of this function, the EAS provides dynamics, environments, and flight system simulation support to the HTS elements of ATB. To support hardware testing, the simulation must necessarily execute in real time. Simulation fidelity, MIL cockpit (if any), math model, and flight system simulation requirements are dictated by individual studies.

### 3.2 ATB MANAGEMENT SYSTEM FUNCTION

The AMS function is the only area of the ATB that is totally new. The AMS functional responsibilities include the following items:

- Test configuration and control
- Test initial condition of synchronization
- System scenes generation
- Scene distribution network
- Intralaboratory voice communication
- System managers display/control
- Crew station simulation
- System data base for test procedures, recorded system test data, and system configuration records
- Data distribution to subsystem managers consoles

The AMS function has access to the System Management Network, HTS Data Management Network, and the Subsystem Managers Console Network. This configuration provides the AMS with high speed communication to all ATB subsystems.

One mainframe computer (VAX 11/780) drives all AMS Functions. This computer system operates in a shared memory multiprocessor configuration with the HTS VAX computer system providing very high speed data link to the EAS function.

### 3.2.1 SYSTEM MANAGERS CONSOLE

The System Managers Console design allows complete reconfiguration by the utilization of flat screen touch sensitive television or plasma displays. All displays, labels, and control switches will be "soft". The same design concept will be used on the crew station where special CRTs for NAV AIDS will enhance reconfigurability.

### 3.2.2 SCENE GENERATOR

A TBD scene generator will provide high resolution scenes at the crew station while LACN (a CATV network) distributes scenes by compatible television to each of the subsystem managers consoles. Recent network designs have utilized CATV for voice, video, and broadband data communication on a single coaxial trunk. A large commercial market for CATV components makes this type of network economical.

### 3.2.3 SYSTEM DATA BASE

A major responsibility of the AMS Function is to initialize tests, control tests via test procedures, and record results for post test data analysis. The system data base provides this function.

All system test procedures are controlled by the system management console computer. This allows accurate repeatability of tests. This function is critical in a geographically distributed processing system such as the ATB.

## 3.3 HARDWARE TESTING SYSTEM FUNCTION

The hardware testing system has six functional areas that are interfaced by the DMN. Figure 3-2 showed the HTS and its six functional areas enclosed within dotted lines. The following paragraphs describe each of the HTS functional areas.

### 3.3.1 HTS DATA MANAGEMENT FUNCTION

The HTS Data Management Function controls and manages all avionics subsystems via the Data Management Network. This network utilizes the MIL-STD-1553B data bus protocol and electrical specifications.

The MIL-STD-1553B data buses are being used in many new aircraft designs such as the F16. The Orbiter data bus is a forerunner of MIL-STD-1553B and is very similar electrically; however, there are many more MIL-STD-1553B components commercially available for data bus development. The Data Systems Branch has done some development on a Data Management Network that is totally distributed with no centralized control processor. This feature is very advantageous in reconfiguration.

The Data Management Network will provide a standard computer based terminal for each node of this network. All hardware prototyping or subsystem experiments will interface the ATB via this standard Data Management Terminal (DMT). A special DMT will interface the Analysis Function through a Data Management computer. This terminal may act as multiple DMTs during system tests.

A subsystem has the following DMT interface options:

- MIL-STD-1553
- IEEE 488 or HIB
- ORBITER DATA BUS
- RS 232
- MULTIBUS (INTEL BUS)

The DMT provides software for the Data Management Network protocol and subsystem interface option. The DMT hardware that supports the Data Management Network is modular and each terminal may have from 1 to 4 MIL-STD-1553B data buses on one DMT. The DMT will have Remote Power Controllers (RPC) integrated into its bus interface. It is; however, the responsibility of the Electrical Power Distribution and Control Lab to design and control the RPCs.

### 3.3.2 FLIGHT CONTROL FUNCTION

The Flight Control Function will utilize the Flight Controls laboratory in the development of hardware such as accelerometers, rate gyro, thrusters and other types of effectors. This function will communicate with other ATB functions via the Data Management Network.

### 3.3.3 NAVIGATION AIDS AND GUIDANCE FUNCTION

The Navigation Aids and Guidance Function will communicate with the avionics system via the Data Management Network. This function has the development responsibility for navigational sensors.

- IMU
- TACAN
- Air Data
- Radar Altimeter
- Airborne Accelerometer
- Global Positioning System
- Rendezvous Radar
- MSBLS
- Star Tracker

### 3.3.4 DISPLAYS AND CONTROLS FUNCTION

The ATB Displays and Controls Function will be responsible for the development of HTS crew stations within the ATB. This development effort will include the investigation of advanced techniques such as color graphic displays, voice entry systems and voice annunciation for caution and warning. This function will also investigate the human factors interactions of the crew to the avionics systems with both touch sensitive display and computer voice systems. This will reduce training requirements.

It is proposed that caution and warning and instrumentation be under the Displays and Controls Function.

### 3.3.5 ELECTRICAL POWER DISTRIBUTION AND CONTROL FUNCTION

The EPDC laboratory will be utilized to test and evaluate the Orbiter interfaced alternate power sources such as PEP or SOC. This function will also be responsible for developing automated power distribution and control within the HTS Data Management Network.

This function will continue to investigate high voltage distribution for future LSS such as SOC and PEP primary power systems.

### 3.3.6 SAIL STS AND GTS INTERFACE FUNCTION

The SAIL STS and GTS Interface Function (SSGIF) is responsible for the interface between the ATB and SAIL. This interface requires further study. Figure 3-1 is one example of a SSGIF under AMS utilizing a DMT with an Orbiter data bus option.

### 3.4 ATB OVERVIEW CONCLUSION

This concludes the functional overview of the ATB system. The following sections will describe a parallel development philosophy in the EAS and HTS systems with the AMS serving as system project management. Both EAS and HTS are designed to provide early independent operations, i.e.; each system can contribute to the program during this development effort before a full ATB is operational.

#### 4. ENGINEERING ANALYSIS SIMULATION

EAS is the analysis and simulation element of ATB. For this presentation it is restricted to time-domain simulations with current or anticipated real-time applications. This excludes, as part of EAS, all non-time-domain applications software and time-domain simulations which have no anticipated real time applications. Designation and control of software as part of EAS is a Level 1 function as explained in section 2.

An overview of EAS use and relationships with the rest of the ATB is given in Section 2. Top-level EAS requirements are described here and a development plan for EAS is offered. The intent is to set down requirements for the EAS as a subset of the ATB. Design and development of the EAS computation system, as well as definition of any non-ATB requirements for that system (such as hosting large-scale engineering applications software), are outside the scope of this presentation.

##### 4.1 EAS REQUIREMENTS

As depicted in Figure 4-1, EAS is comprised of two elements, the MIL cockpit and the computation system. Requirements for these two elements are described in the following paragraphs.

A hardware system configuration for EAS is included here for completeness. This configuration is an example only, and no recommendation is offered or intended regarding the merits of this configuration in competition with any others. The example hardware configuration is comprised of three Control Data Corporation (CDC) mainframe computers linked through Simulation Network (SN), CDC's local network system Loosely Coupled Network (LCN) for this example and CDC Network Operating System (NOS). The LCN provides local network interconnect for host-to-host access for a variety of mainframes including IBM 370 and DEC Virtual Address Extension (VAX). The EAS is linked to the other ATB functional areas via the SN and a DEC VAX 11/780. The SN uses a single coaxial trunk as a communication mechanism.

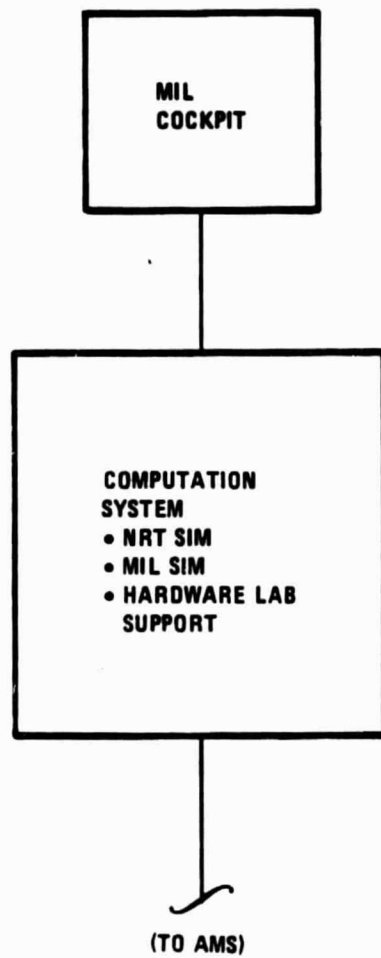


Figure 4-1.- Engineering Analysis Simulation.

In this example, the EAS Shuttle Engineering Simulator is interfaced via a SEL 32/55 to support Orbiter enhancements. The mainframe computer network provides realtime simulation flight dynamics, environments, and required elements of the flight systems. The environments are communicated to the various hardware prototyping interfaces via the SN and finally through the HTS Data Management VAX computer system. The HTS Data Management VAX system uses two networks, MIL-STD-1553B for data management network communications and Ethernet for environment communications. The HTS Data Management VAX computer system can also operate as a stand alone environment simulator for a variety of hardware prototyping tests. This system configuration frees the EAS for other level 2 tasks.

Computation system size and speed requirements for EAS have not been quantified, nor have EAS to HTS interface data rates been defined. The major driver in both instances is the simulation in real time of large flexible structures and the systems necessary to stabilize and control such structures. Some studies have been undertaken to define LSS computation, system and interface requirements, but only estimates have been made available to date. The data and technology necessary to define the simulation requirements is readily available, and early initiation of such a study is strongly recommended.

#### 4.1.1 OPERATING MODES

Three operating modes are required for EAS:

- Batch mode for background execution of large-scale simulation problems, which may incorporate iterative or Monte Carlo techniques.
- Demand mode, with multiple ports, including support to interactive terminals.
- Real-time mode, either stand-alone EAS (level 2), including closed-loop MIL simulations, or supportive of hardware laboratory elements of ATB (level 1).

#### 4.1.2 SOFTWARE PORTABILITY

A key factor in the efficiency and utility of ATB is software portability. Development and maintenance of multiple versions of software to do the same



job is wasteful and unnecessary. The implementation of level 1 standards and requirements for ATB software portability will eliminate this waste by ensuring that code developed and maintained for applications in one area is most easily used for the same or similar applications in other areas. For example, code developed and maintained for NRT applications should be executable for real-time applications, and transportable as required for special applications in hardware laboratories.

#### 4.1.3 USER ACCESS

Hands-on accessibility to EAS for development of NRT applications software is required. Access is required via batch and demand modes for development and analysis of GN&C and other applications software.

#### 4.1.4 MIL COCKPIT

The MIL cockpit is comprised of three elements: displays, controls, and scenes. Requirements for these three elements, individually and collectively, will vary widely, depending on study objectives. In general, the requirements are functional, to quantify the dynamics of the system with the man as a part of it. The MIL cockpit is not required as a cockpit design tool, nor is it suitable for crew training or crew procedures development.

### 4.2 EAS DEVELOPMENT PLAN

The bulk of EAS activities in the ATB timeframe will involve orbital flight simulation. Some Shuttle enhancement ascent and entry studies may be required, along with other programs like the all-electric airplane, but most of the programs identified in table 1-1 are directed toward orbital operations. Specifically, the two programs of highest interest at JSC are the Shuttle and its transition into a platform for performing orbital operations, and SOC. A plan for development of EAS orbital simulation capabilities is presented in figure 4-2. The plan includes some parts of current or planned activities in ASD and other divisions. The plan is not intended to account for, nor to constrain those activities, but rather to give an overview of requirements for EAS in support of the Shuttle and SOC.



**Figure 4-2.- EAS development plan.**

In figure 4-2, the circled labels identify major simulation capabilities. The smaller circles signify summations or joining of the input capabilities. The milestone triangles with flags identify major study requirements as they occur in the flow. The calendar scale is for reference.

Current capability as identified in figure 4-2, is contained in the combination of SSFS (see paragraph 3.1.1) and SES (see paragraph 3.1.2). SSFS is presently resident on the Univac 1110 system at JSC, Building 12, with conversion to the CDC system at JSC Building 16, scheduled for mid-year, 1982. Following conversion, as shown in the figure, flexible payload, proximity operations, rendezvous, and flexible orbiter autopilot studies will be performed. SES is resident in the SEL computer complex at JSC Building 16. For the on-orbit mission phase, it is used primarily for MIL simulation studies of the RMS and manual proximity operations. Studies are in progress to plan the most efficient use of SSFS and SES and their host computer systems in Building 16.

The plan is divided into two segments, payload development and Orbiter development. The payload segment is comprised of one main sequence, starting with a rigid free payload capability, adding flexibility, with combined Orbiter simulations at appropriate points in the sequence. Payload simulation capability includes attached or deployed payloads as required, leading up to simulation of SOC element deployment, retrieval, and docking operations, including RMS. The Orbiter segment contains two main sequences, the rigid, free vehicle sequence, and the flexible vehicle sequence, which includes RMS capability. Common to the two Orbiter sequences is the RCS DAP, the essential element in any six-degree-of-freedom simulation capability. The rigid, free vehicle sequence incorporates rendezvous radar, Guidance and Navigation (G&N), and thrust capability, all directed toward long-range trajectory dynamics simulation of rigid vehicles. The flexible vehicle sequence incorporates flexible orbiter dynamics, along with flexible payload and RMS capability, as appropriate for detailed stability and control analyses.

Eight major study areas are identified in figure 4-2. These are described in the following paragraphs.

P1-Rigid Payload (Payload Free Sequence)

Stability and control of rigid free fliers, including pointing, maneuvering, orbit maintenance studies. Primarily directed toward definition and analysis of SOC onboard system requirements.

P2-Flexible Payload (Payload Free Sequence)

Stability and control of flexible free fliers. Flight control interaction with flexible structures, including definition structure of loads resulting from flight control activities. Primarily directed toward definition and analysis of SOC onboard system requirements.

PR1-Prox Ops - DAP (Payload/Rigid, Free Vehicle Sequences)

Manual mode, Orbiter based proximity operations studies directed toward definition and development of Orbiter manual flight control mode requirements for proximity operations.

PR2-RDZ, Prox Ops (Payload/Rigid, Free Vehicle Sequences)

Manual and automatic rendezvous and proximity operations studies to develop and enhance long-range to close-in Orbiter system requirements.

F1-DAP, OEX DAP (Flexible Vehicle Sequence)

Studies to define DAP requirements for stability and control of a flexible Orbiter, directed primarily toward definitions and analysis of the OEX DAP.

F2-DAP/RMS - Unloaded (Flexible Vehicle Sequence)

Studies to define DAP and RMS control system requirements for system stability and control.

PF1-DAP/Payload Deploy (Payload/Flexible Vehicle Sequences)

Studies to define Orbiter DAP requirements for stability and control through mate/deploy mate sequences for flexible payload. Also allows for cooperative control studies with Orbiter and payload control systems active.

#### PF2-DAP/RMS - With Payload

Studies to define Orbiter DAP and RMS control system requirements for system stability and control, including flexible payload effects.

## 5. HARDWARE TESTING SYSTEM

The HTS will be analyzed operating in the independent mode as shown in figure 5-1. The major difference in this operation is the source of simulated environment. In a full-up operational ATB system (not independent mode), the environment models may be resident in either the EAS mainframe computer or the HTS interface computer. The HTS interface computer will provide low resolution simulations in the independent mode. Note that the interface between the two systems is considered to be part of the HTS. This interface has the VAX 11/780 computer (shown in figure 3-3) as part of the network distribution/multiplexer between the EAS and HTS. One reason VAX 11/780 was selected as the multiplexer interface between the HTS and the EAS is because it is compatible with hardware and software of the CDC loosely coupled network (LCN). This allows the VAX 11/780 to be located remote to the EAS area. It is recommended that the VAX 11/780 be located in the Data Systems laboratory which is in close proximity to the HTS development area.

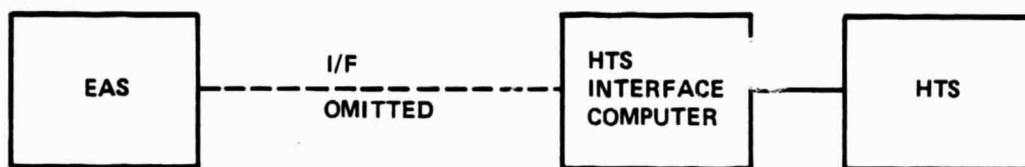


Figure 5-1.- ATB independent operational mode.

The proposed VAX 11/780 will support multiusers allowing it to be the software development computer for the HTS microprocessors. This system has cross compilers and assemblers for most of the 16 and 32 bit microprocessors. It also is targeted as one of the first host computers for a certified Ada compiler. These are the major reasons for selecting a VAX 11/780 as the HTS computer.

During early HTS development the VAX 11/780 will provide the system simulation environments. Figure 5-2 is a graphic example of the VAX 11/780 in the early development of the ATB. It is proposed that Ethernet be used to distribute simulated parameters within HTS. The same Ethernet configuration will also be

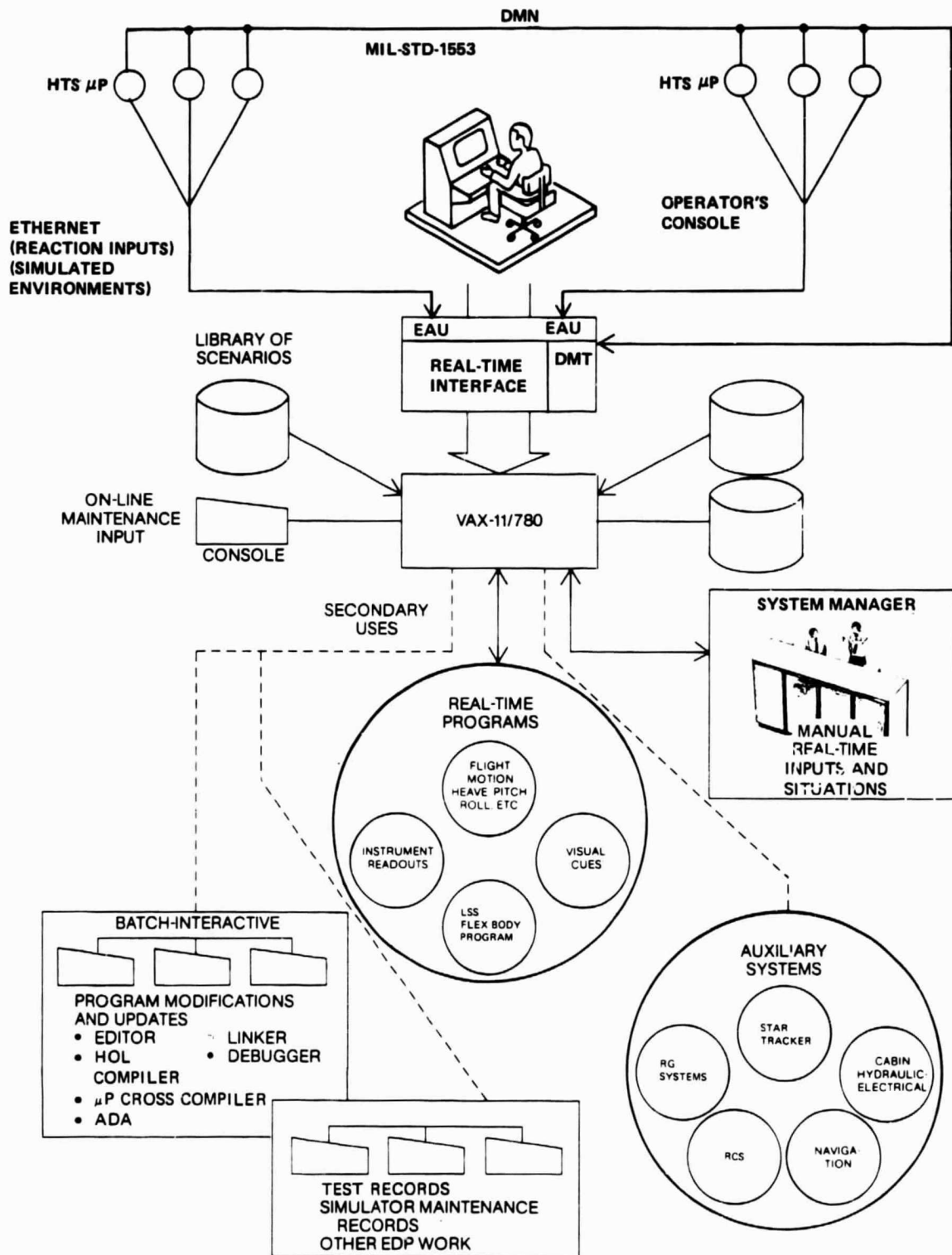


Figure 5-2.- VAX 11/780 independent operating mode.

used for distribution of simulation parameters from EAS with the VAX 11/780 used as an interface and multiplexer. The VAX 11/780 is also targeted as one of the first systems for Ethernet.

## 5.1 HTS PROJECTED TASKS

The HTS design objectives include the design goals stated for the ATB and in addition will provide an engineering test facility for the following tasks.

### 5.1.1 HTS DATA MANAGEMENT TASKS

The HTS Data Management tasks include:

- Evaluating distributed system techniques
- Developing redundancy management techniques for distributed systems
- Developing procedures for partitioning and allocation of avionics tasks in a distributed system
- Developing a Time Distribution System for a SOC Avionics System
- Developing Data Management System Configuration for SOC
- Evaluating data bus configurations for SOC Avionics System
- Developing microprocessor architectures that reduce the cost of software development through the use of high-level Languages such as Ada
- Investigating the use of Programmable Logic Arrays and Array Arithmetic processors as a cost effective method of increasing the maximum operation rate of processors
- Investigate MIL-STD-1750 microprocessors such as the 9450
- Investigating Dynamic Task Reallocation
- Evaluating mass memory technologies
- Investigating mass memory configurations
- Evaluating error detection and correction techniques for use in avionic  $\mu$ P solid state memories.



### 5.1.2 ELECTRICAL POWER AND DISTRIBUTION TASKS

Electrical power and distribution HTB tasks include:

- Developing Automated Power Management techniques
- Developing Automated Power Distribution and Control techniques
- Investigating switching mechanism for redundant resources (powered vs. unpowered redundant set)
- Evaluating high voltage distribution (AC vs. DC)
- Investigating power instrumentation and HV isolation techniques
- Preparing requirements for a distributed fault-tolerant system
- Investigating power control configurations
- Testing advanced power components
- Developing data bus controlled Remote Power Controller (RPC)

### 5.1.3 DISPLAYS AND CONTROLS TASKS

Displays and Controls tasks include:

- Developing better information-transfer methods by use of voice at crew station
- Comparing various advanced display systems such as flat screen CRT, plasma, and LCD
- Investigating crew station simplification and reduced system training requirements by use of stored procedures, touch sensitive displays and voice talkback
- Developing "soft" switch/controls to reduce control panel retrofit as system configuration changes
- Investigating use of color displays to enhance crew interface
- Investigating use of standard computer terminal as crew interface
- Developing system fault isolation techniques using crew station

#### 5.1.4 FLIGHT CONTROL TASKS

Flight Control tasks include:

- Investigating new effector technologies
- Developing and testing electromechanical actuator systems
- Investigating control system redundancy management concepts

#### 5.1.5 NAVIGATION AIDS AND GUIDANCE TASKS

Navigation Aids and Guidance tasks include:

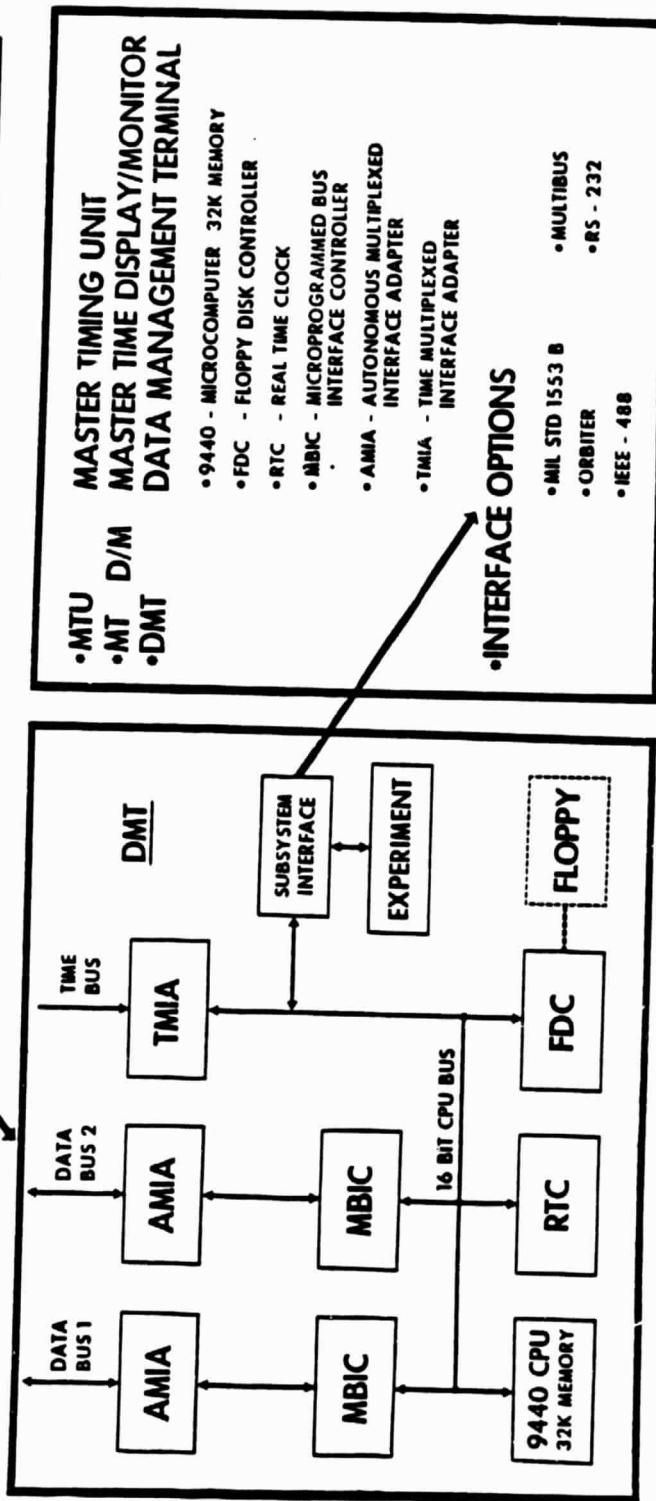
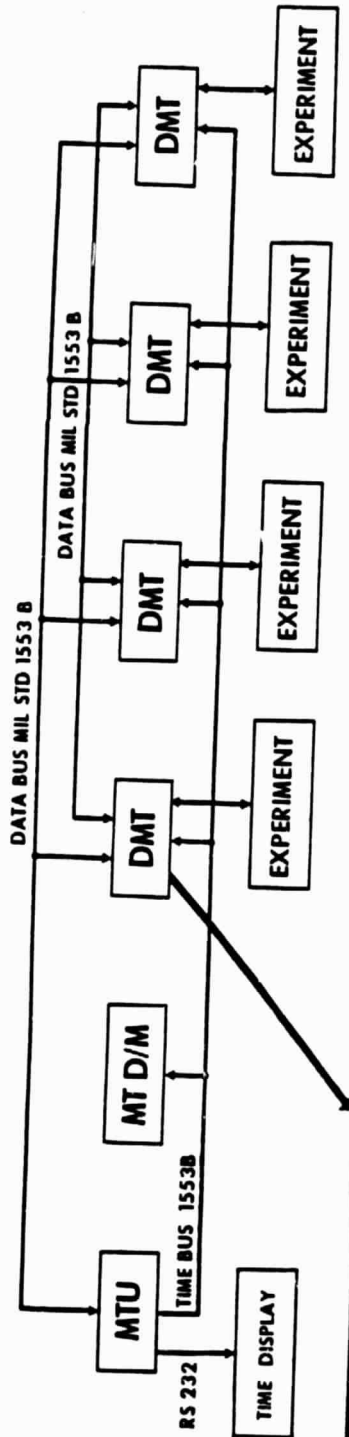
- Developing advanced inertial measurement systems
- Conducting inertial systems performance evaluations
- Investigating laser gyro technologies
- Evaluating redundancy management concepts
- Investigating new sensor technologies
- Improving software utilization techniques

### 5.2 DATA MANAGEMENT DEVELOPMENT SYSTEM

Figure 5-3 shows the existing Data Management Development System, which is the basis of the preliminary HTS design. The present state of development engineering in this area has been concentrated on the development of a protocol using MIL-STD-1553B for autonomous communication between distributed microprocessors. Several important facts have resulted from this engineering task.

1. The utilization of a high level language (FORTRAN IV) operating with a realtime multitasking software system in a microprocessor is feasible when most of the communication link overhead is controlled by hardware input/output processors. The system in figure 5-3 allows asynchronous communication between any two systems with or without software intervention. This is accomplished by a microprogrammed controller using direct memory access (DMA) and intelligent VLSI circuits to control all data bus communications. This system utilizes a virtual memory technique for high speed communication between system processors.

# DATA MANAGEMENT NETWORK (DMN) DEVELOPMENT SYSTEM



**MASTER TIMING UNIT**  
**MASTER TIME DISPLAY/MONITOR**  
**DATA MANAGEMENT TERMINAL**

•MTU  
 •MT D/M  
 •DMT

- 9440 - MICROCOMPUTER 32K MEMORY
- FDC - FLOPPY DISK CONTROLLER
- RTC - REAL TIME CLOCK
- MBIC - MICROPROGRAMMED BUS INTERFACE CONTROLLER
- AMIA - AUTONOMOUS MULTIPLEXED INTERFACE ADAPTER
- TMIA - TIME MULTIPLEXED INTERFACE ADAPTER

**•INTERFACE OPTIONS**

- MIL STD 1553 B
- ORBITER
- IEEE - 488
- MULTIBUS
- RS - 232

Figure 5-3.- Data management development system.

2. Time is very important in correlating distributed data terminals. The Master Timing Unit in figure 5-3 utilizes MIL-STD-1553B protocol transmitting at 100  $\mu$ s intervals.
3. Multiprocessing (parallel processing) will be required for LSS avionics throughput requirements. Appendix A (separate supplement) explains by example, the gains in processor computation rate and volume by the use of multiprocessors.

Refer to Appendix B (separate supplement) for details on HTS microprocessor evaluation. The following section is on the background information used in the selection of HTS microprocessor system.

### 5.3 SELECTION OF HTS PROCESSORS AND SOFTWARE

A major area of concern in the development of an avionics control system for LSS such as SOC is the control system processor speed requirements. Early estimates from SOC and LSS control systems studies indicate potential flight processor requirements of 20 to 50 MFOPS (million floating-point operations per second). This very high computation rate is required in flight control for vibration and damping due to very large arrays of sensors and effectors.

This computation capability far exceeds the processors shown in figure 5-3 or the present Orbiter GPC. Array processing has been suggested as one possible solution; however, several recent technological developments may also provide a more general purpose solution to the problem. A VLSI 32 bit microprocessor, iAPX432, which uses an object-based architecture that is directed towards Ada as its primary programming language is available. This microprocessor has built-in hardware to support multiprocessing and redundancy checking, a highly desirable feature in avionics systems. The iAPX432 is a microprocessor with today's mainframe capabilities. Details on the iAPX432 is in Appendix B (separate supplement).

It is not the object of this document to define a data management or avionics system configuration but to define hardware that is easily reconfigured for evaluation of many different system configurations while providing sufficient

computational speed to perform realtime control system simulations. Several assumptions were made in the defining of the hardware for HTS processors.

- The system may operate with or without a DMT or a combination of both.
- Ada will be the final language for the system, but due to necessary early development of the HTS, FORTRAN will be used until programmers are trained for Ada and certified compilers are available.
- The objective of the HTS is not to select a particular processor or processor architecture, but to evaluate distributed processing for avionics systems.
- It is assumed that no single processor will support more than eight data buses with a maximum of four active at any one instant.

Although MIL-STD-1553B is considered the data bus protocol in this discussion, the design of the HTS general processor allows different protocol to be considered because the protocol interface overhead is microprogrammed in hardware. Minor changes may be required in the software drivers if completely different protocols are evaluated.

It is proposed that two major processors be available for use on the HTS: a minor processor and a major processor. Each processor will have the capability of operating in any bus configuration and will have a multitasking operating system with drivers for each data bus. Application software and subsystem interfaces are all that are required by a user to implement a subsystem. In the simplest processor configuration, it becomes a DMT as described in section 3.3. Figures 5-4 and 5-5 demonstrate the two major processors.

#### 5.4 HYPOTHETICAL HTS CONFIGURATION

Reference figure 5-6 for a configuration utilizing the HTS general processor. This figure defines a hypothetical system that has dual redundant regional processors set (A1, B1) and (A2, B2). The redundant set (A1, B1) share a dual redundant subsystem or local set of processors (SA12, SB12) and (SA21, SB21). The redundant processor set (A2, B2) has dual redundant data buses. Dual

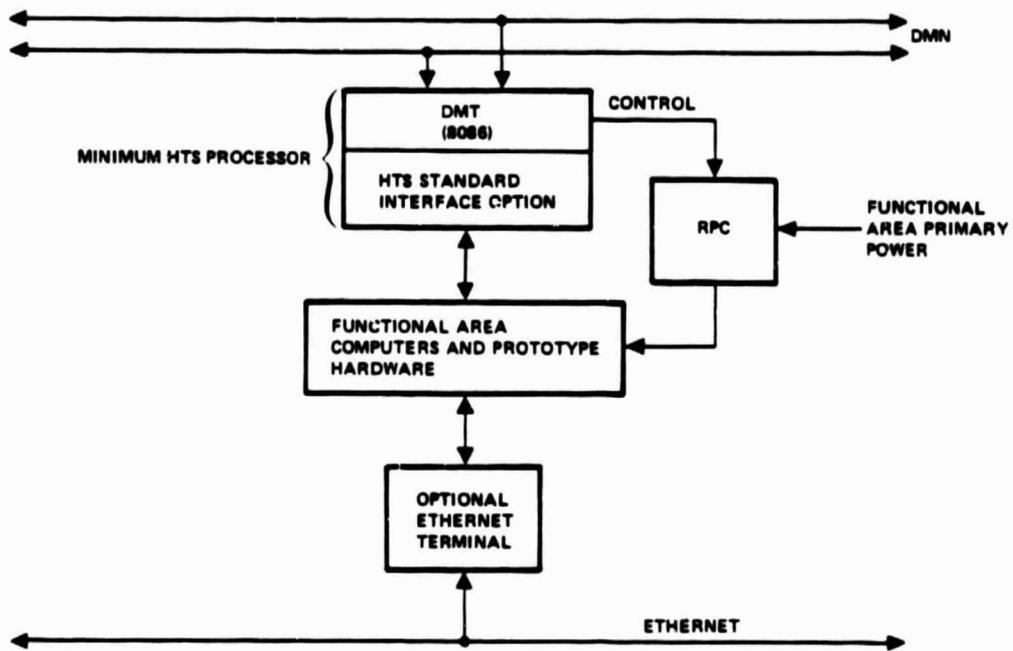


Figure 5-4.- Data Management Network terminal.

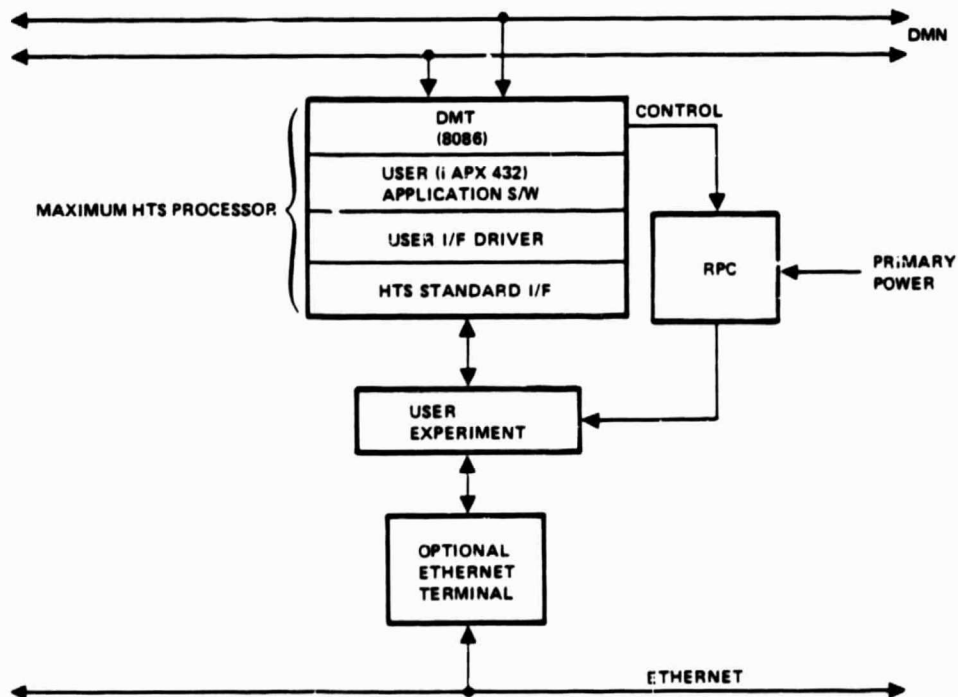


Figure 5-5.- Independent HTS processor terminal.

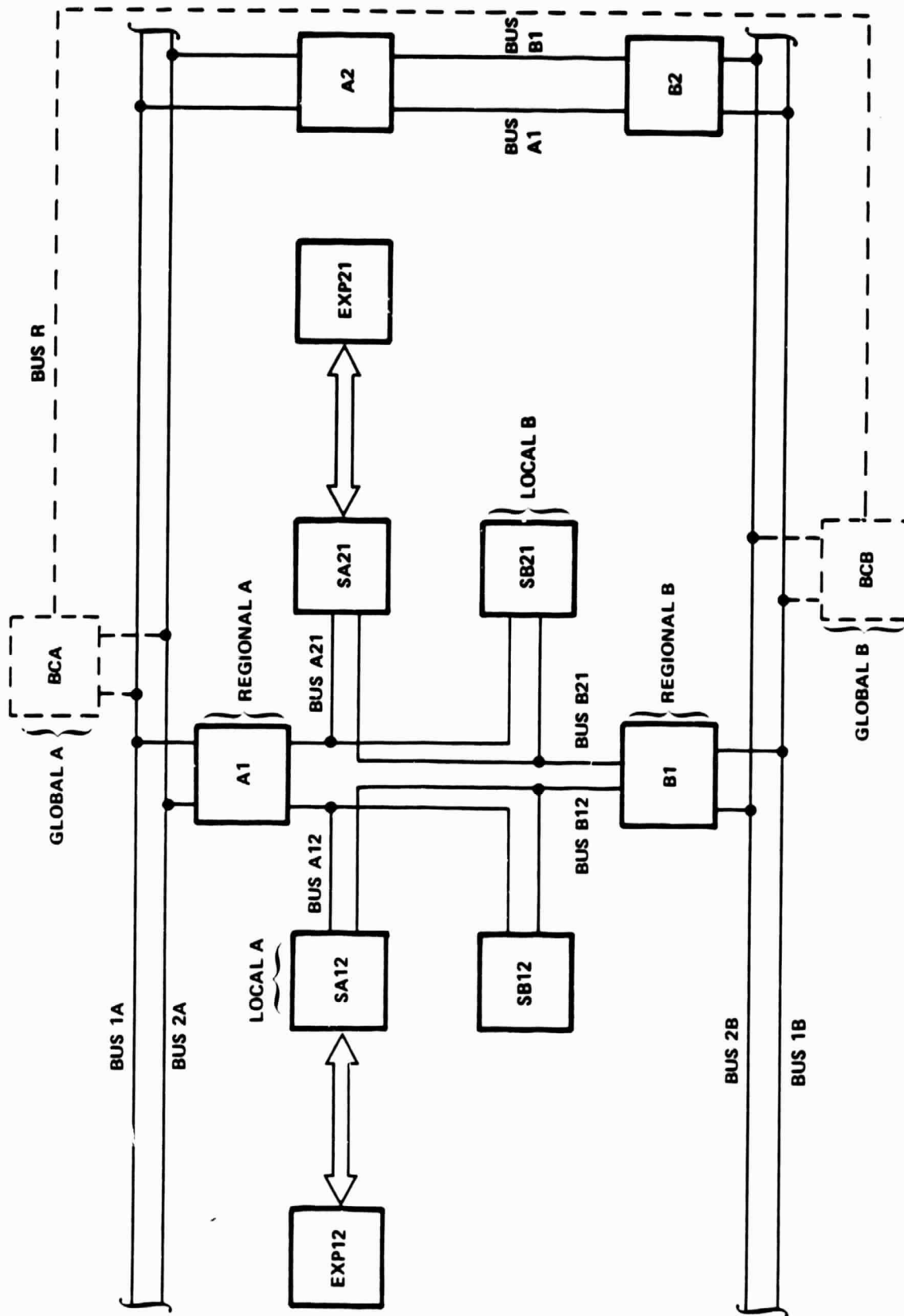


Figure 5-6.- Hypothetical HTS configuration.

redundant global processors (BCA, BCB) are shown in dotted lines because proposed HTS processors can operate equally well with or without a bus controller under MIL-STD-1553B by the use of an automatic polling bus interface adapter.

The redundant subsystem set (SA12, SA21) interface experiments via one of the ATB Processor interface options.

- IEEE-488                      ● RS 232
- MIL-STD-1553B              ● Orbiter Data Bus
- MULTIBUS

The two proposed HTS processors or DMTs have identical interface options and each may be operated with MIL-STD-1553B (eight maximum) configured as either a bus controller only, remote terminal only, software controller terminal, or automatic polling.

The MIL-STD-1553B bus terminal interface allows a message transaction between two terminal units that consists of 1 to 32-16 bit words. The bus terminal interface provides a software controlled interface that is compatible with a High Order Language (HOL). All transfers between the bus terminal interface and the host computer occur under Direct Memory Access (DMA). The host computer can request a variety of options such as:

- On line/off line                      ● Buffer write protection (via busy states)
- Buffer memory location              ● Status response
- Interrupt after completion              ● Transmitter disable
- Buffer size

A typical avionics development system for SOC using the DMTs is shown in figure 5-7.

Figure 5-8 defines the HTS MIL-STD-1553B command word format. The content of the data buffers and the protocol for their use is user defined thus providing a wide range of user configurations.



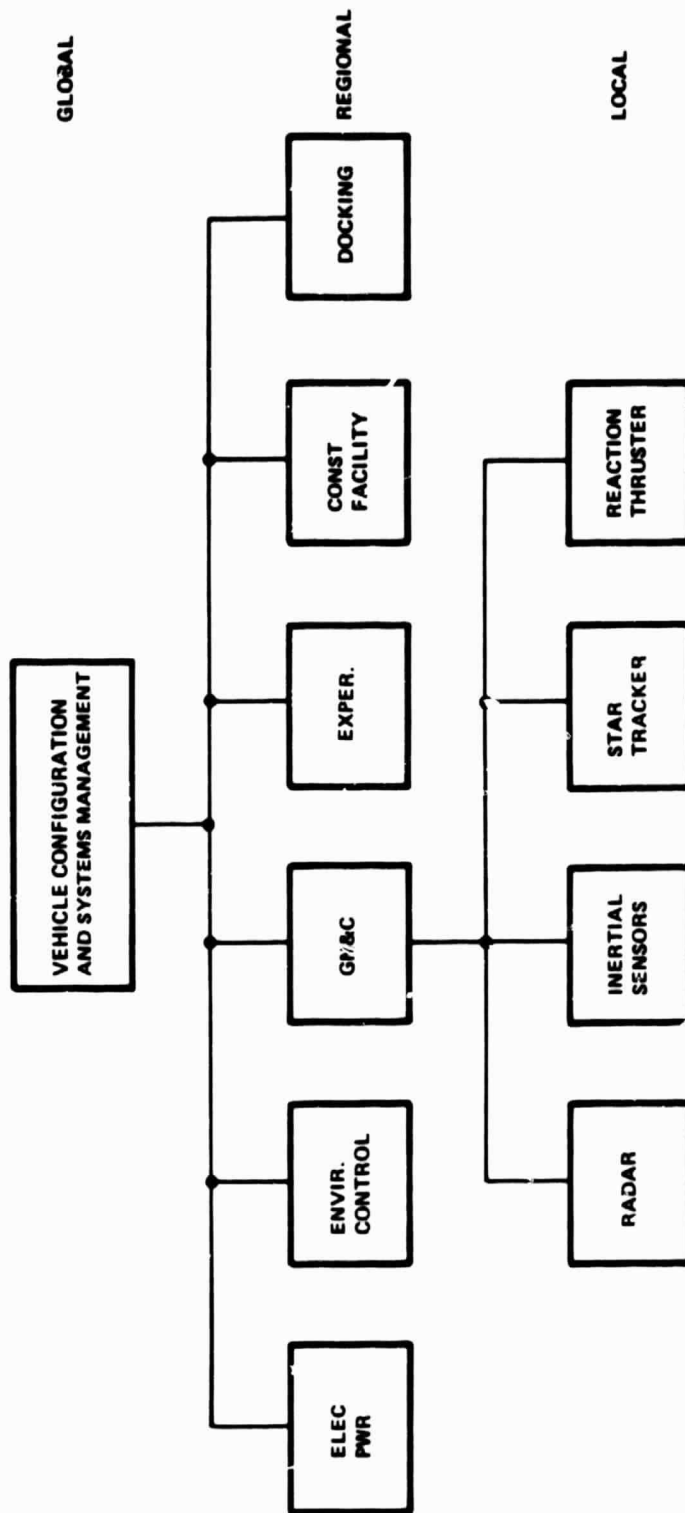


Figure 5-7.- HTS SOC avionics system block diagram.

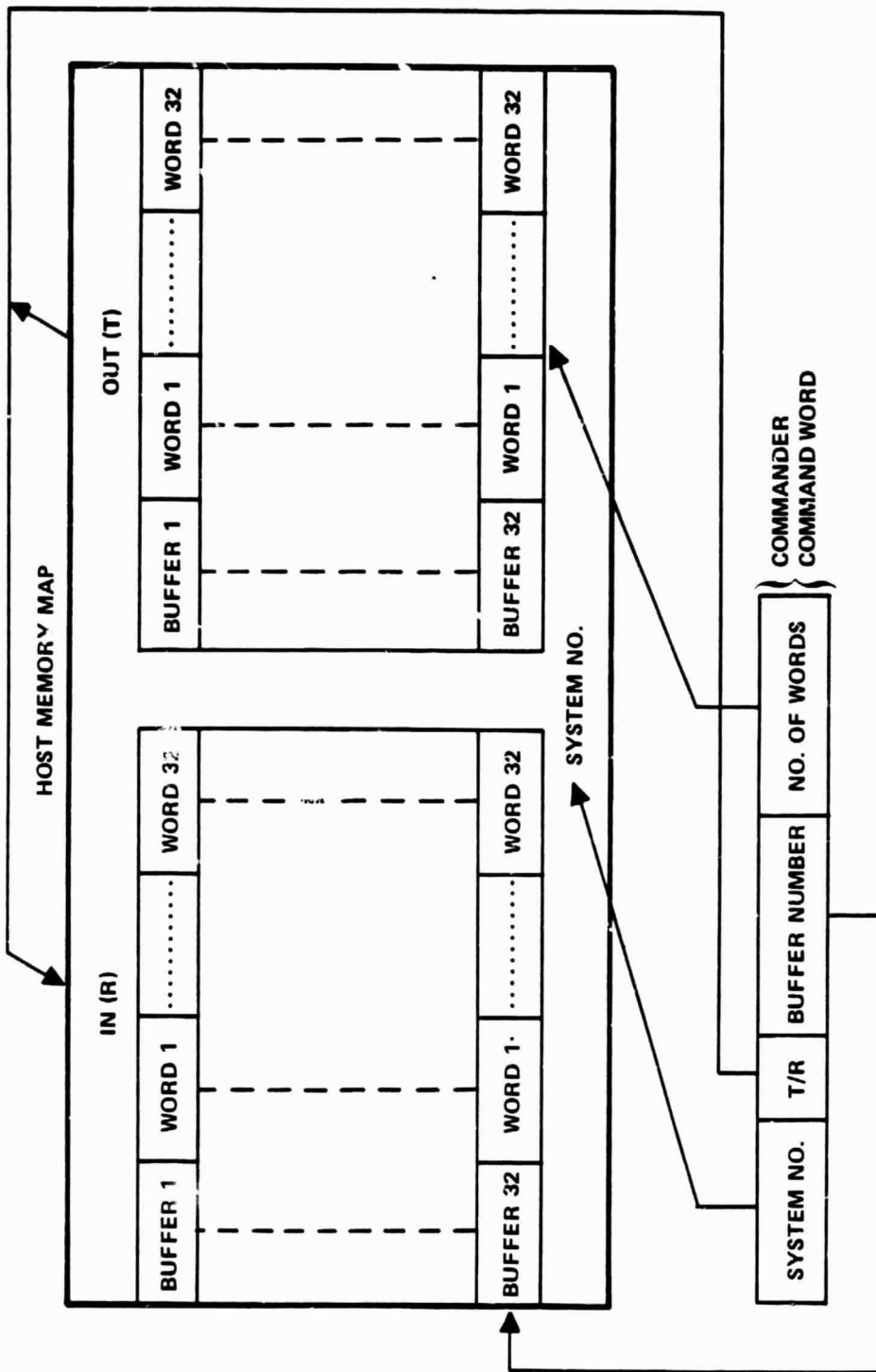


Figure 5-8.- ATB MIL-STD-1553B command word format.

A typical mode of operation might be system A requesting system B to pass 1 to 32 words from output buffer n in an immediate mode. This message transaction may be completed with or without processor B software knowing the time of the transaction.

### 5.5 GENERAL HTS PROGRAMMING LANGUAGE

Ada will be used exclusively in HTS except in areas such as embedded processors and during early development prior to release of Ada.

Ada is the name of the DOD common high order language that is being developed by Defense Advanced Research Projects Agency (DARPA). Ada compilers must be certified by DOD standards before release. Several corporations such as Intel, Honeywell, and Telesoft are nearing certification of Ada compilers. Ada evaluation workshops at Honeywell concluded the following:

- Ada is readable and maintainable
- Portable (machine independent)
- Reliable - Ada reduces the amount of coding and, therefore, the chances of error
- Modular
- Conceptually simpler to use in supporting multiprocessor computer systems

Ada has a broad support base with DOD, academic, and industrial users. It is proposed that all HTB software be developed in Ada computer language.

### 5.6 EAS TO HTS INTERFACE

A key component in the development of the HTS area is a VAX 11/780. In review, the VAX 11/780 was selected because:

- The hardware and software is compatible with CDC's Loosely Coupled Network for interfacing the Engineering Analysis/Simulation to HTS.
- It supports Ethernet for geographic distribution of simulation parameters.
- It is one of the first targeted computers for Ada certified compilers.

- Cross compilers and assemblers for most microprocessors are available. This will reduce the cost of software development by providing a common machine for software development.
- It has field proven hardware/software for supporting realtime and batch operations.
- It is a cost competitive system with many second sources for system components.
- The throughput and computation capabilities can be easily increased either by addition of parallel processors or array processors.
- The VAX 11/780 does not require special facilities such as 400 Hz power or chilled water.
- The VAX 11/780 is equiped with a cross assembler to the MIL-STD-1750 16 bit and MIL-STD-1862 32 bit insctruction sets.

The proposed VAX 11/780 packaged system is configured with:

- 1 megabyte of ECC MOS memory
- an REM80 single access 124 megabyte disk drive with MASSBUS Adapter
- a TEU77 (125 inches/second, 800 or 1600 bpi) magnetic tape transport unit with MASSBUS Adapter
- an LA-120 DECwriter III console terminal
- and a BA11-K expansion mounting box containing one DD11-DK expansion backplane mounting unit and one DZ11-A asynchronous multiplexer for connection of eight EIA STD communication lines
- a high performance floating-point accelerator (FP780-AA)

#### 5.6.1 OPERATING SYSTEM

VAX/VMS is the general-purpose operating system for VAX systems. It provides a reliable, high performance environment for the concurrent execution of multiuser timesharing, batch, and realtime applications written in BASIC, COBOL, FORTRAN, PASCAL, BLISS, CORAL, PL/I, and assembly language (which is included with the operating system).

The system features virtual memory management, event-driven priority scheduling, shared memory, file, and interprocess communication, data protection based on ownership and application groups, user privileges and resource allocation control, and an easy-to-use, easily extended command language.

Other system features include multijob batch processing, program development tools, extensive file and record management services, programmed system services for process and subprocess control and interprocess communication, Common Run-Time Procedure Library, and system maintenance utilities.

The VAX/VMS product includes the following facilities: Operating system nucleus, including virtual memory manager, swapper, system services, and input/output device drivers; user authorization control program; job initiator account manager; and operator communications manager.

Other components include error logging and print utility, DEC Command Line (DCL) command interpreter, Monitor Console Routine (MCR) command interpreter, interactive and batch editors, macro assembler, linker with cross reference, library maintenance utility, Common Run-Time Procedure Library, symbolic debugger for native programs, Record Management Services, FILES-11, SORT/MERGE utility, User Environment Test Package, and software maintenance release update utility.

Although Ada is proposed as the primary language for all HTS development software, trained personnel and support compilers will not be available until late 1983 or early 1984. It is therefore suggested that FORTRAN-77 be used during early HTB development. VAX-11 FORTRAN is a full implementation of FORTRAN-77 and it is optimized to achieve high execution speed. A majority of the realtime simulation software for SAIL support is written in FORTRAN-77.

#### 5.7 SPECIAL HTS EQUIPMENT

Any equipment that is not required in the normal operation of the HTS such as test equipment that costs more than 10K is considered to be special HTS equipment.

### 5.7.1 MICROPROCESSOR DEVELOPMENT SYSTEM

At least three types of Intel microprocessors will be used in the development of the HTB. Whether these microprocessors are used as general purpose computers, post processors, or embedded processors, it will be necessary to have a hardware and software microprocessor development system. There are numerous microprocessor development systems that are either dedicated or generalized, however, only one system is available for iAPX432 development. This system has a trade name Inteltec by Intel Corporation, the manufacturer of the iAPX432 microprocessor. The Inteltec can be configured as a development system for the following.

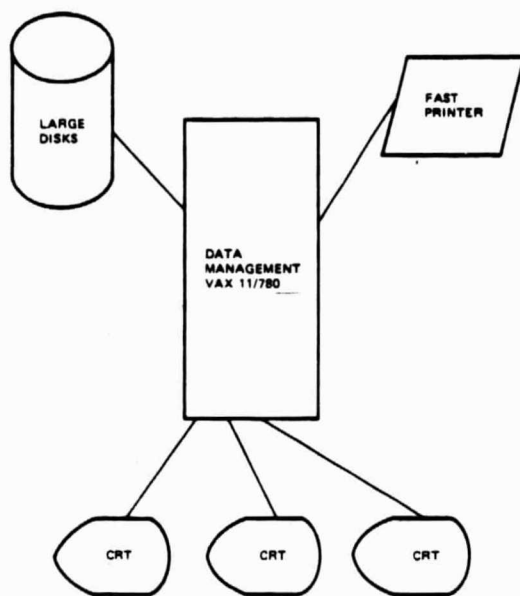
- |           |        |                  |       |
|-----------|--------|------------------|-------|
| ● iAPX432 | ● 8088 | ● Intel Ethernet | ● 286 |
| ● 8086    | ● 8085 | ● 186            |       |

It is planned that all may be used in the HTS. Additionally, the Intel model 311-VX Software Development Package contains a set of software development tools for the iAPX 86, 88, and (iAPX432 available mid '82). This package lets the user develop, edit, compile, and link and locate programs on a VAX 11/780 that have source-level and object-level compatibility with programs developed on an Inteltec Development System shown in figure 5-9.

The Inteltec Development System environment can be used to debug an application created in the VAX 11/780 environment. Source and object modules may be downloaded to an Inteltec Development System (figure 5-10) via the Mainframe Link for Distributed Development (MDS-384) and debugged using the symbolic features of the In Circuit Emulator (ICE)-86 emulator.

Source and object files created in an Inteltec system may be stored on the inteltec system for quick access or uploaded to the VAX 11/780 for storage and control.

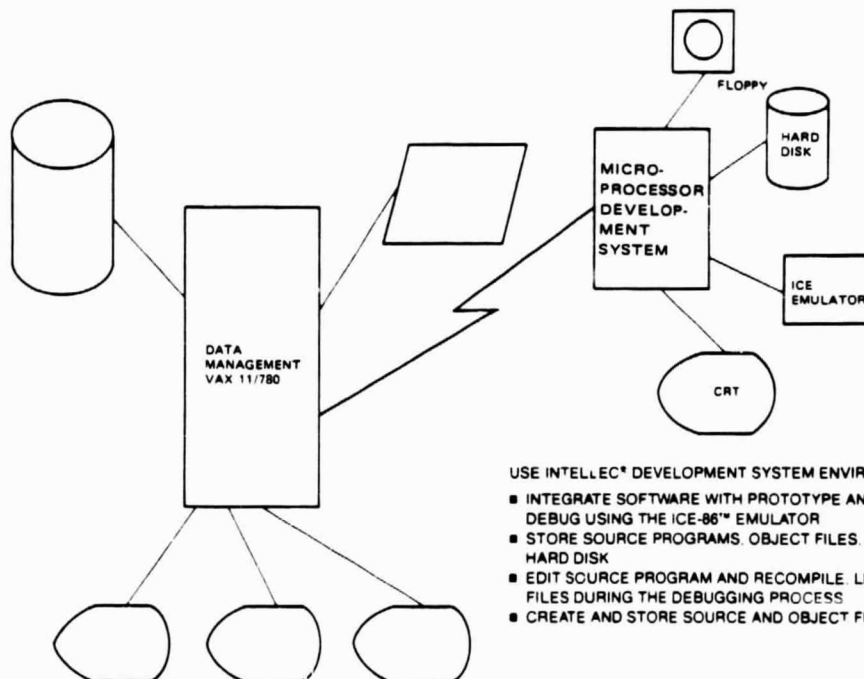
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USE DATA MANAGEMENT VAX  
11/780 ENVIRONMENT TO:

- CREATE AND EDIT PL/M 86/88 AND ASM 86/88 PROGRAMS USING MULTIPLE CRT'S AND VAX/VMS EDITOR
- LIST PROGRAMS USING FAST PRINTERS
- COMPILE OR ASSEMBLE PROGRAMS INTO OBJECT FILES
- LINK AND LOCATE OBJECT FILES
- STORE SOURCE AND OBJECT FILES ON LARGE DISKS
- TRACK CURRENT VERSIONS OF FILES
- PROTECT ACCESS TO FILES
- SHARE COMMON LIBRARIES AND MASTER PROGRAMS

Figure 5-9.- VAX 11/780 environment.



USE INTELLEC\* DEVELOPMENT SYSTEM ENVIRONMENT TO

- INTEGRATE SOFTWARE WITH PROTOTYPE AND SYMBOLICALLY DEBUG USING THE ICE-86™ EMULATOR
- STORE SOURCE PROGRAMS, OBJECT FILES, AND SUBMIT FILES ON HARD DISK
- EDIT SOURCE PROGRAM AND RECOMPILE, LINK AND LOCATE OBJECT FILES DURING THE DEBUGGING PROCESS
- CREATE AND STORE SOURCE AND OBJECT FILES

Figure 5-10.- Microprocessor development system.

### 5.7.2 NETWORK MONITORS

The ATB depends upon several network systems for distribution of data. A monitor or network analyzer will be necessary for development and maintenance of the Ethernet, MIL-STD-1553B and LACN (data link) networks. Cost for these items is not available and each may require an in-house design such as the Data Systems Laboratory's Universal Bus Interface Controller (UBIC) system that has been used as an Orbiter data bus analyzer.



## 6. ATB MANAGEMENT SYSTEM

The EAS and the HTS have been defined as separate, independently operated systems with their development proceeding in parallel during the early phases of ATB development. The ATB Management System (AMS) requires both hardware and system engineering resources. An organization element discussed in section 7 will be created specifically for the system management of the ATB. The goal of this organization will be to coordinate the design and configuration of the two systems for a major integrated facility. Additionally, the AMS function requires the design of a System Management Computer System. As presently conceived, this function will be based in one VAX 11/780 operating in parallel with the HTS Data Management Function VAX 11/780 computer (reference figures 6-1 and 3-1). The two mainframes will communicate via a 32 bit parallel high performance bus (DEC-DR780). This computer system also has access to the MIL-STD-1553B and Ethernet networks for system performance monitoring and data logging. The AMS function VAX 11/780 has its own private wideband video communications network (LACN). The LACN capabilities are shown in figure 6-1. This network is referred to as the System Management Network and it is used to control the subsystem manager's consoles located in each of the ATB functional areas. Additional AMS function features follow.

### 6.1 SYSTEM MANAGERS CONSOLE

The System Managers Console design allows complete reconfiguration by the utilization of flat screen touch sensitive television or plasma displays. All displays, labels, and control switches will be "soft". The same design concept will be used on the cockpit. Special CRTs for NAV AIDS will enhance reconfigurability.

### 6.2 SCENE GENERATOR

A TBD scene generator will provide high resolution scenes at the crew station while a CATV network (part of LACN) distributes scenes by compatible television to each of the subsystem managers consoles. Recent network designs have utilized CATV for voice, video, and broadband data communications on a single coaxial trunk.

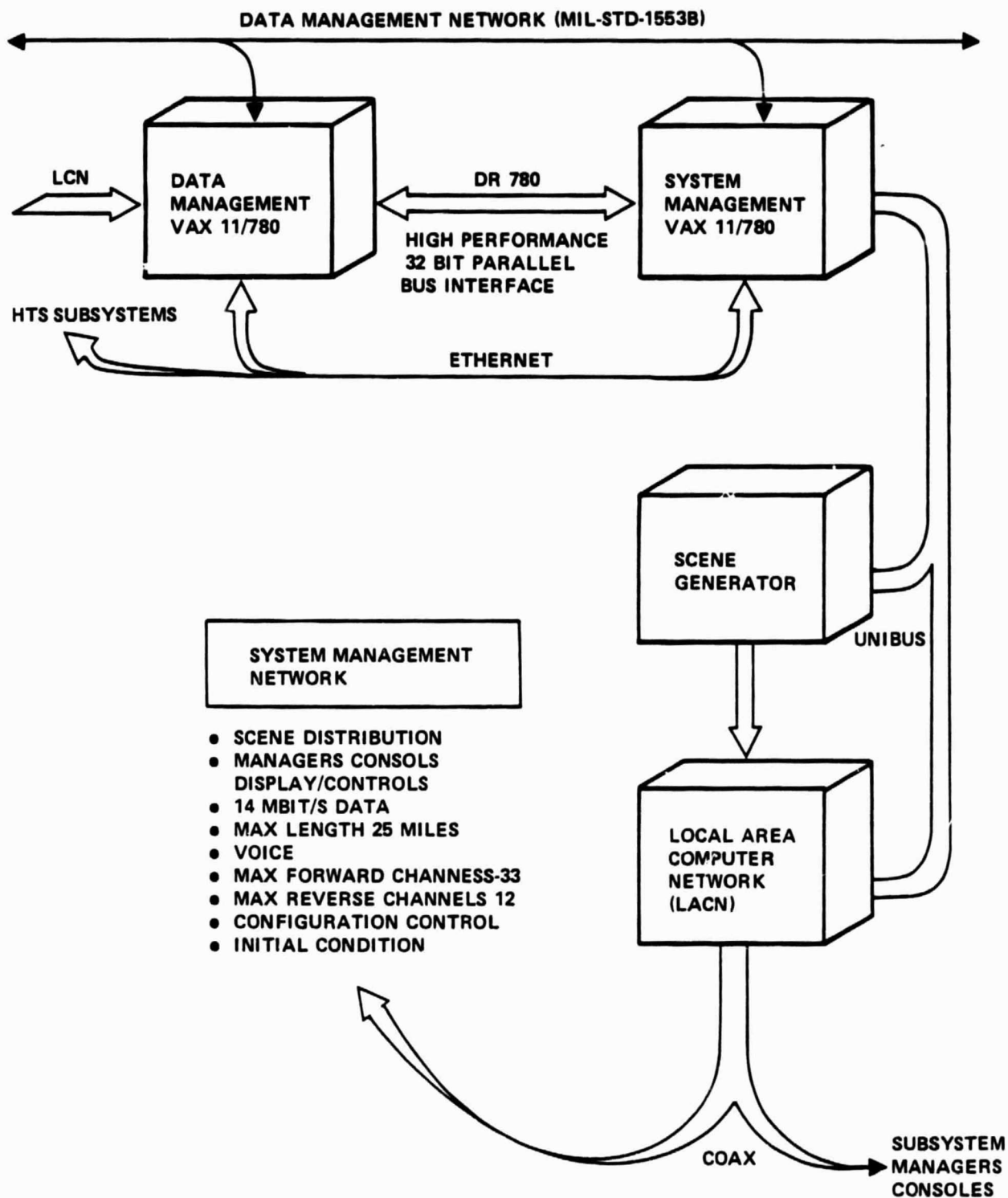


Figure 6-1.- ATB Management System function computer system.

A large commercial market for CATV components makes this type of network economical.

### 6.3 SYSTEM DATA BASE

A major responsibility of the AMS function is to initialize tests, control tests via test procedures, and record results for post test data analysis. The system data base provides this function.

All system test procedures are controlled by the system management console computer. This allows accurate repeatability of tests. This function is much more critical in a geographically distributed processing system.

## 7. MANAGEMENT AND BUSINESS PLAN

In this section the existing organizational environment is discussed as it relates to the development of the ATB. A concept of an appropriate management structure for the definition, development, and operation of the ATB is presented. Finally, recommendations are made for the implementation of the management scheme, and NASA and support contractor roles are discussed.

### 7.1 ORGANIZATIONAL ENVIRONMENT

The management structure for the ATB must be one that evolves from the existing system as the ATB concept is further defined and funds are made available for its implementation. Recognition must be made of the large number of inter- and intra-organizational interfaces which currently exist and will, by design, continue into the future. A major tenet of the ATB concept is that individual laboratories, simulation facilities, technical disciplines, etc. maintain their sovereignty and capability in functioning as independent entities. However, these entities must also be capable of functioning in an integrated fashion with each other as program requirements dictate. The need for cooperation and coordination between various organizations, both NASA and contractor, with potentially conflicting priorities becomes a major concern in the development of the ATB.

### 7.2 MANAGEMENT CONCEPTS

In the following paragraphs, a proposed ATB management concept is developed which considers the issues presented above and identifies the organizational functions which must be addressed. No attempt will be made to specify in a detailed chart which functions will be addressed by an existing or future NASA or contractor organization. Rather, each function's responsibilities, interfaces, and implementation will be covered. In order to avoid confusion with topics identified as functions elsewhere in this document, the organizational concepts or functions will be termed "Operations".

### 7.2.1 AVIONICS SYSTEMS ENGINEERING OPERATION

In the present environment, the requirements for the analysis, evaluation, and testing of avionics software and hardware are generated by a number of diverse sources. Requirements are developed from existing NASA programs such as the Space Shuttle, from advanced technology application projects such as the electromechanical actuator and fiber optic data bus, and from anticipated needs of future programs such as the SOC. Each type of requirement is handled individually in the various technology areas, and interdisciplinary issues are not routinely addressed unless there is a specific program requirement. As spacecraft become larger and more complex with subsystems geographically distributed yet interdependent, additional requirements for interface interaction and evaluation will be generated. These requirements will result in the need for the establishment of an Avionics Systems Engineering Operation (ASEO). This operation will address the issues associated with total avionics development from an overall system viewpoint. It should define technology thrusts and plan the development activity required. One key responsibility will be to define avionics analysis, test, and evaluation requirements and to provide this information to the operations responsible for the ATB. This operation should be staffed with a core group of systems engineering professionals supported by technical experts in the various disciplines.

### 7.2.2 ATB PROJECT OPERATION

Due to the large number of organizations which will be effected by the ATB concept and utilization, an ATB Project Operation (APO) should be established. The APO will be the top level management organization for the ATB. It will be responsible for coordinating system level avionics requirements with the ASEO, for the ATB design specifications, for math model configuration control and software transportability requirements, for the establishment of all formal interfaces, and for the overall management of the ATB. The APO will also be responsible for the direction of the ATB Management System (AMS) function described in paragraph 3.1.2. Supplemental tasks will include evaluating and establishing requirements for support elements or systems such as PERT for scheduling and CADAM for automated design activities. In addition to its interfaces with the independent laboratories, functions, and technical areas, the APO will consist of at least two major sub-elements or operations:

#### 7.2.2.1 ATB Development Operations

The ATB Development Operation (ADO) will be responsible for the detail definition and design of the ATB system. Fabrication or procurement of the required hardware and its installation, check-out, maintenance, improvements, and routine operation are the ADO's major assignments. This dedicated organization will establish and maintain appropriate interfaces with other concerned areas to ensure all mutual and independent objectives are met.

#### 7.2.2.2 ATB Utilization Operation

The ATB Utilization Operation (AUO) will be responsible for all tests and evaluations utilizing the ATB in an integrated mode. It will be responsible for coordinating test requirements, procedures, schedules, and for the conduct of the test. Test configuration control, data management, and documentation are among the AUO's major activities. ATB user interface is also a prime responsibility of this dedicated organization.

#### 7.2.3 INDEPENDENT OPERATIONS

The ATB concept allows for the continued individual operation and function of the various technology laboratories, simulation and analysis facilities, and engineering capabilities. However, these independent operations will be required to establish, maintain, and operate appropriate interfaces with the ATB to provide an integrated capability. Close coordination and cooperation between the dedicated ATB operations and these independent areas must be a top level management requirement for the ATB to achieve its full potential.

#### 7.3 SUMMARY AND IMPLEMENTATION

The ATB will require the establishment of several new organizations and numerous new organizational relationships as depicted in Figure 7-1. It is recommended that the ASEO and APO functions be established as soon as practical to initiate the required planning and organizational activities.

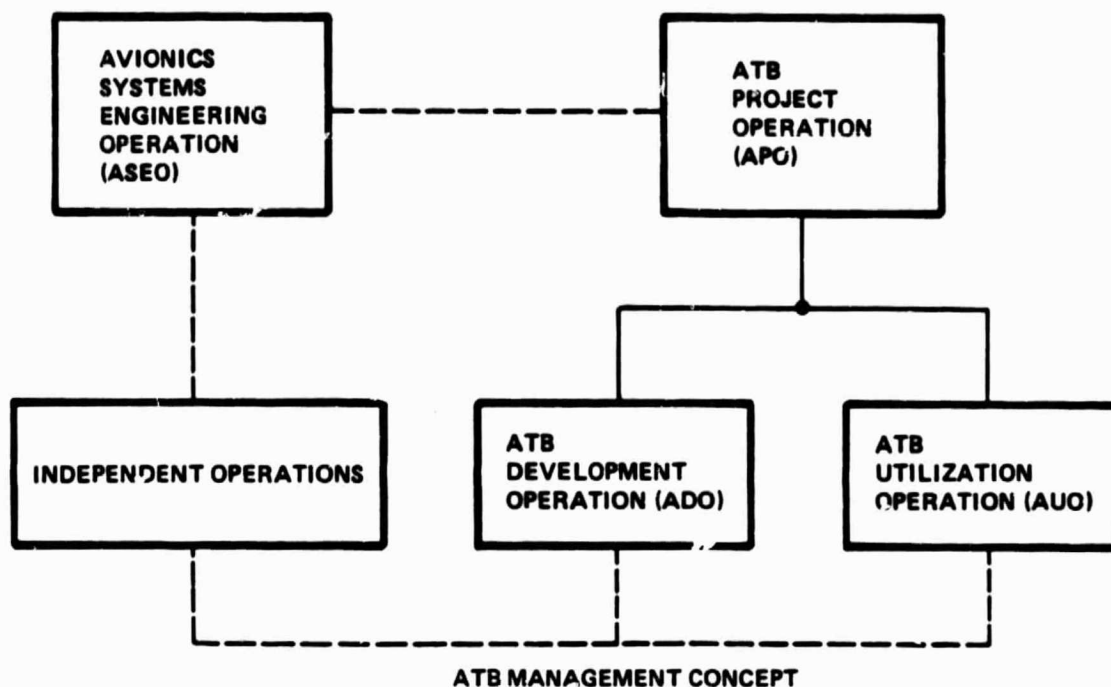


Figure 7-1.- ATB management concept.

These two operations should evolve from the existing organizations whenever possible, but will also require the addition of system engineering expertise. In this initial period the APO should develop ATB design requirements and establish working interfaces with the various independent operations. The independent operations in turn should assign specific responsibilities related to the ATB to personnel in their respective organizations.

The ASEO is envisioned as a NASA Office reporting at the Division level. The independent operations will continue as NASA Branch level operations, with contractor support. The NASA APO should initially be a NASA Office level organization with the potential to grow to the division level. The APO, ADO, and AUO functions are suitable for assignment to a support contractor. These operations could easily evolve from the existing contractor support to the various independent operations or laboratories. The most efficient method in

the long term is considered to be the assignment of a mission type support contract to encompass the tasks associated with the ATB operations as well as those of the independent labs.

Although a detailed management plan is beyond the scope of this document, the above concepts are provided for consideration and to provide a basis for further study.



## 8. CONCLUSIONS

This document has defined a development plan for a practical and economical approach to implementing an Avionics Test Bed (ATB). The utilization of existing NASA ASD laboratory resources and commercial hardware and software systems makes the approach economical. An ATB management system (AMS) function was described to coordinate the early parallel development of Engineering Analysis Simulation (EAS) and Hardware Testing System (HTS) operations. This AMS function will evolve into an ATB computer management system for an operational ATB.

Several areas require additional study such as the computation requirements for the EAS, design requirements for the HTS SOC configuration, and the AMS design requirements. Specific design requirements for each of the functional areas of the HTS will be prepared by the AMS function as ATB tasks evolve.

Aside from this document, this project also required a survey of the ASD computer and software resources that may be used for ATB development. Two documents, (1) Hardware Survey for the Avionics Test Bed, LEMSCO-16838, JSC-17451, and (2) Software Survey for the Avionics Test Bed, LEMSCO-16941, JSC-17490, have been completed and delivered.

Finally, a memo was delivered to the NASA Data Systems Branch, EH4, with a cost estimate for materials and manpower to implement the HTS and AMS segments of the ATB. This estimate identified several large equipment purchases (such as the VAX 11/730 computer) with long procurement lead times. These items should be procured in FY82 to have an operational ATB by 1984.

It is recommended that additional tasks be initiated in FY82 to begin the implementation of the ATB. These tasks include:

- 1) EAS design requirements
- 2) Design and fabrication of HTS data bus terminals
- 3) HTS development
- 4) AMS design definition