FINAL REPORT

VOLUME 1
EXECUTIVE SUMMARY

DEFINITION OF AVIONICS CONCEPTS FOR A HEAVY LIFT CARGO VEHICLE

for Marshal Space Flight Center

Contract Number NAS8-37578

September 1989

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16. Abstract

The major objective of this study task was to define a cost effective, multiuser simulation, test, and demonstration facility to support the development of avionics systems for future space vehicles. The technology needs and requirements of future Heavy Lift Cargo Vehicles were analyzed and serve as the basis for sizing of the avionics facility although the lab is not limited in use to support of Heavy Lift Cargo Vehicles. This volume of the final study report provides a summary of the vehicle avionics trade studies, the avionics lab objectives, a summary of the lab's functional requirements and design, physical facility considerations, and cost estimates.

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1.0 INTRODUCTION

The Executive Summary, (Volume 1, Final Report), was developed by the Space Systems Avionics Group of General Dynamics. It satisfies the requirements of Data Requirement 4 of the "Definition of Avionics Concepts for a Heavy Lift Cargo Vehicle" study for the Marshall Space Flight Center under contract NAS8-3578.

1.1 SCOPE

This document contains a summary of:

- Significant achievements and activities of the study effort.
- Results, methodologies and selected options
- Trade Studies, recommended approaches,design impacts and analysis
- Cost estimates of major elements of the Ground Based Testbed.

1.2 BACKGROUND

The HLCV avionics study was originally meant to focus the development of advanced avionics systems for the next ten to fifteen years. Figure 1.2-1 shows the role the HLCV Avionics study was envisioned to play. Scoped to start with an expendable, Shuttle derived booster, it was to define an optimum progression of upgrades and transitions until a fully reusable fixed wing booster system was achieved. Not limited to boosters, the study was to explore second stages, recoverable modules, and the attendant ground support systems.

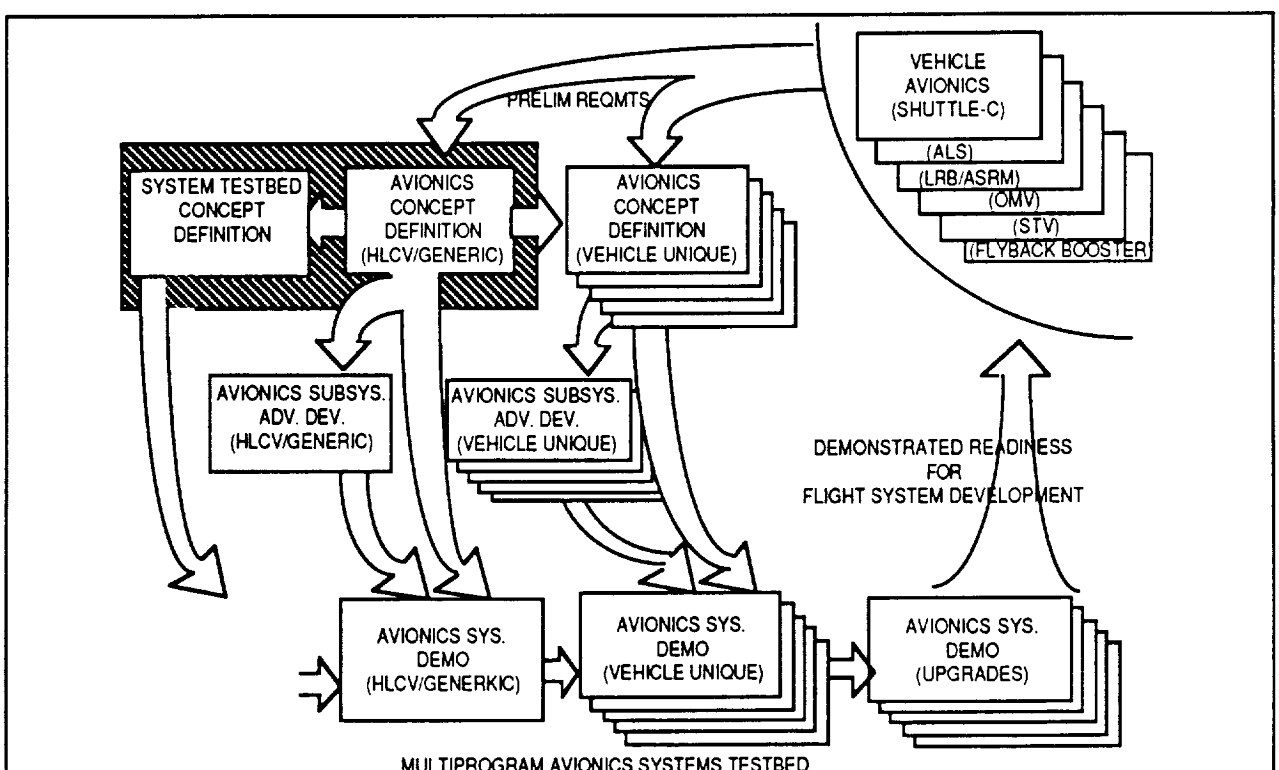


FIGURE 1.2-1 HLCV AVIONICS STUDY: FOCUS FOR AVIONICS ADVANCED DEVELOPMENT

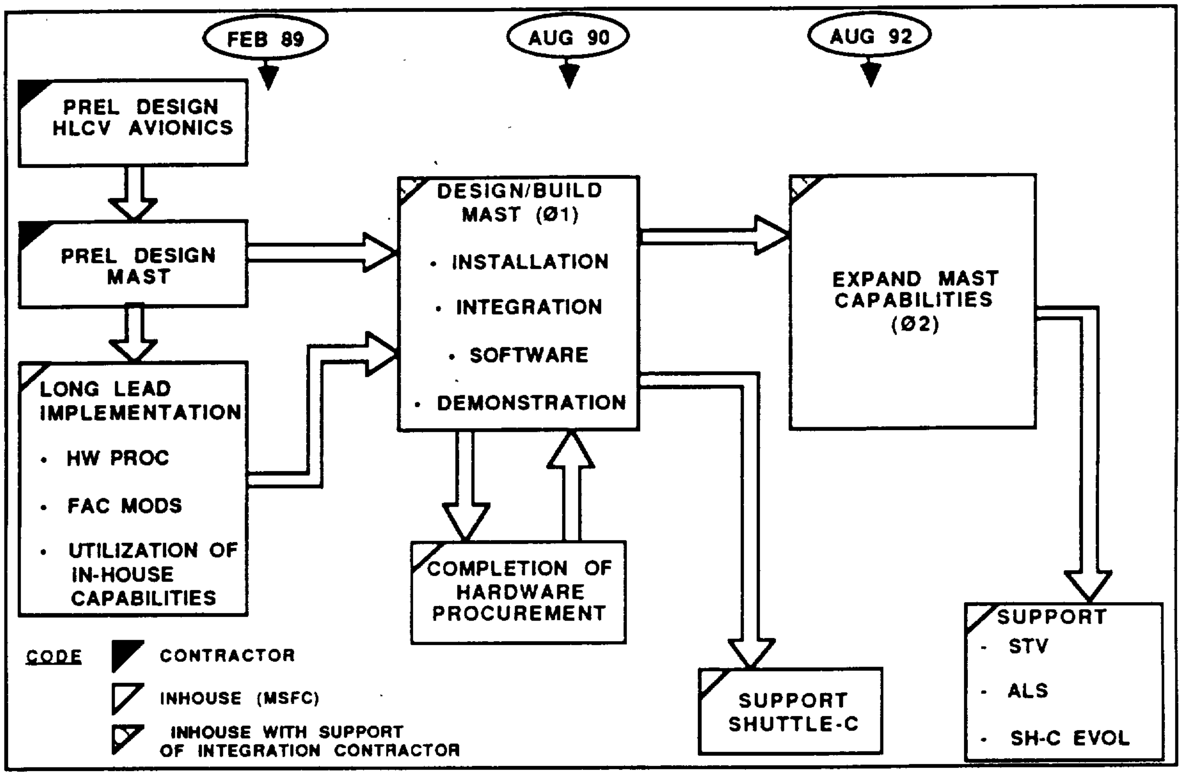


FIGURE 1.2-2 HLCV / GBT IMPLEMENTATION

Methods for accelerating the application of beneficial new technologies to existing and future systems were needed. To this end, a Ground Based Testbed was to be defined. Though not a stated goal, lowering the overall cost per pound of orbiting a payload drove the study to include the definition of the optimal mix of ground and airborne check out capability. Autonomous operation of the far term vehicles was felt to be a logical goal.

Shortly after the first review, the customer directed a shift in emphasis to the definition of the Ground Based Testbed, (GBT), that would support development of the HLCV avionic systems. The HLCV reference vehicle avionic systems were defined to the level required to size the GBT main processor, G&N Extension, and interconnecting busses and networks.

A target implementation schedule was provided by MSFC in October linking the HLCV GBT and the Marshall Avionics System Test bed (MAST) efforts (see Figure 1.2-2.). Also defined were specific functional support levels with dates and projected budget allocations A candidate site for the GBT/MAST was also provided The third Quarter Review reflected these inputs and specifically costed the Phase 1 lab configuration. For purposes of this study the terms MAST and GBT are synonymous.

The Executive Summary was structured to parallel the presentation at the 4th Quarter Review. It is intended to supplement the presentation and contains back-up information not included in the presentation materials.

1.2.1 STUDY OBJECTIVES

The initial objectives of the study were enumerated in the Study Plan as:

1. Define the avionics requirements and recommended avionics concepts for an expendable Heavy Lift Cargo Vehicle in the 1992-1995 time span.

2. Define the avionics requirements and recommended avionics concepts for a highly reusable HLCV to be operational in the 2000 era.

3. Define the requirements, concepts, developmental plans, and costs for an avionics test bed(s). The avionics test bed will support the development and testing of the recommended vehicle and vehicle support components, software modules, subsystems and systems.

4. Develop a transition plan from the expendable to the highly reusable HLCV.

5. Develop a follow-on plan to define advanced development activities.

As previously stated, the study emphasis shifted to definition of the avionics test bed, Objective #3, shortly after the first Quarterly review. Details were hammered out in the August Technical Interchange Meeting (TIM). The study plan was changed and a no-cost contractual change initiated to offset the additional tasks and products associated with this change, objectives 4 and 5 were rescoped and de-emphasized.

1.2.2 STUDY TASKS & SCHEDULE

Figure 1.2.2-1 is the revised Master Schedule that reflects the final contract changes. The six major task classifications are shown and the deliverables identified.

MASTER SCHEDULE

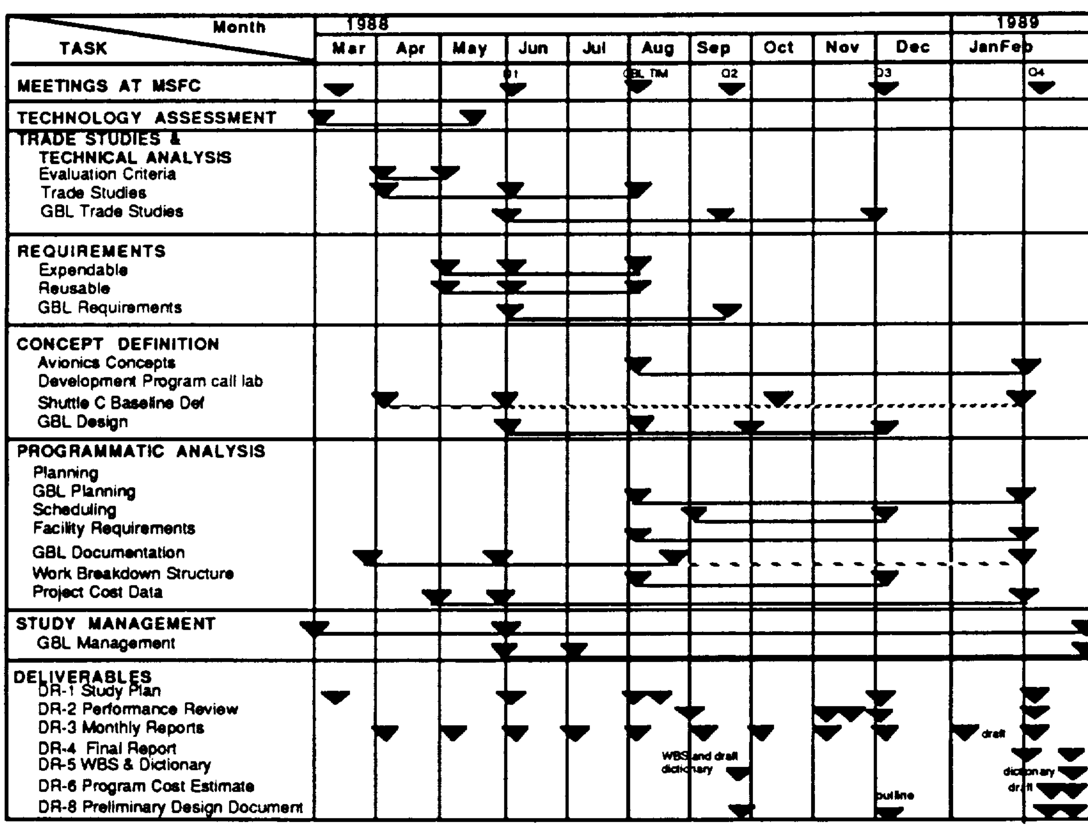


FIGURE 1.2.2-1 REVISED MASTER SCHEDULE

2.0 GBT DESIGN OBJECTIVES AND PHILOSOPHY

The GBT is envisioned as a general resource facility providing to new vehicle programs a cost effective method of evaluating the concepts and technologies employed in their design. This resource will permit complete end-to-end simulations of system operation in the simulated mission environment desired.

The GBT is to be set up to encourage use by all HLCV era vehicles during their initial design phases. Review of past projects involving total vehicle or subsystem development have repeatedly shown the need for such a readily accessible and powerful test and evaluation facility. The traditional dedicated test and development facilities have not been able to support their projects early enough to optimize system requirements and design. New projects must initially use facilities dedicated to other projects . Seldom do such facilities provide all the necessary testing capabilities or time for the required work.

The key to the HLCV GBT success is seen to simply be: Cost Effectiveness. To obtain this objective, the Lab must be readily accessible at the time when new projects traditionally don't have their own dedicated facilities. GBT access must be simple and bound with a minimum of red tape. Once accessed, the GBT must provide a user friendly environment, an environment that can quickly be configured to access the required testing and logging resources. The resources must be capable of evaluating the concepts, technologies or designs to the required level of accuracy and against recognized performance benchmarks. Finally, the GBT must provide not only easy replication of the testing, but also provide the ability to thoroughly analyze the results and report the results in forms which effectively communicate their significance.

2.1 GBT OBJECTIVES

The major objectives for the GBT are to provide a cost effective, multiuser simulation, test and demonstration facility to:

1. Support early development and quantitative evaluation of proposed avionics systems during the early phases, (phase A/B),of a program.
   - surfaces avionics, systems, integration and software problems early
   - supports early requirement s development
2. Accelerate new avionics technology testing and application to future programs.
3. Provide a productivity center for evaluating/demonstrating major new design advances from NASA and industry.
4. Promote continuity of avionics architectures, software, and hardware across projects.
5. Demonstrate the "integration-ability" of new subsystems or components and their impact on the performance of an existing vehicle system.

Figure 2.1-1 shows four HLCV era vehicles to be supported by the GBT. The first two are shuttle derived vehicles, SDV-2ES and SDV-2R. The 2R version has reusable propulsion and avionics as opposed to being expendable as the 2ES is. An alternative to the SDV-2RS is the Advanced Launch System Core and Booster. The fourth GBT supportable vehicle shown is the Fully Reusable Booster/Partially Reusable Cargo Vehicle, FRWB/PRCV. In addition to these, the GBT will also support upper stages, the Space Transfer vehicles, and several payloads.

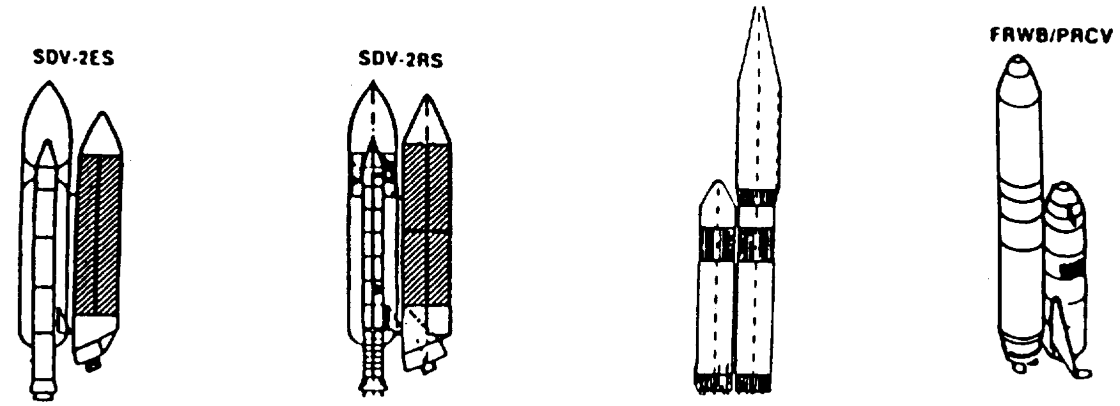


FIGURE 2.1-1 HLCV ERA CANDIDATE VEHICLE CONFIGURATIONS

2.2 GBT PHILOSOPHY

The major points upon which the GBT design philosophy is based are:

a. Reconfigurable Design
b. Real Time
c. Functional Testing
d. Modular Design
e. Flexible
f. Demonstration Oriented
g. User Friendly

The broad based, non project dedicated, generic nature of the GBT is implied in the first point. The GBT must be an evolving facility, capable of supporting several current and near term avionic systems. This translates to a firm requirement for rapid reconfigurability. It must not only be able to switch from one test configuration to another, but it also must have sufficient capability to support several parallel efforts simultaneously. These efforts will include everything from basic evaluation of single units in an open loop environment, to full up, multi-string system simulation.

To be truly useful to a number of projects simultaneously, the GBT must accommodate a variety of software and hardware configurations. This characteristic encompasses several traits which include an continuing capability to support several current and near term avionic systems. Implicit to this capability would be a rapid and easy reconfigurability made possible by an architecture that presents a broad compatibility to both hardware and software. This compatibility includes the ability to provide a Real-Time hardware and software interface. This interface must be capable of duplicating the normal interface the Unit Under Test encounters in its native system. Only with such an interface can testing and evaluation be carried out at the required level of fidelity. Just as important is the ability to precisely manipulate the interface characteristics. Fault insertion and off limit operation can enhance the thoroughness of testing.

The GBT is modular at all functional levels so, as it develops and the support requirements change, the lab can add or access the required resources. This translates to the GBT being able to accommodate any vehicle or system simulation of similar complexity to the then current defined reference vehicle and systems. Modular design in both the GBTs hardware and software facilitate an orderly expansion of capability. The foundation of hardware model benchmarks will be validated against real equipment. Once proven, a combination of real and simulated hardware models can be utilized to evaluate any number of proposed system architectures.

Since one of the GBTs primary functions is to provide timely support to new projects, it must have the ability to quickly adapt to the specific needs of those projects. This flexibility must be a basic consideration in the GBT architecture so it can perform that level of testing or simulation required in a more cost effective manner than currently available to new projects.

The current implementation plan for GBT establishes an August 1990 IOC to support Shuttle-C, (figure 1.2-2). In actuality, the GBT will have more than half of its total planned capability at this point. The software tools and models developed for the Shuttle-C are basically generic in nature, with separate data files supplying the unique values for this vehicle, its subsystems, and mission profiles. In most cases, only data set value changes would be required to switch from one vehicle configuration to another.

3.0 TRADE STUDIES AND TECHNICAL ANALYSIS

Several technical issues had to be resolved prior to the definition of the three HLCV avionic system designs and the Ground Based Test Bed.

The range of studies originally considered covered the three HLCV reference vehicles and the GBT. Those chosen for further study included:

- RVU replacement of EIU
- Vehicle Processors
- Software Language and Tool selection
- Flight Control Actuators
- Vehicle Power
- Lab Architecture
- Data Buses and High Speed Networks

3.1 ENGINE INTERFACE UNIT REPLACEMENT

The feasibility of replacing the current Space Shuttle Main Engine (SSME) EIU with a modified Remote Voter Unit (RVU II) was investigated for the SDV-2ES (Shuttle C). Figure 3.1-1 summarizes the results. Though future plans point to simpler engine control requirements, the current assumptions, of a total functional replacement for the SSME EIU didn't prove to be economically feasible. Section 3 of Volume 2 contains the details of this study. Notable, however, is that this study lead to investigation of RVU replacement of the Orbiter MDMs and RJD in the SDV-2ES avionics system. This in turn lead to the Shuttle C Option C avionics configuration. The Concept Definition Section of Volume 2 contains this design.

	RECURRING COSTS	RECURRING OPER. COSTS	NON-RECURRING COSTS	PERFORMANCE MIN REQ	PERFORMANCE GROWTH	RELIABILITY	RISK FACTOR
RVU II	SAME	same as other units	SAME	HIGH	HIGH	HIGHER	HIGH
EIU	SAME	unique unit & test	SAME	HIGH	LIMITED	LOW	LOW

- THE ABOVE ARE RANKED IN ORDER FROM HIGHEST TO LOWEST
- NO ADVANTAGES IN GOING WITH THE RVU II

NOTE: Reduced Engine Control Requirements may alter conclusion.

FIGURE 3.1-1. RVU II-EIU TRADE STUDY RESULTS

3.2 VEHICLE PROCESSORS

Selection of the best current CPU for the HLCV centered about the 16 bit, 1750 processors. Figure 3.2-1 shows the units investigated. The PSC 1750A was selected. 32 bit processors were also considered for far term application.

	Availability	Risk	Cost	Performance	USE			Rating
					Air	Ground	Lab	
Existing PSC	88	Lowest	Lowest	1.3-2.6	√			Best
PACE 1750A	now	Moderate	TBD	1.3-2.6	√			
Improved PSC RCA CMOS/SOS	TBD	High	High	High	√			
PSC 1750A RCA CMOS/SOS 1750A	88		TBD	2.8	√			
HI RICMOS GVSC	89		TBD	1.1-3.7	√			
Self-Checking PSC PACE 1750A	now	Moderate	Low	1 - 2	√			
LSI Logic L64500	now		TBD	900k	√			
UTMC 1750A	now		TBD	750k	√			
MACDAC 281	TBD		TBD	600k	√			
Fairchild F9450	Now		TBD	700K	√			
Mikros M2750	Future		TBD	High	√			Lowest
TISLC 1750A	TBD	High	TBD	High				
PACE II 1750A	Near Term			3.5 MIPS at 40M Hz				
CDC 444 1750 CMOS DOS	Near Term			3 - 4 MIPS				

FIGURE 3.2-1. TECHNOLOGY MATRIX - 1750 PROCESSORS

3.3 COMPUTER LANGUAGES

Nine criteria were examined in selection of the software language to be used in the GBT, Vehicle, and ground Checkout facilities. Figure 3.3-1 summarizes these results. Ada was chosen with "C" selected for use in special test equipment and small simulations until software and tools become available in Ada.

	Compatability	Availability	Risk	Cost	PERFORMANCE		USE			Rating
					Speed	Lines of Code		Ground	Lab	
Ada	Excellent	Now	Low	Low	Very Good	Low		√	√	Excellent
Jovial	Good	Now	Low	Moderate	Good	Low				Good
HAL/S	Poor	Now	Low	Moderate	Very Good	Low				Acceptable
Assembly	Good	Now	Low	Very High	Excellent	Highest		√	√	Acceptable
"C"		Now	Low	Low	Good	Low			√	Excellent
Fortran	Very Good	Now		High	Good	Moderate		√	√	Good
Goal	Poor	Now	Low	High	Moderate	Moderate		√	√	Acceptable
Dist. Ada	TBD	Near	Low	Lowest	Excellent	Low		√	√	Very Good

FIGURE 3.3-1. TECHNOLOGY MATRIX - COMPUTER LANGUAGES

3.4 FLIGHT CONTROL ACTUATORS

The large Thrust Vector Control, (TVC) actuators proved to be the major area of concern in the developing area of Flight Control Actuators. Mid and Far Term vehicles will employ significantly more engines. The five primary ascent engines of the Shuttle will give way to clustered engine configurations using 14 to 20 engines on some future applications. The impact to ground processing and maintenance look to be intolerable if hydraulic actuators are retained. Electromechanical and Hyrostatic actuators present a better potential. Large EMAs, of the 50+ Horsepower range required, are still in development. Though control system design is adequate, development is needed in the power supply and distribution system areas. Figure 3.4-1 shows the three types of actuators investigated.

Recommendations included the retention of hydraulic actuators on near-term vehicles that still had relatively few engines. Design provisions should be made, even on these vehicles, for replacement with EMAs in the future. Emphasis on EMA and ancillary system development was felt to be imperative in light of the potential savings in maintenance, production and ground operations costs. Performance gains were felt possible, particularly in reusable, clustered engine configurations. Here the potential weight savings and increases in system reliability are significant.

	Compatability	Availability	Risk	Cost	Performance	Rating
HYDRAULICS	EXCELLENT	NOW	LOW	LOWEST	GOOD	BETTER
ELECTROMECHANICAL	POOR	NEAR*	HIGH	HIGHER	GOOD	GOOD
ELECTROHYDROSTATIC	POOR	NEAR*	HIGH	HIGHEST	GOOD	GOOD

*LABORATORY PROTOTYPE MODELS

	HYDRAULIC	EMA	EHA
NEAR/INITIAL	◊		◊
INTERIM	◊		◊
FAR TERM	◊	◊	
GROUND USE	◊	◊	◊
TEST LAB	◊	◊	◊

FIGURE 3.4-1. TECHNOLOGY MATRIX: ACTUATORS

3.5 VEHICLE POWER

The HLCV short duration missions seemed to dictate from the start that batteries rather than fuel cells would be the logical choice. A number of batteries were examined, along with a generic fuel cell, for near and far term applications. Figure 3.5-1 shows the general results. The analysis pointed to Lithium Thionyl Chloride as the best primary battery with Zinc Silver as a good back-up source. Fuel cells were shown to become more viable on long duration missions.

Power Distribution System designs were also explored. High and low voltage DC systems were compared with AC systems whose frequencies ranged from 400Hz to 20KHz. The standard 28VDC system was shown adequate for near term designs. When EMAs are integrated into the HLCV era vehicles, a complete in depth reappraisal must be done.

Bottom line architectural decisions emphasized a modular approach at all levels. Phase 1 hardware includes a half filled Primary Processor, limited Avionics Hardware testbed capabilities and a full up G&N lab. The open architecture and modularity of the GBT permits an orderly upgrade of capability phase to phase.

	Compatability	Availability	Risk	Cost	Performance	USE Air	Ground	Lab	Rating
Li/SIOCl2	Good	Near	Low	Low	Excellent	√			Excellent
Li/SO2	Good	Now	Moderate	High	Very Good	√			Good
Zn/AGO	Good	Now	Low	High	Good	√			Good
Li/V205	Good	Now			Good	√			Acceptable
Ma/MNO2	Good	Now	High		Moderate	√			Poor
Zn/HGO	Good	Now	TBD	High	Moderate	√			Acceptable
Zn/MnO2	Good	Now	Low	High	Low	√			Acceptable
Ni/Cl	Good	Now	Very Low	High	Low	√			Low
Li/FeCl3	Good	Now			Very Low	√			Poor

FIGURE 3.5-1. TECHNOLOGY MATRIX: POWER GENERATION

3.6 LAB ARCHITECTURE

The GBT software and hardware architectures evolved from the functional requirements, GDSS base of experience and selected analysis of available hardware and software. Figure 3.6-1 summarizes the GBT functions. The architecture must accommodate these functions in harmony with the GBT philosophy and objectives.

Volume II contains a series of trades and/or analysis on each major GBT functional element. These analysis included a recommended level of simulation fidelity and discussed a phased implementation of the Target capability. Software and hardware issues were addressed.

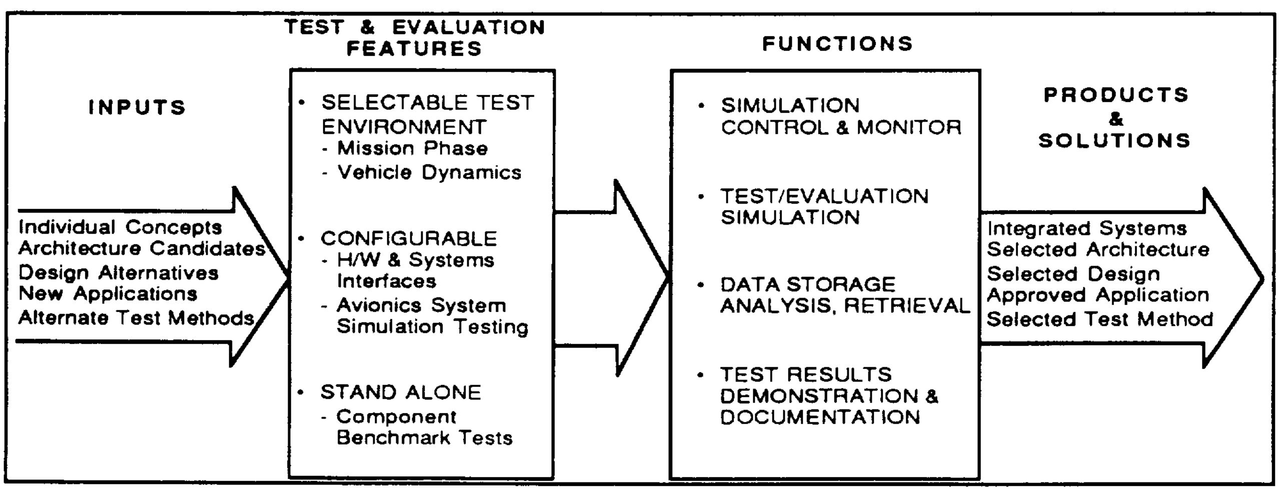


FIGURE 3.6-1. GBT FUNCTIONS

3.7 DATA BUSES & HIGH SPEED NETWORKS

Closed-loop, real time, high fidelity simulations are basic to GBT success. The proper selection of data bussed and high speed networks for data transfer and sharing between GBT elements not only required establishment of throughput but also a survey of currently available products. Volume II Section 2 covers this study. Figure 3.7-1 shows the four basic types of busses in the GBT. Phase 1 bus selection includes 1553 for the vehicle bus, Pronet 80 for the communications and control bus and VME Bus for the DMA bus.

VEHICLE BUS

FUNCTION - Simulates Vehicle Systems and Maintenance Bus Traffic/Operations
- 1553 - 1 MBS
- 1773 FIBER-OPTIC - 1 MB/S
- FUTURE BUSSES-- HSDB , ETC 50 MB/s

•INSTRUMENTATION BUS

FUNCTION - Simulates Vehicle Instrumentation and Sensor Busses
- Speed - 1-100 MB/S

COMMUNICATION & CONTROL BUS

FUNCTION - Data Transfer and Simulation Control
- Speed - 80 MB/S

HIGH SPEED / DMA BUS

FUNCTION - Processor to Processor Data Sharing
- Speed - Processor Dependent (2.5 GB/s - Butterfly)

FIGURE 3.7-1. GBL BUS CLASSIFICATIONS

3.8 GBT MAIN PROCESSOR TECHNICAL DEMONSTRATION

With the shift of emphasis to design of the GBT, selection of the primary lab processor took on added importance. The scope of the trade study used to determine the performance characteristics of this unit and the attendant survey of potential vendors required a special effort. A technical demonstration was conceived that would permit a performance comparison of those processors and their software tools thought capable of fulfilling the basic requirements. The test would involve tasks similar to those planned for the GBT and use programs supplied by both the customer and GDSS.

The initial selection process of potential processors considered about 20 candidates. Figure 3.8-1 shows some of the selection criteria and the candidates that fulfilled the criteria. The "paper study" was followed up with a hand-to-hand performance comparison. Three benchmarks were selected to evaluate the processors and their attendant software tools. The first benchmark was from MSFC and was a mature Fortran coded model of the SSME. The second was provided by GDSS and was a modular model of the ALS avionics system coded in "C". The third benchmarks were industry standards chosen by the participants.

The final phase of the tech demo has been extended to include two additional processors for evaluation. Current results are found in Volume II Section 5.

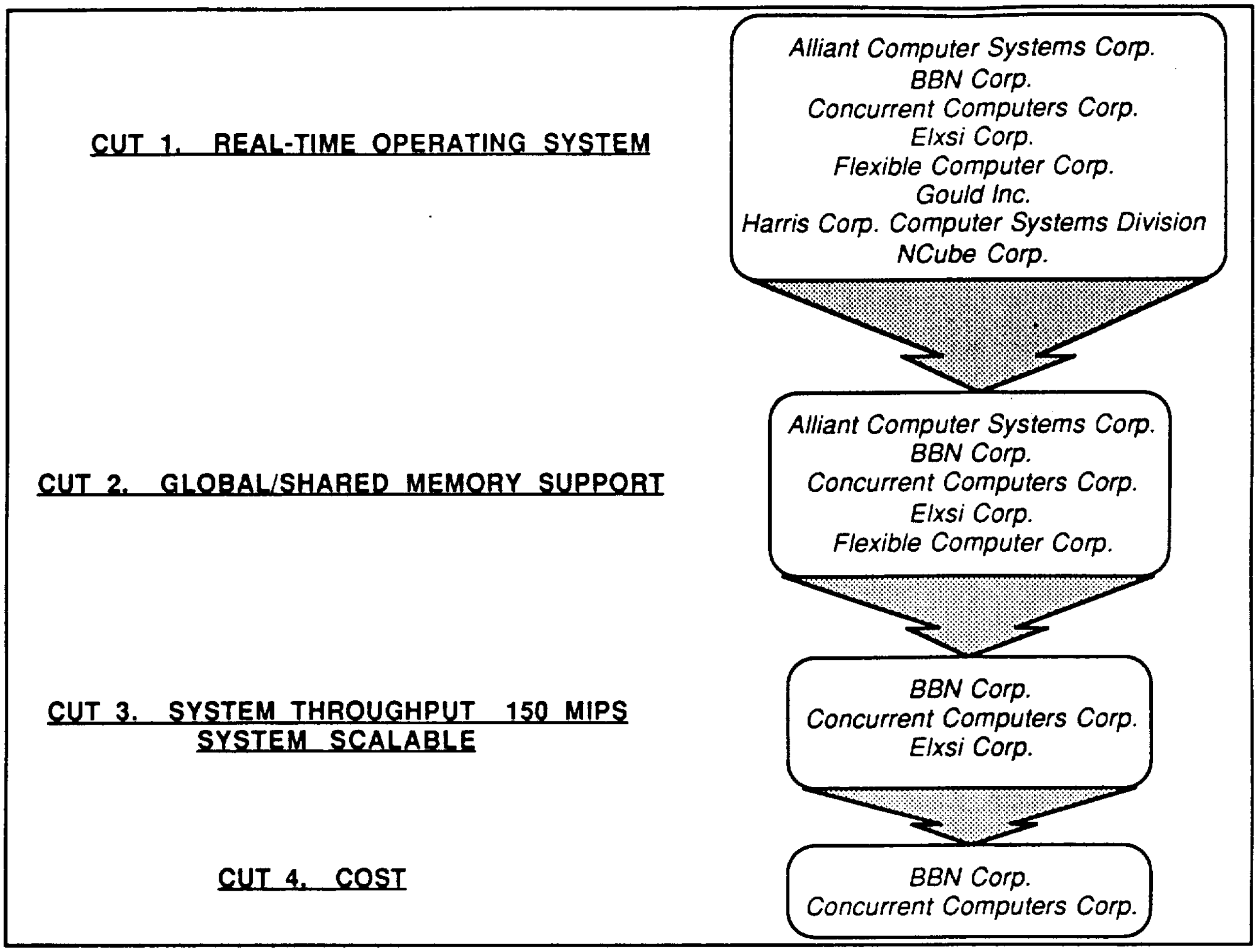


FIGURE 3.8-1.

4.0 GBT FUNCTIONAL REQUIREMENTS

The requirements to which the GBT must respond fall into three general categories: Program driven requirements include such things as vehicle dynamics, mission profile/timelines and vehicle avionic system architecture. The second general category,Technology driven requirements, include design problem areas that are not meeting performance criteria or are limiting system efficiency or upgrade. The last general category of functional requirements is Facility/Resource driven requirements. These requirements are related more to the physical aspects of the test facility itself and the limitations of the resource equipment used in testing.

4.1 PROGRAM DRIVEN REQUIREMENTS

The GBT was conceived to provide support to new vehicle/spacecraft programs primarily before their respective Preliminary Design Reviews, (PDRs), or when the nature of the required support was beyond the capabilities of their local, dedicated facilities. Figure 4.1-1 outlines some of the requirements associated with these vehicles and their mission profiles. Figure 4.1-2 highlights some of the program driven issues to be discussed in later sections.

4.1.1 PHASE 1 (STV, SHUTTLE C, SDV 2ES)

The HLCV expendable booster, (SDV-2ES), Shuttle-C, and Space Transfer Vehicle developmental programs are the basis for the Phase 1 GBT functional requirements. As was shown in Figure 1.2-2, the Initial Operational Capability, (IOC), of the GBT is currently set for August 1990. The Shuttle-C was agreed upon to serve as the forcing function for the Phase 1 lab. The functional block diagram for this three-string avionics system is shown in Figure 4.1.1-1.

Vehicle	Shuttle C	ALS Core	ALS LRB	FRWB
Reusability	SRB's	None	BRM	Full Reuse
IOC	1995	1998	1998	2002
Engines	3 + 2 SRB	3	7	6 + 6 A/B
Man Rating	TBD	0.99981	0.99995	TBD
Reliability	Cargo carrier Prox OPS & De-orbit	Deorbit to ocean. FO/FS Manned Cargo	Sub-orbital FO/FS Manned Cargo	Return & Landing FO/FS Manned Cargo
Max Mission Duration	6-1/2 hours plus s.s ops	Core de-orbit T + 98 min.	T + 162 seconds	Less than 1 hour
Mission/Year	Few	Many	Many	Many
Number of Vehicles	Moderate	Many	Many	Few
Integrated Systems	Separate LPS, GSE Prod C/O	UNIS for Integrated Data	UNIS	UNIS
Launch Processing	LPS	Expert System App	Expert Systems App.	Near Autonomous
P/L and Vehicle I/F's	Shuttle Bay Interface	None	None	None
Vehicle Management	Central computers O.S Command Uplink	Mission manager Expert Systems	Controlled from Core	Near Autonomous Manual Backup
Rendezvous & Docking	OMV Assisted	None	None	None
Data Flow	TBD Fairly low rate	GN&C 3 - <1 MBPS Instru 1 - 256 KBPS	Interface to Core	GN&C 3 - <10 MBPS Instru 1 - 320 KBPS
Processing	300 KOPS	GN&C 3 - 3 MIPS Propulsion 3 - 1 MIPS Instru 1 - 3 MIPS Miscellaneous < 1 MIPS	Share core GN&C Propulsion 7 - 1 MIPS Share core Instru Miscellaneous <1 MIPS	GN&C 3 - 6 MIPS Propulsion 6 - 1 MIPS Instru 1 - 3 MIPS Imaging 10 MIPS Miscellaneous <2 MIPS

FIGURE 4.1-1 HLCV AVIONICS REQUIREMENTS

Its accompanying Design Reference Missions (DRMs), are shown in Figure 5.1.1-2 These DRMs must be considered when building the software environmental and vehicle models.

4.1.2 PHASE 2 (ALS CORE, ALS BOOSTER, SDV 2RS)

The Phase 2 IOC is set for August 1992. The Phase 2 GBT support capabilities will be extended to include the ALS Core and Booster, SDV-2RS, and the upgraded Shuttle-C. Since the ALS Core and Booster closely fit the SDV-2RS functional requirements, they were chosen for the reference vehicles for the Phase 2 GBT. Figure 4.1.2-1 through 4.1.2-3 show the ALS Core and Booster avionics systems and the associated vehicle processing requirements. Figure 4.1.2-4 associates the ALS Core throughput requirements with its design reference mission timeline.

- VEHICLES
  - PERFORM AVIONICS ANALYSIS/SIMULATION TO VERIFY RE-TEST AND RE-USE CAPABILITY OF FRWB AND BRM MULTI-MISSION AVIONICS
- LAUNCH PROCESSING AND VEHICLE MANAGEMENT
  - PROVIDE THE PROCESSING THROUGHPUT AND MEMORY CAPACITY FOR EXPERT SYSTEM APPLICATION DEVELOPMENT OF BOTH LAUNCH PROCESSING AND ON-BOARD MISSION MANAGER
- RENDEZVOUS AND DOCKING
  - PROVIDE A 3D DISPLAY PROCESSING CAPABILITY FOR SHUTTLE C CARGO CARRIER/ OMV/ SPACE STATION. PROVIDE A FUTURE CAPABILITY IF ALS CORE DEVELOPS THIS TYPE OF MISSION
- IOC
  - 1994 SHUTTLE C PROVIDE PROVISIONS FOR SIMULATING MODIFICATIONS TO EXISTING HARDWARE AND SOFTWARE
  - 1997 ALS REQUIRES EXPENDABLE CAPABILITY AS ALS SOFTWARE IS EXPANDED
  - 2000 FRWB WIDE CAPABILITY
- MAN RATING
  - SHUTTLE C CARGO CARRIER FO/FS FOR SPACE STATION PROXIMITY OPERATIONS. DIFFERENT CARGO CARRIER FOR INJECTION MISSIONS?
  - ALS CORE FO FOR DE-ORBIT, FO/FS FOR MANNED CARGO
  - FRWB FO/FS FOR FLYBACK AND LANDING. FO/FS FOR MANNED CARGO
  - HLCV GBT SIMULATE REDUNDANCY PROVISIONS TO MEET ABOVE GOALS
- ENGINE SYSTEM INTEGRATION
  - 3 SHUTTLE C, 10 TO 14 ALS FUTURE SYSTEMS
  - TVC ENGINE CONTROL INTEGRATION (~1 MIPS PER ENGINE)
  - SIMULATE ARCHITECTURE PARTITIONING FOR BRM RECOVERABLE AVIONICS

FIGURE 4.1-2 PROGRAM DRIVEN ISSUES

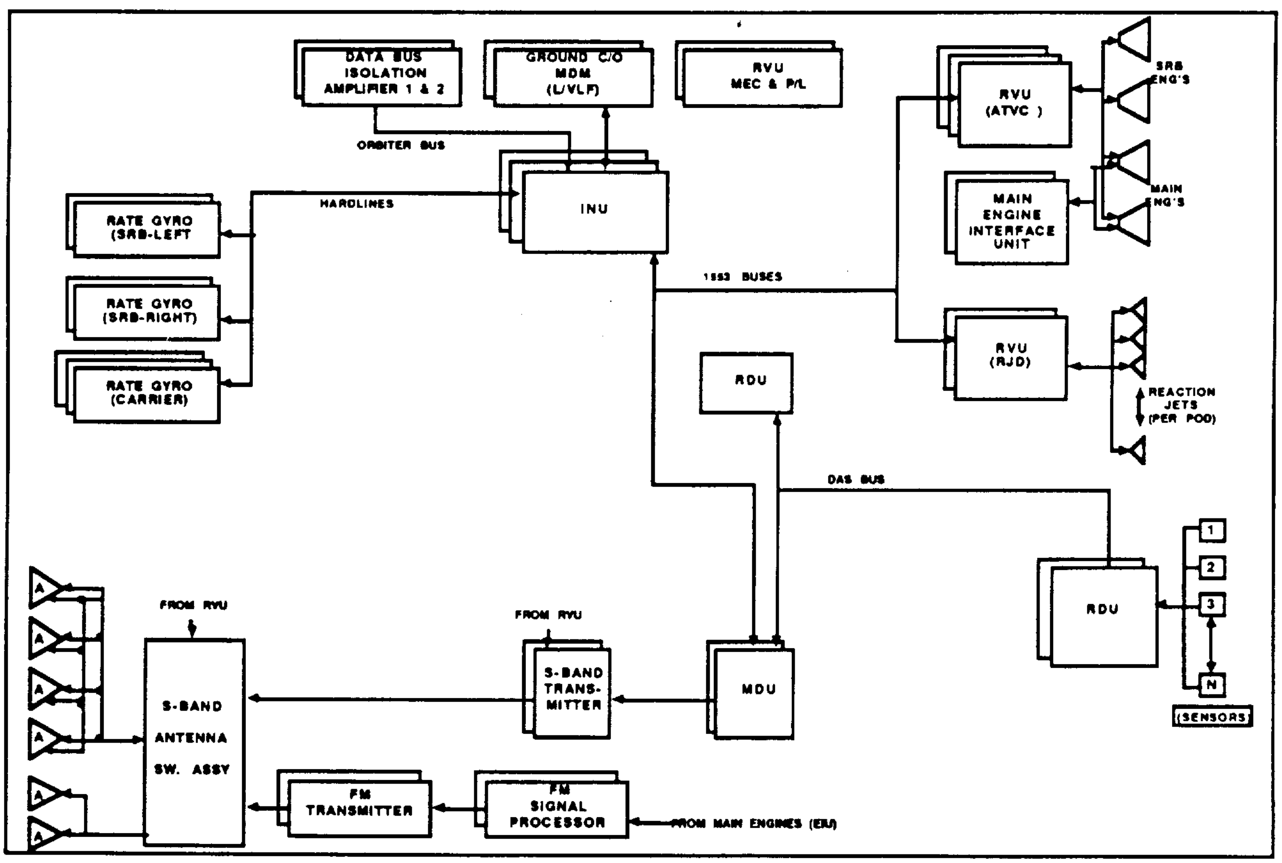


FIGURE 4.1.1-1. GBT PHASE 1 SHUTTLE-C AVIONICS BASELINE

DISCRIMINATING CHARACTERISTICS	DESIGN REFERENCE MISSIONS (DRM'S)			PERFORMANCE REFERENCE MISSIONS (PRM'S)	
	(1) UNMANNED SPACE STATION ASSY W/OMV	(2) ORBITAL DEPLOY	(3) SUB-ORBITAL DEPLOY	(1) POLAR LAUNCH FROM ETR	(2) POLAR LAUNCH FROM WTR
LAUNCH SITE	ETR	ETR	ETR	ETR	WTR
SECURE	NO	POSSIBLY	POSSIBLY	POSSIBLY	YES
INCLINATION	28.5'	28.5'-63.5'	28.5'	98.7'	98.7'
RENDEZVOUS & PROX OPS	YES	NO	NO	NO	NO
REFERENCE ALTITUDE	220 nmi	110 nmi	≥ 100 nmi	100 nmi	100 nmi
DOCK/BERTH	YES	NO	NO	NO	NO
ON-ORBIT STAY TIME	APPROX. 14 DAYS	1 DAY	UNSPECIFIED	≤2-1/2 HR	≤2-1/2 HR
CIRCULARIZATION	YES	YES	NO	YES	YES
PAYLOAD DEPLOYED	NO	YES	YES	YES	YES
PAYLOAD EXTRACTED	YES	NO	NO	NO	NO
MANNED PRESENCE	YES	NO	NO	NO	NO
MIXED CARGO	YES	POSSIBLY	NO	POSSIBLY	POSSIBLY
OMV	YES	POSSIBLY	NO	NO	NO
MINIMUM INJECTED WEIGHT @ REFERENCE ALTITUDE	100,000 LB	80,000 LB	100,000 LB	TBD	TBD
INSERTION	DIRECT	STANDARD	SUBORBITAL	UPSPECIFIED	UNSPECIFIED

FIGURE 4.1.1-2. SHUTTLE C MISSION REFERENCES

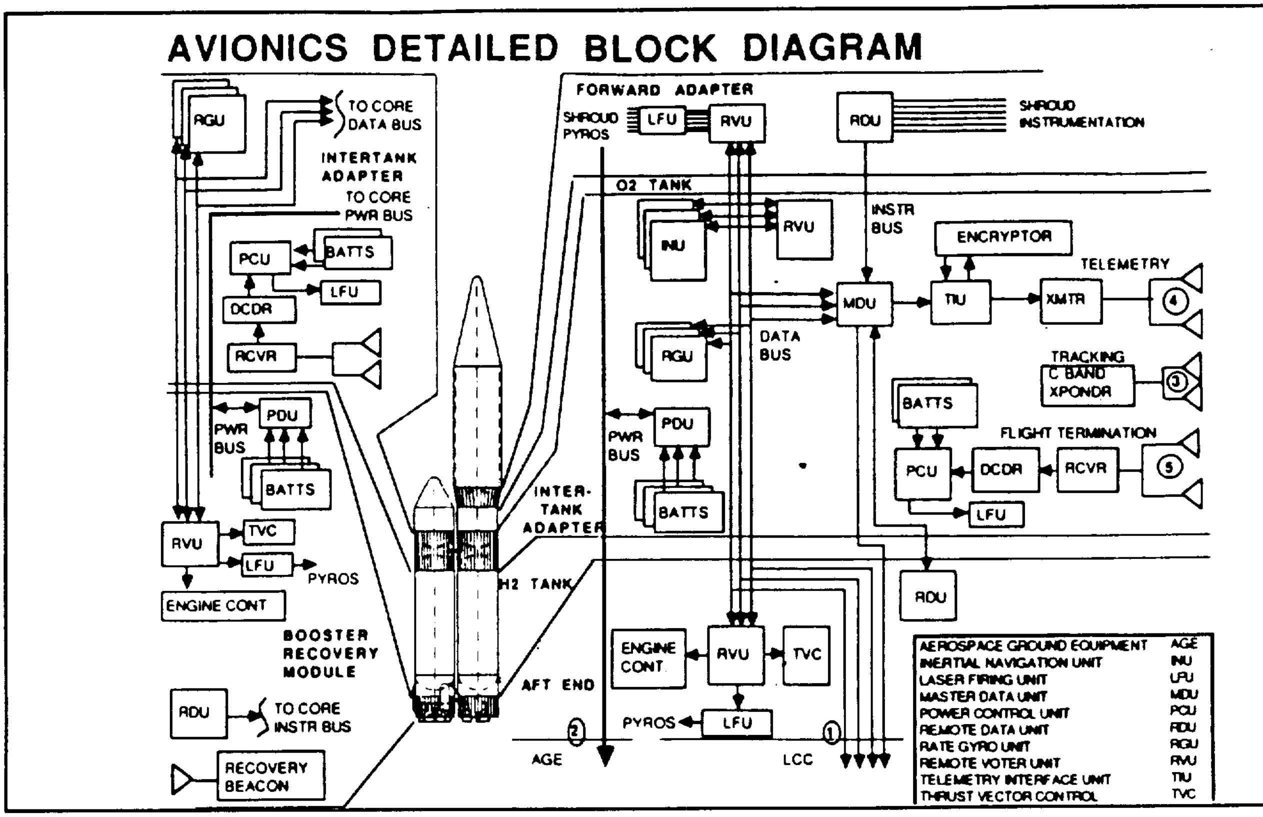


FIGURE 4.1.2-1 ALS AVIONICS & POWER SYSTEMS

ALS CORE

SUBSYSTEM (WITH HEALTH MONITORING)	WITH LIMITED EXPERT SYSTEMS			
	THRUPUT (MIPS)	TOTAL MEMORY (MBYTES)	I/O DATA RATE (MBPS)	I/O DEVICES (QUANTITY)
PROPULSION	3 (IMIPS/ENG)	0.288	0.375	819
FLUIDS	<0.1	<0.1	0.216	241
POWER	<0.1	<0.1	<0.01	100
# INSTRUMENTATION	<3	<0.002	0.256	1500
GN&C (ADAPTIVE)	4.063	0.988	0.153	600
SYSTEMS SOFTWARE	0.21	0.59	--	--
COMMUNICATIONS	<0.1	<0.1	<0.01	100
VEHICLE ELEMENT INTERFACE	<0.1	<0.1	0.072	262
TOTAL	10.47	2.06	1.09	3622
SHUTTLE COMPARISON	0.343	0.42	NA	~4000

INCLUDES SENSOR PROCESSING NOT COVERED UNDER THE OTHER SUBSYSTEMS.

NOTE: REDUNDANCY INCLUDED ONLY WHERE KNOWN (E.G., PROPULSION)

NOTE: THE PROCESSING REQUIREMENTS DO NOT INCLUDE ANY ALLOWANCE FOR MARGIN, OR FAILURE TOLERANCE. (EXCEPT FOR PROPULSION)

FIGURE 4.1.2-2 ALS CORE PROCESSING REQUIREMENTS

ALS LRB

SUBSYSTEM (WITH HEALTH MONITORING)	WITH LIMITED EXPERT SYSTEMS			
	THRUPUT (MIPS)	TOTAL MEMORY (MBYTES)	I/O DATA RATE (MBPS)	I/O DEVICES (QUANTITY)
PROPULSION	7 (IMIPS/ENG)	0.672	0.875	1911
FLUIDS	--	--	0.216	241
POWER	--	--	<0.01	75
# INSTRUMENTATION	--	--	0.100	750
GN&C (ADAPTIVE)	--	--	0.153	300
SYSTEMS SOFTWARE	0.10	0.20	--	--
COMMUNICATIONS	--	--	--	--
VEHICLE ELEMENT INTERFACE	<0.1	<0.1	0.072	262
TOTAL	7.2	0.972	1.426	3539
SHUTTLE COMPARISON	0.343	0.42	NA	~4000

INCLUDES SENSOR INTERFACING NOT COVERED UNDER THE OTHER SUBSYSTEMS.

NOTE: REDUNDANCY INCLUDED ONLY WHERE KNOWN (E.G., PROPULSION)

NOTE: THE PROCESSING REQUIREMENTS DO NOT INCLUDE ANY ALLOWANCE FOR MARGIN, OR FAILURE TOLERANCE. (EXCEPT FOR PROPULSION)

FIGURE 4.1.2-3 ALS LRB PROCESSING REQUIREMENTS

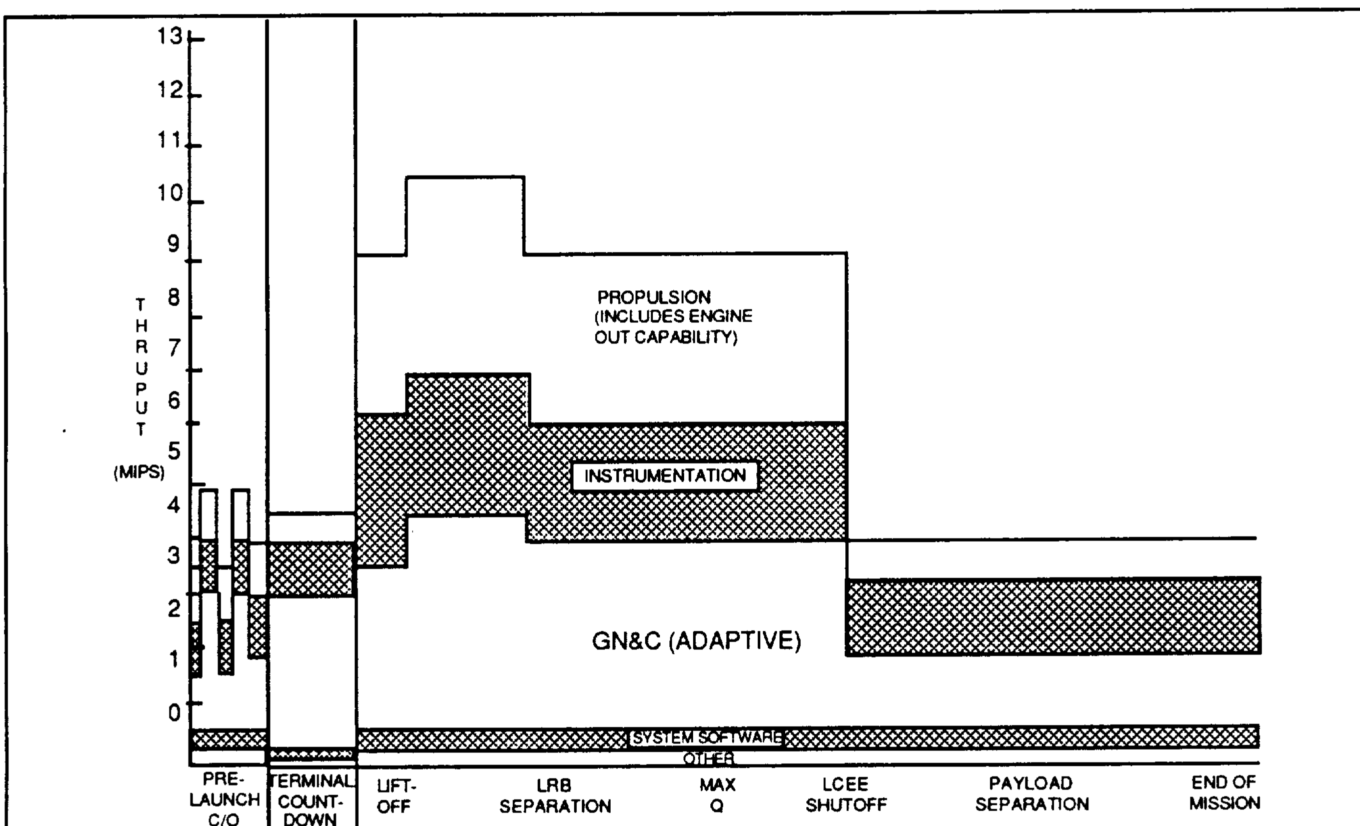


FIGURE 4.1.2-4 ALS THROUGH-PUT REQUIREMENTS

4.1.3 Target (FRWB, FRWB, PRCV)

The Phase 3 or Target configuration IOC has not been set, but if it is tied to the Fully Recoverable Wing Booster (FRWB), and the Partially Reusable Cargo Vehicle (PRCV) programs, it should be in 1996 to 1998.

Figure 4.1.3-1 outlines the Processing Requirements for the FRWB while Figure 4.1.3-2 associates the throughput requirements with the FRWB mission timeline. The FRWB avionics system is designed to be fully autonomous from launch to landing and roll out. The GBTs capability to support FRWB and PRCV development must start long before the 1996-1998 IOC. The GBT functions must include FRWB/PRCV related inputs in both Phase 1 and Phase 2. Typical of these inputs are:

(1) Electromechanical Actuator applications in vehicle aero control and Thrust Vector Control systems;

(2) Redundancy Management using Expert Systems and a distributed processing system; and

(3) An autonomous, robust GN&C system capable of near all-weather launches and minimum tailoring of software mission to mission.

These technology driven requirements are discussed in the next section.

FULLY REUSABLE WINGED BOOSTER (FRWB)

SUBSYSTEM (WITH HEALTH MONITORING)	WITH LIMITED EXPERT SYSTEMS			
	THRUPUT (MIPS)	TOTAL MEMORY (MBYTES)	I/O DATA RATE (MBPS)	I/O DEVICES (QUANTITY)
*PROPULSION	6 (IMIPS/ENG)	1.152	06	3264
FLUIDS	<0.1	<0.1	0.32	380
POWER	<0.1	<0.1	<0.01	180
# INSTRUMENTATION	<3	0.0048	0.320	4000
GN&C (ADAPTIVE)	5.199	1.264	0.394	1225
SYSTEMS SOFTWARE	0.24	0.79	--	--
COMMUNICATIONS	<0.1	<0.1	<0.01	120
VEHICLE ELEMENT INTERFACE	<0.1	<0.1	0.0256	5
TOTAL	14.64	3.42	1.67	9174
SHUTTLE COMPARISON	0.343	0.42	NA	~4000

* PROCESSING IS TIME SHARED BETWEEN BOOSTER ENGINES AND AIR BREATING ENGINES.
# INCLUDES SENSOR PROCESSING NOT COVERED UNDER OTHER SUBSYSTEMS.
NOTE: REDUNDANCY INCLUDED ONLY WHERE KNOWN (E.G., PROPULSION).

NOTE: THE PROCESSING REQUIREMENTS DO NOT INCLUDE ANY ALLOWANCE FOR MARGIN, OR FAILURE TOLERANCE (EXCEPT FOR PROPULSION).
NOTE: THE PROCESSING REQUIREMENTS DO NOT INCLUDE THE IMAGING SENSOR PECULIAR PROCESSING WHICH IS ASSUMED TO BE SELF CONTAINED.

FIGURE 4.1.3-1. FRWB PROCESSING REQUIREMENTS

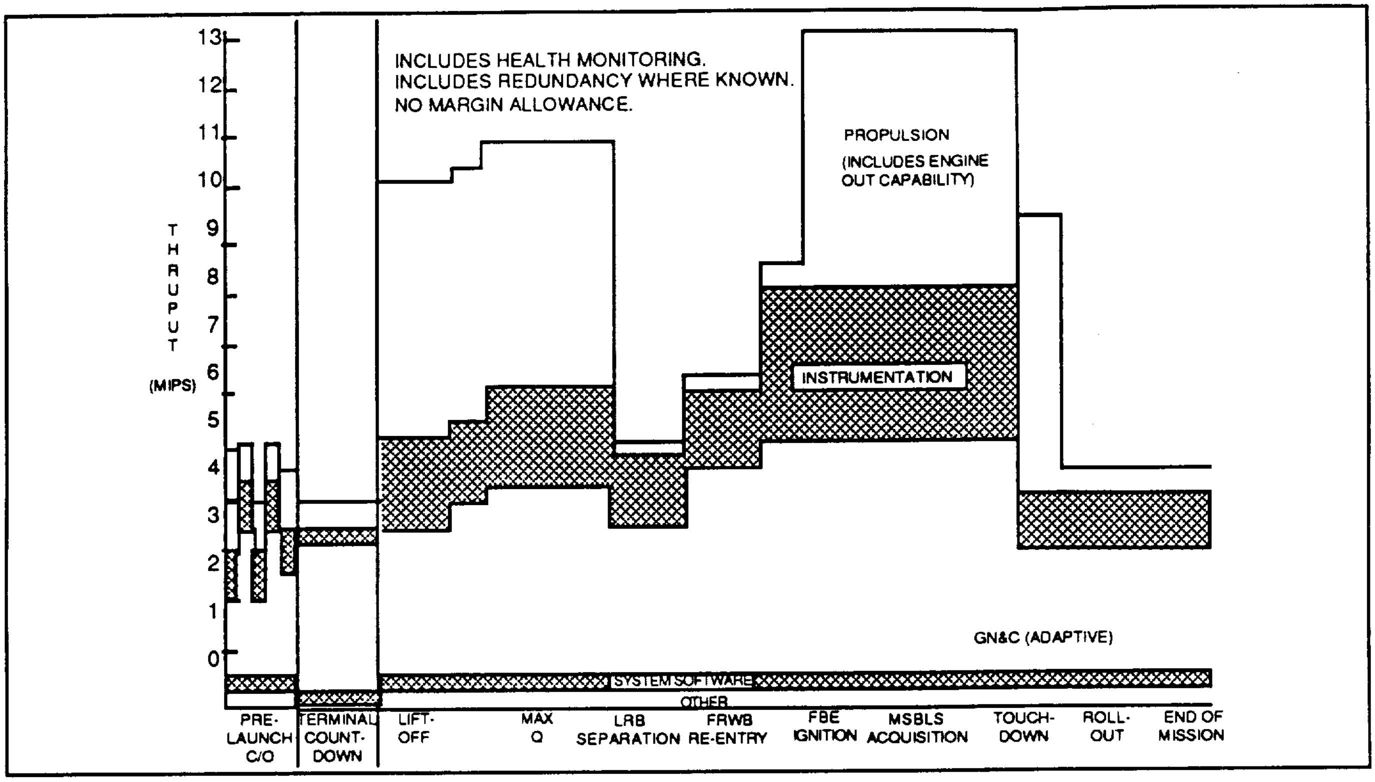


FIGURE 4.1.3-2. FRWB THROUGH-PUT REQUIREMENTS

4.2 TECHNOLOGY DRIVEN REQUIREMENTS

Several pacing technologies were investigated during the initial stages of this study. Each was associated with their specific application on the HLCV era avionics systems and prioritized as to their role in achieving the design goals. The following paragraphs show the impact on the GBT design.

4.2.1 SYSTEM ARCHITECTURES/REDUNDANCY MANAGEMENT

One of the most fundamental drivers of the GBT processing/throughput requirements involves the basic vehicle architectures to be simulated and the operational environment in which they must be tested. The basic Phase 1 through the complex Target GBT configuration had to be sized to full-up, end-to-end, real-time vehicle system simulations. This translates into a throughput requirement for the lab of about 150 million instructions per second (MIPS) for the Phase 2 GBT. The processor assigned to model the system architecture had to be able to model a parallel, distributed, multi-string system; duplicate the redundancy management logic of that system and be able to monitor, control and provide external stimuli to the system under test. The FRWB avionics system is fully autonomous and, therefore, includes Integrated Health Monitoring (IHM), and a high precision launch to launch GN&C system that may incorporate a multi-spectral Image Processing System. Much of the traditional GSE functions will be performed by the FRWB system. All these factors will drive the GBT throughput and parallel processing capacity well beyond the 150 MIPS of the Phase 2 lab. This mandates a main processing capacity which can be expanded incrementally without having to replace the original equipment.

4.2.2 POWER DISTRIBUTION, CONDITIONING AND MANAGEMENT

The HLCV era vehicles are required to perform over a wide ranging series of missions that last from 90 minutes to several months. The reliability required of the supporting power systems plus the new demands of cost effectiveness have driven a re-examination of traditional solutions and a search for new designs. The increasing demand for power by electromechanical actuators and the new designs being utilized in their attendant power supplies have elevated this once stable design area into new activity. The GBT power extension will be able to evaluate alternate power sources (batteries, fuel cells and solar cells), power distribution system architectures, redundancy management schemes, and different methods of power conditioning and management.

4.2.3 ELECTRO MECHANICAL ACTUATORS

The clustered rocket engines of many of the HLCV vehicles have accelerated development of fast response high power (> 50 hp) electromechanical actuators. The HLCV GBT will support this effort in Phase 2. Development will be in the power supply design as well as that of the basic actuator.

The integration of actuator development and testing in the total vehicle development program involves several areas. The end-to-end testing would, in its highest fidelity mode, require the actuator under test to be dynamically loaded. This loading would be controlled in part by inputs from the missions environmental and vehicle dynamic models. The dynamic load cell and its attendant support equipment could represent a prohibitively high investment. Use of existing or dedicated actuator labs may prove the most cost effective method of providing this resource. A high data rate, broadband data link to the GBT could be used in closed loop testing. EMA power supply development could be accommodated in the GBT Power Systems extension.

4.2.4 ADAPTIVE GUIDANCE, NAVIGATION & CONTROL

HLCV traffic models force a more robust launch capability. Not only do vehicles have to be easy to process and launch, they must be strong enough and smart enough to handle less favorable environmental conditions. Supporting Adaptive Guidance, Navigation & Control would include everything from concept evaluation through sensor design testing. Primary impact of this technology support by the GBT would be in the area of software development, and attendant processor capacity and flexibility. Special software analysis tools will be required in the investigation of various load relief concepts, sensor applications and vehicle dynamic control modeling.

4.2.5 IMAGE PROCESSING

The application of image processing to HLCV functions seems particularly attractive in the areas of rendezvous & docking and approach & landing. The delays and subsequent risks involved in the remote docking techniques used in OMV can be potentially mitigated with a "smart" docking system. Such a system could be used on the STV or retrofitted on the OMV. Use of image processing to detect/identify the target, its range and orientation are well within current state-of-the-art capabilities. Application in the FRWB approach & landing functions is another application to be investigated.

Impact to the GBT design would include software tools required for high fidelity 3D Target modeling and animation. Hardware requirements would include prototype sensors, TV camera, large, high resolution graphic monitor and an image processing workstation.

5.0 GBT IMPLEMENTATION PLANNING

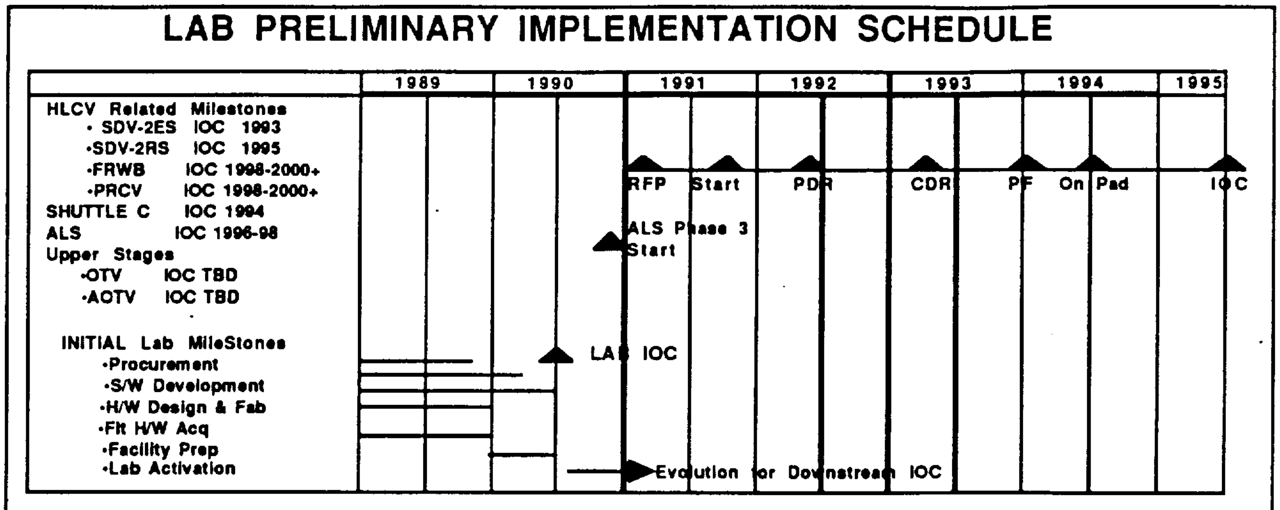
From the beginning, it was recognized that the Ground Based Test beds capabilities would be tied to meeting current program system testing requirements. The GBTs role was to encompass vehicle simulation and testing needs from inception to the Preliminary Design Review (PDR). Looking at the projected vehicle developmental schedules, it was all too clear that the first operational GBT capabilities would have to be focused on the critical developmental problems. If vehicles like the Shuttle C or STV were to be supported prior to their PDRs the GBT must be at least operational by August 1990. Basic avionic system architectural issues would have to be addressed first. The initial GBT would have to provide high fidelity, precision guidance & navigation simulations that supported evaluation of the several configurations being investigated. This dictated identification of long lead items like the 3-axis table.

Software model development is another key factor in the implementation plan. Fidelity of the vehicle dynamic and system models is critical to establishing the GBT as a valuable program development resource. This usually requires actual hardware being used to develop and verify the fidelity of the respective software models. Availability of similar hardware often proves to be another pacing element.

Accelerating the application of new, useful technologies into current and future programs was another stated goal of the GBT. To this point, all the GBT capabilities were directed at specific problems of specific programs because of time related and money related constraints. The implementation plan has evolved to the point that permits visibility as to how this goal can be realized. First, the basic GBT hardware and software design is modular and thus can be changed easily to accommodate different requirements. The early phases of implementation require the building of a specific number of these basic modules to satisfy a limited number of needs. To satisfy a greater set of requirements relatively few new modules are required.

Figure 5.0-1 shows an early implementation schedule and its assumptions. One of the most difficult problems of the implementation schedule, shown earlier in figure 1.2-2, is the amount of work to be done in the first phase. Between February 1989 and August 1990, over 60% of the total task must be accomplished. This is not consist with the relatively low front end funding guidelines that were provided for this study. Figure 5.0-2 shows this problem graphically.

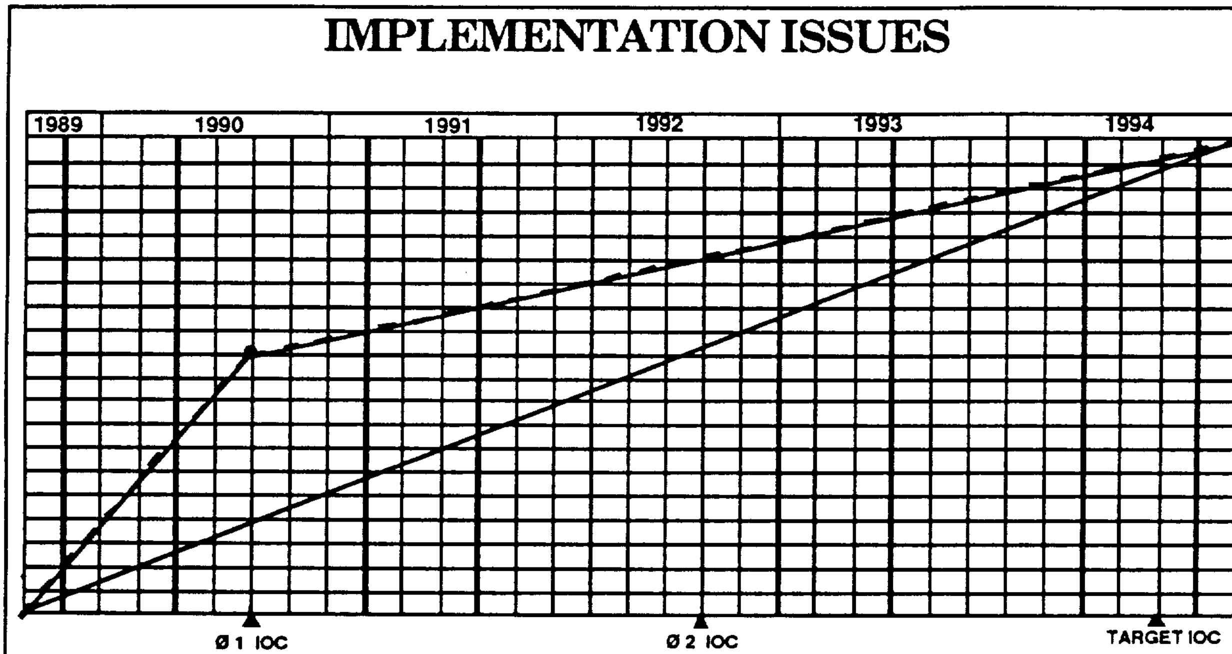
The bottom line for GBT success is being able to supply the most cost effective and useful test facility at the time when new programs need it the most. This implies that the projects are willing to pay their way and plan for such usage initially. This idealistic form of funding must be recognized as supplemental to basic level of funding needed to initially implement and later maintain GBT operations. Internal Research & Development projects are also a source of funding. This type of function typically accelerates the application of useful, new technologies and test concepts upon which later major programs are built.



Lab Program Drivers

- **4 Year Development Cycle**
- **IOC First Launch. Delivery to pad 1 year prior to Launch.**
- **Full Scale Engineering Development Systems Integration Laboratory with Pathfinder Activity**
- **APC Supports Early PDRs**

FIGURE 5.0-1. IMPLEMENTATION PLAN



ISSUES

- SOFTWARE DEVELOPMENT TIME
  - 70% of Target S/W needed by Aug 1990
- HARDWARE ACQUISITION
  - 3 Axis Table requires 1 Year lead time
- FACILITY
  - Site modifications not completed for ø 1

LEGEND

- Projected Funding
- Current Requirements

FIGURE 5.0-2 IMPLEMENTATION ISSUES

6.0 GBT ARCHITECTURE

This section covers both the hardware and software architectures of the GBT. It should be noted that the GBT has been structured to allow for a phased implementation of capabilities. The Target GBT is the full-up, third step configuration. It was designed to support the third HLCV reference configuration. This Fly Back Booster and Partially Reusable Cargo Vehicle must be accommodated in the Target GBT end-to-end real-time simulation.

6.1 HARDWARE CONFIGURATIONS

6.1.1 GBT TARGET CONFIGURATION

The GBT Target Configuration is shown in figure 6.1.1-1. The GBT core has a main processor which is functionally divided into the primary processor and the avionics system simulator.

The primary processor function includes running the simulation of the test vehicle dynamics, the mission environment and all other interfacing elements to the vehicle avionics system.

The avionics system simulation function includes running the simulation of the test vehicle avionics system. This includes the monitor and control of all interfaces to real hardware being tested or run on the Avionics Hardware Test Bench.

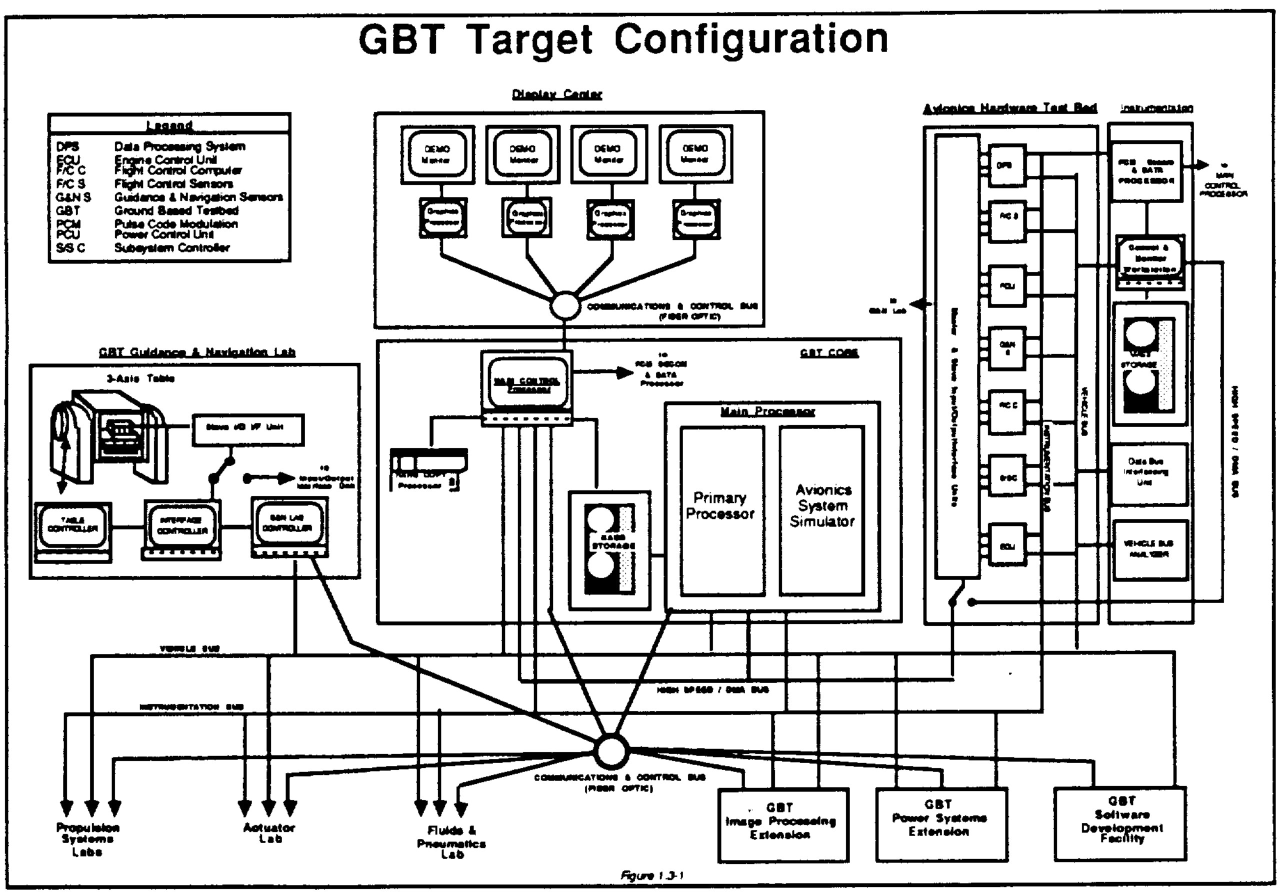


FIGURE 6.1.1-1. GBT TARGET CONFIGURATION

REQUIREMENT: 150 MIPS - For Real Time simulation of HLCV era vehicles

BASIS: EXTRAPOLATION FROM CURRENT SIMULATION

- 6 DOF Flight Trajectory Simulation
  - 96 state variables
  - 20 millisecond Autopilot cycle
  - X10-20 Intercycle
  - 2 NASTRAN modes, Bending mode
  - Autopilot functions, bending modes, distributed aerodynamics, mass distribution updating
- Apollo 3000 Workstation runs non-real time simulation in 10 hours. Real time: 270 seconds (Real time speed up: 133X for identical task)
- Increased Scope of Simulation
  - Add 4 rate gyros
  - Distributed Accelerometers
  - Air data sensors
  - X5 propulsion system interface
  - Adaptive guidance
  - Autoland
- Increase for Growth

FIGURE 6.1-2. CORE PROCESSOR THROUGH-PUT SIZING ENVIRONMENT/VEHICLE DYNAMICS

Core Processing throughput sizing is shown in figure 6.1.1-2. This estimate of processor power and speed was made by extrapolation from a current simulation. A second method based upon sensor input and other system operational parameters came up with a slightly higher figure. An analysis of the scope and nature of the simulation required to yield an end-to-end, real-time simulation of the FRWB and PRCV indicated a minimum rating for the primary processor should be 150 MIPS. Prudent design practice would require a modular architecture in which the processor could be scaled-up to meet the job.

The four other main elements of the GBT core are the Main Control Processor, Mass Storage Unit, Hard Copy Processor and Interconnecting network/buss structure. The Main Control Processor is primarily tasked with the allocation and control of GBT resources. It controls most of the various busses and networks running throughout the GBT and supervises use of the Mass Storage and Hard copy Processor.

The Mass Storage units permits rapid access to the application, development, test and custom software/data. The Hard Copy Processors provide hard copy records of screen displays, system status, or test results.

The Avionics Hardware Test Bed is the second major segment of the GBT Target Configuration. It contains the interfacing units, busses and harnesses necessary to accommodate the GBT Benchmark hardware. The benchmark hardware is a collection of current avionics units which, when connected to the required interfacing harness, comprise a fully functional avionics system.

The Instrumentation segment is a subset of the Avionics hardware test bed that permits local control and monitoring of the test bed hardware or units under test. It functionally duplicities an instrumentation ground station and is equipped to analyze vehicle bus traffic.

The GBT Display Center electronic equipment is shown in part in figure 6.1.1-1. It primarily consists of four graphics processors driving four large screen monitors. The graphics processors are used to develop display and other support type graphics. Working with the large screen monitors, the processors can reproduce demonstration graphics depicting anything from real-time test parameters to reproduction of demonstration graphics. These monitors may be used to supplement the status displays available to the core's main control processor. The graphics processors will also supplement the Main Control Processor in controlling parallel operations going on within the GBT.

The G&N Lab is one of the most important resources available to the GBT. Though capable of fully independent operation, in an acceptance test procedure role, its primary value is in closed-loop simulation of an integrated avionics system. The precision 3-axis table can supply all necessary stimuli, except acceleration, to evaluate the best inertial elements of the HLCV era. The Slave I/O interface box will provide the local real-time interfaces to accommodate such testing.

6.1.2 PHASE 1 CONFIGURATION

The initial Phase 1 GBT configuration is scheduled to be operable in August of 1990. Figure 6.1.2-1 lists several of the support capabilities to be demonstrated at that time. SDV-2ES is the first HLCV reference vehicle and functionally equivalent to Shuttle-C. Its mission profile is depicted in figure 6.1.2-2. Four software mission phase models are required for the Phase 1 IOC. They include Launch, Ascent, Orbital maneuvering and a ballistic type of controlled entry.

Benchmark hardware includes the equivalent of 1 string of the Shuttle-Derived Vehicle avionics system. Limited interface capabilities on the Avionics hardware testbed can accommodate only two "boxes". (This capability will be expanded substantially during Phase 2).

1. **MISSION MODELS - (2DV-2ES)**
   - **Launch**
   - **Ascent**
   - **On Orbit (maneuver)**
   - **Entry**
2. **SYSTEM TEST**
   - **SDV Reference System**
     - **IMU**
     - **Computer**
     - **DAS**
     - **MDU**
     - **RDU**
     - **MDM * Interface only**
     - **EIU * Interface only**
3. **OUTSIDE RESOURCES**
   - **SSME Lab Interface**
   - **EMA (option)**

FIGURE 6.1.2-1. PHASE 1 CAPABILITIES AND CONSTRAINTS

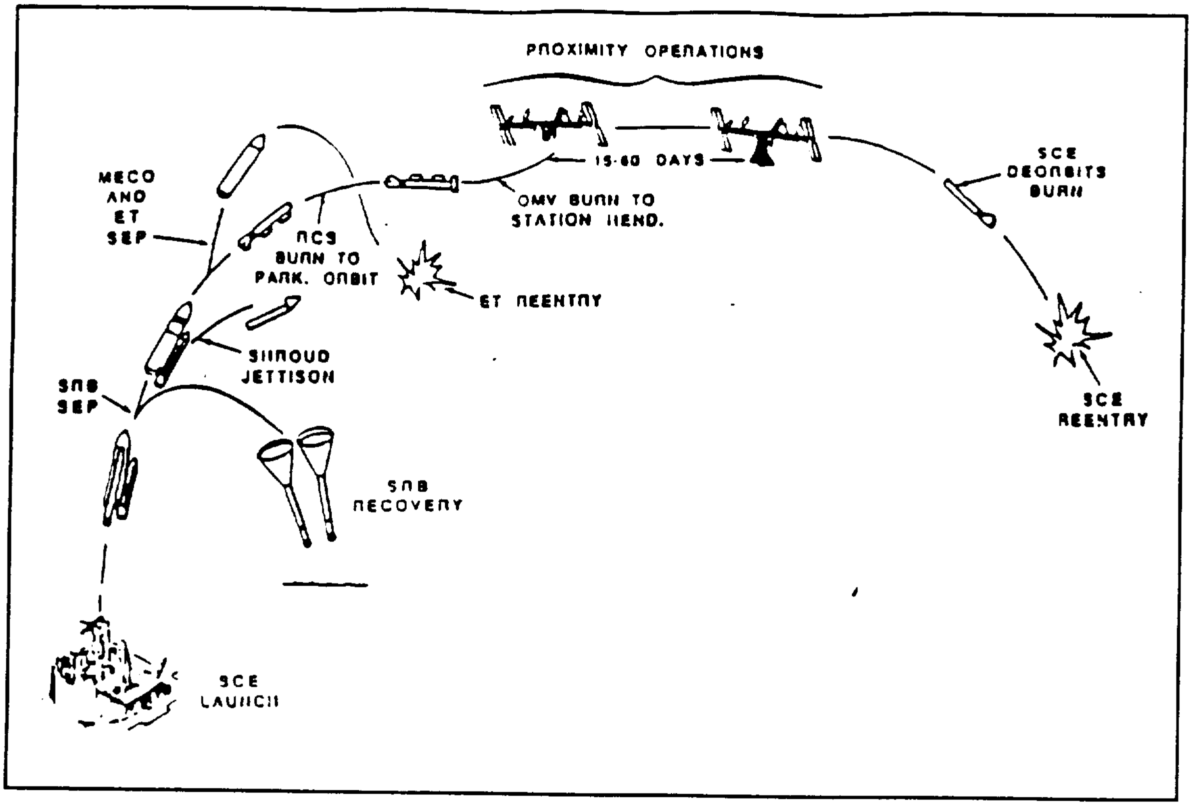


FIGURE 6.1.2-2. MISSION PROFILE

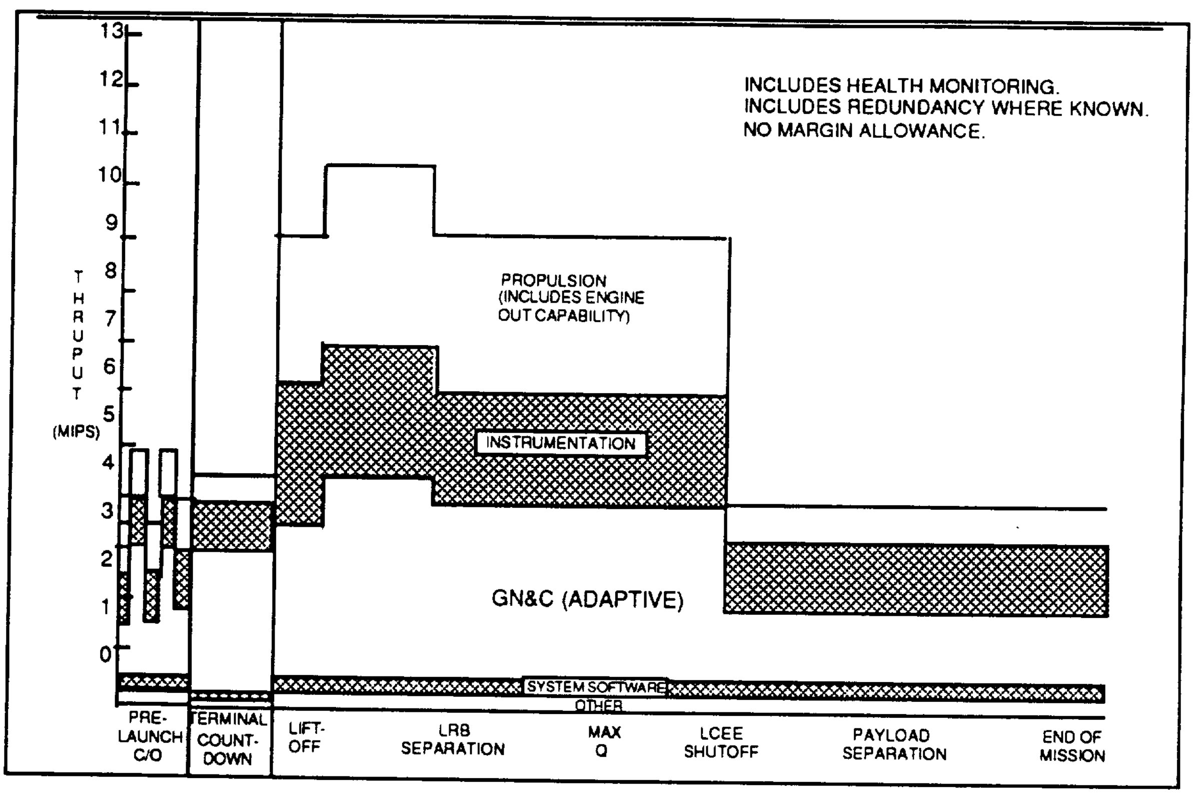


FIGURE 6.1.2-3. PHASE 1 VEHICLE PROCESSING TIMELINE

Figure 6.1.2-3 shows a vehicle processing throughput as a function of time. These projected through-put levels added to the requirements for vehicle dynamics and mission environment require the core processor to equal or exceed its projected 70+ MIPS configuration for Phase 1.

Flight operations for Shuttle-C, shown in figure 6.1.2-4 were used in projecting the throughput requirements.

The Phase 1 GBT Configuration is pictured in figure 6.1.2-5. Many target capabilities are absent. Among these are the interface provisions to many of the resource labs and extensions. The G&N Lab is the exception where a full link is present. The Propulsion Lab also will have a port available on the fiber optic communications and control bus.

- **AUTONOMOUS FLIGHT CONTROL TO ORBITAL INSERTION, CIRCULIZATION AND DEORBIT**
  - **Simplex Shuttle-C mission control center**
  - **Basic Shuttle-C avionics for this function**
  - **Precursor mission planning (simplex), payload integration to cargo bay by Shuttle-C**
- **ORBITAL DEPLOY MISSIONS (E.G., PLANETARY AND OTHER FREE FLYING SPACECRAFT**
  - **Payload developer responsible for operations from POCC after payload separation**
- **SPACE STATION MISSIONS**
  - **Precursor mission (Δ on orbit) planning done as part of OMV/SS activity**
  - **OMV/Space Station control center responsible for rendezvous, Prox-ops, docking, mission operations (e.g., assembly) and deorbit from SS/OMV control center or multi-purpose control center**
  - **Very limited "kit on" Shuttle-C delta avionics including batteries, etc.**

FIGURE 6.1.2-4. FLIGHT OPERATIONS

The GBT Core Processor is only partially filled, giving it a throughput of about 70+ MIPS. The software will be developed initially on the Graphic Processors residing in the display center. The function of the display/demo center and software development will be performed at that location. The benchmark hardware used in the avionics hardware testbed will probably be a single string of the Shuttle-C architecture. The interfacing capabilities of the Master I/O unit will accommodate only the equivalent of an Inertial Navigation Unit (INU) and a Remote Voting Unit (RVU) simultaneously.

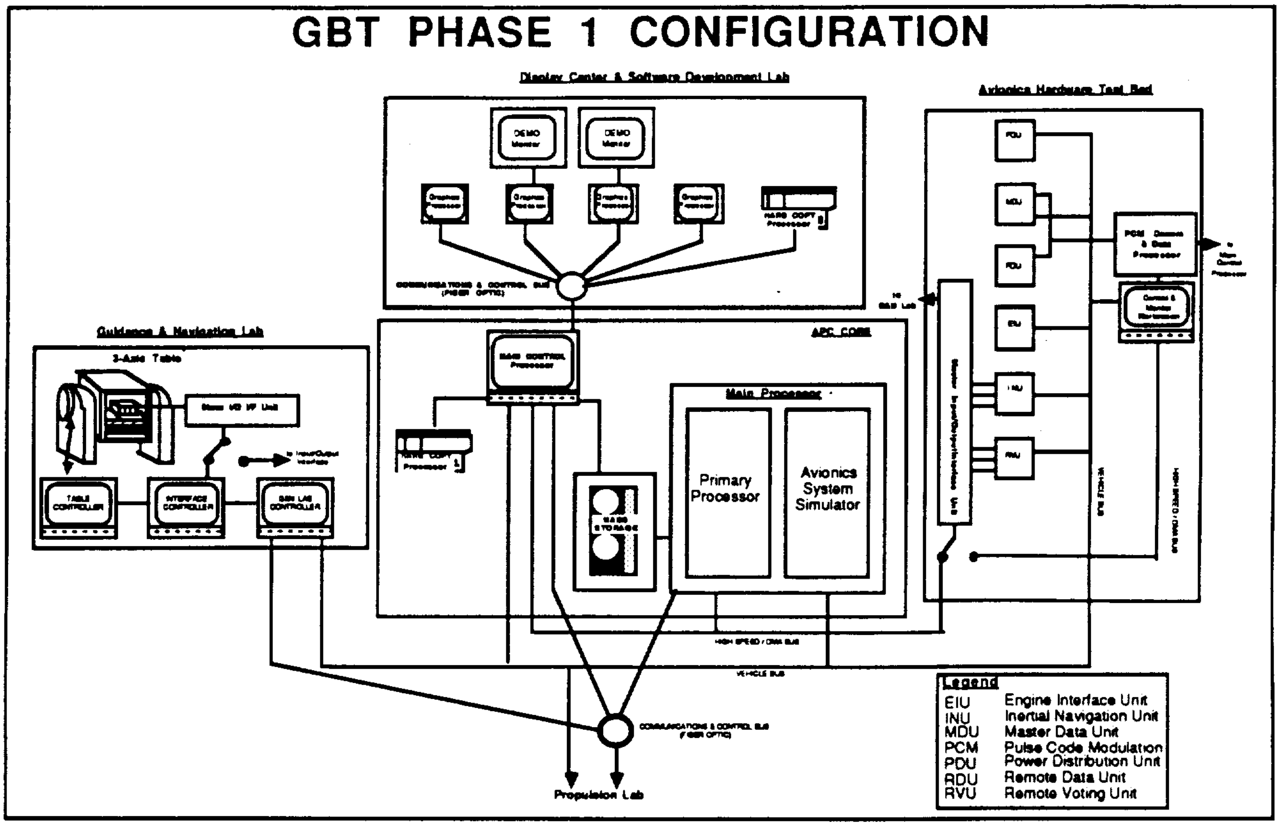


FIGURE 6.1.2-5 GBT PHASE 1 CONFIGURATION

6.1.3 PHASE 2 CONFIGURATION

The Phase 2 GBT capabilities and constraints are listed in figure 6.1.3-1. Vehicle simulation capabilities now include the ALS Booster and Core. The overall simulation capability is more generic than before, with the complete range of software modules completed. The Core Processor has been fully expanded to the target configuration, permitting complete end-to-end, real-time simulations. Rendezvous and Docking and Precision Entry simulations will also be possible in Phase 2.

Hardware testing of a complete "string" of avionics equipment will be possible with the avionics hardware test bench. A more complete set of generic software models will be available for use.

Figure 6.1.3-2 depicts the Phase 2 GBT configuration. Note the changes in the hardware test bed and display center. Now a separate software development facility is available and links are available to a variety of labs and extensions.

1. MISSION MODELS - Shuttle-C, ALS, (~Generic)
   - Launch
   - Ascent
   - On Orbit (STV) Maneuver, Rendezvous & Docking
   - Entry (Controlled and precision)
2. SYSTEM TEST - Shuttle-C, ALS, STV (~Generic)
   - G/Ns
   - F/CS
   - F/CP
   - DAS
   - PC
   - S/SC
3. OUTSIDE RESOURCES
   - SSME Lab Interface
   - Actuator Lab

FIGURE 6.1.3-1. PHASE II CAPABILITIES/CONSTRAINTS

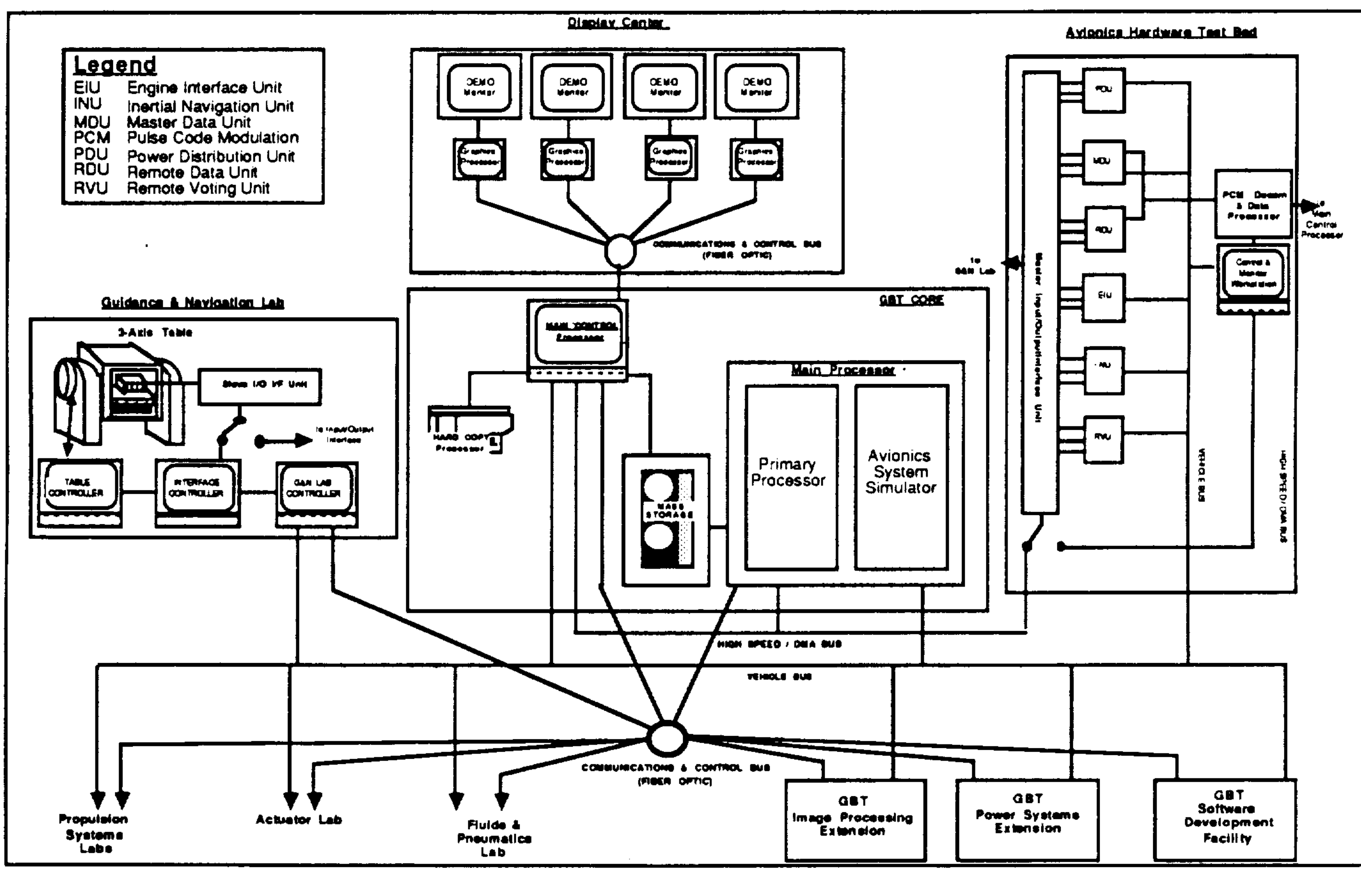


FIGURE 6.1.3-2. GBT PHASE II CONFIGURATION

7.0 HLCV GROUND BASED TESTBED FACILITIES

The detailed facility requirements for each major GBT element are contained in the Preliminary Design Document, (PDD). These requirements cover the basic power, space and environmental needs of the major GBT elements but don't address the overall Lab layout. This section will summarize the recommendations from which the layout will be determined. Fuller definition of the layout was deferred pending definition of the actual GBT site and the modification possible with the funds allotted.

7.1 LOCATION

Key to the utility of the Ground Based Testbed is its proximity to the resources it must draw upon and serve. Early utilization will be enhanced if it is close to exhausting testing facilities. As the GBT primary processor and attendant communication networks are brought onto line, closed loop simulations, involving one or more adjacent labs will become possible. Early attention to those existing laboratory resources that would most befit from the added GBT capabilities should be a factor in selecting the GBT location.

A second factor involves the GBTs potential to become an effective and convenient demonstration facility. This potential will obviously be enhanced if the GBT is in close proximity to the existing conference and administrative sites. Figure 7.1-1 shows the candidate GBT site and the adjacent test and administrative facilities.

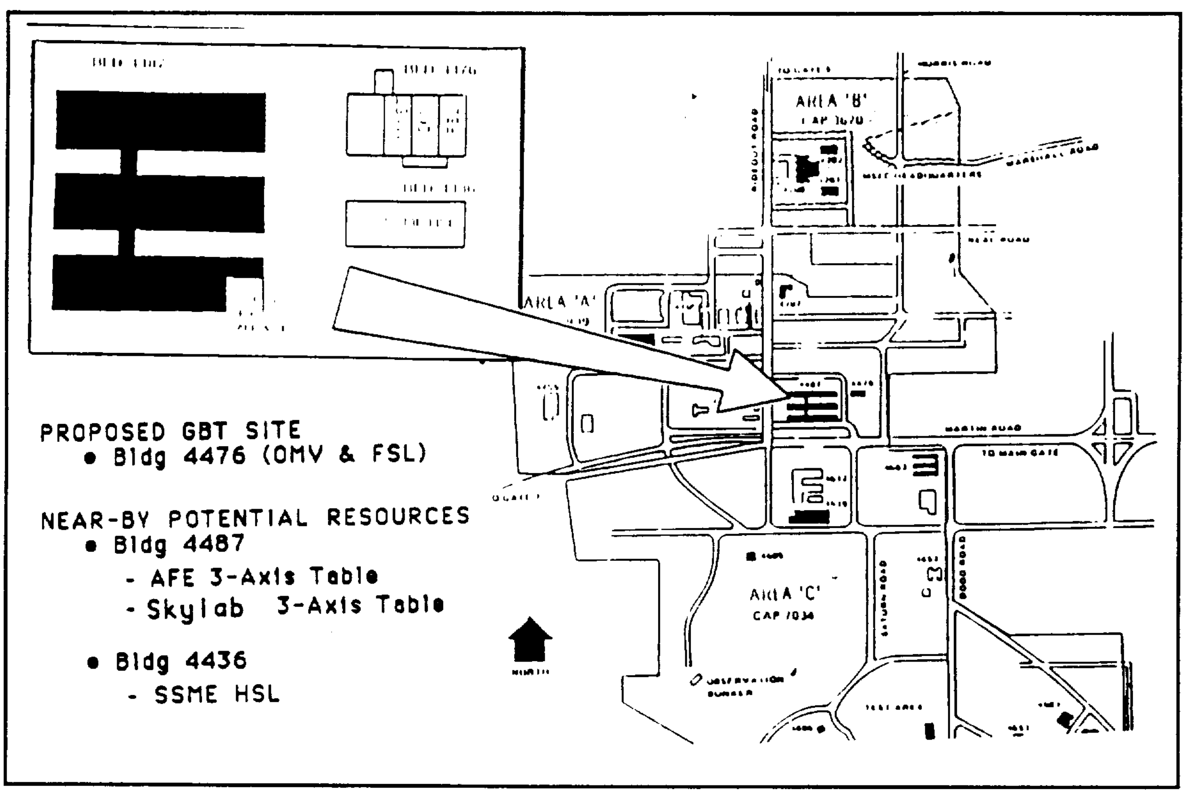


FIGURE 7.1-1. GBT FACILITY LOCATION

7.2 GBT LAYOUT

Figure 7.2-1 shows the basic Building 4476 1st floor plan. The area designated for the GBT is shown in figure 7.2-2.

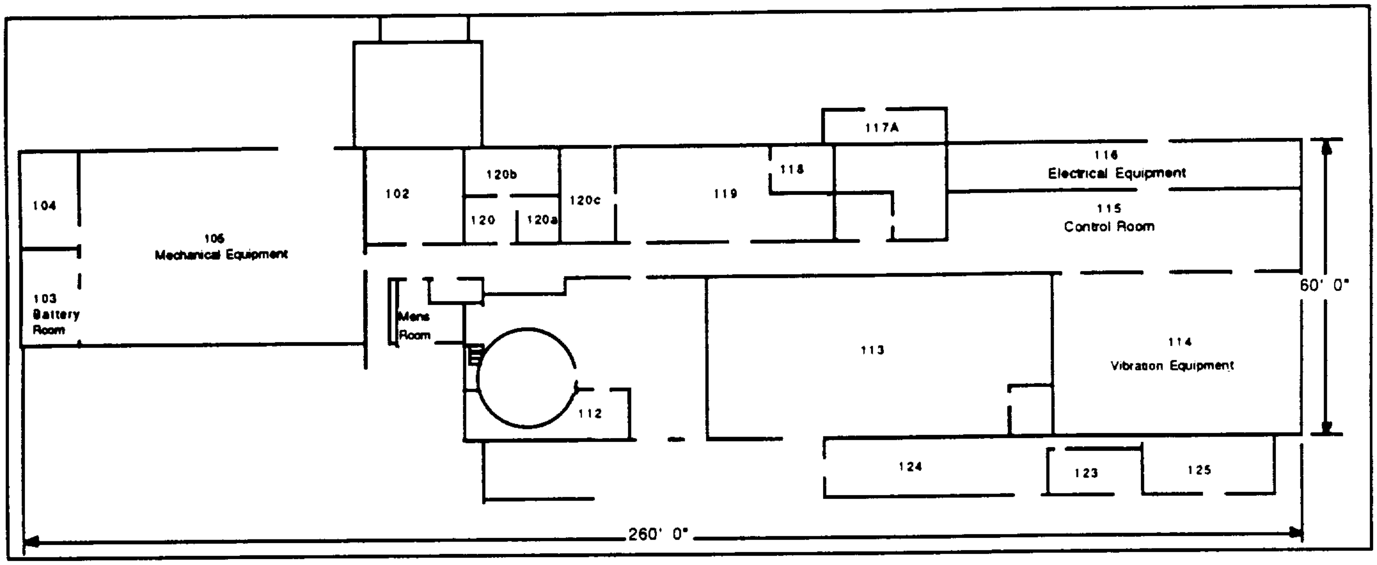


FIGURE 7.2-1. BUILDING 4476, MSFC, FIRST FLOOR

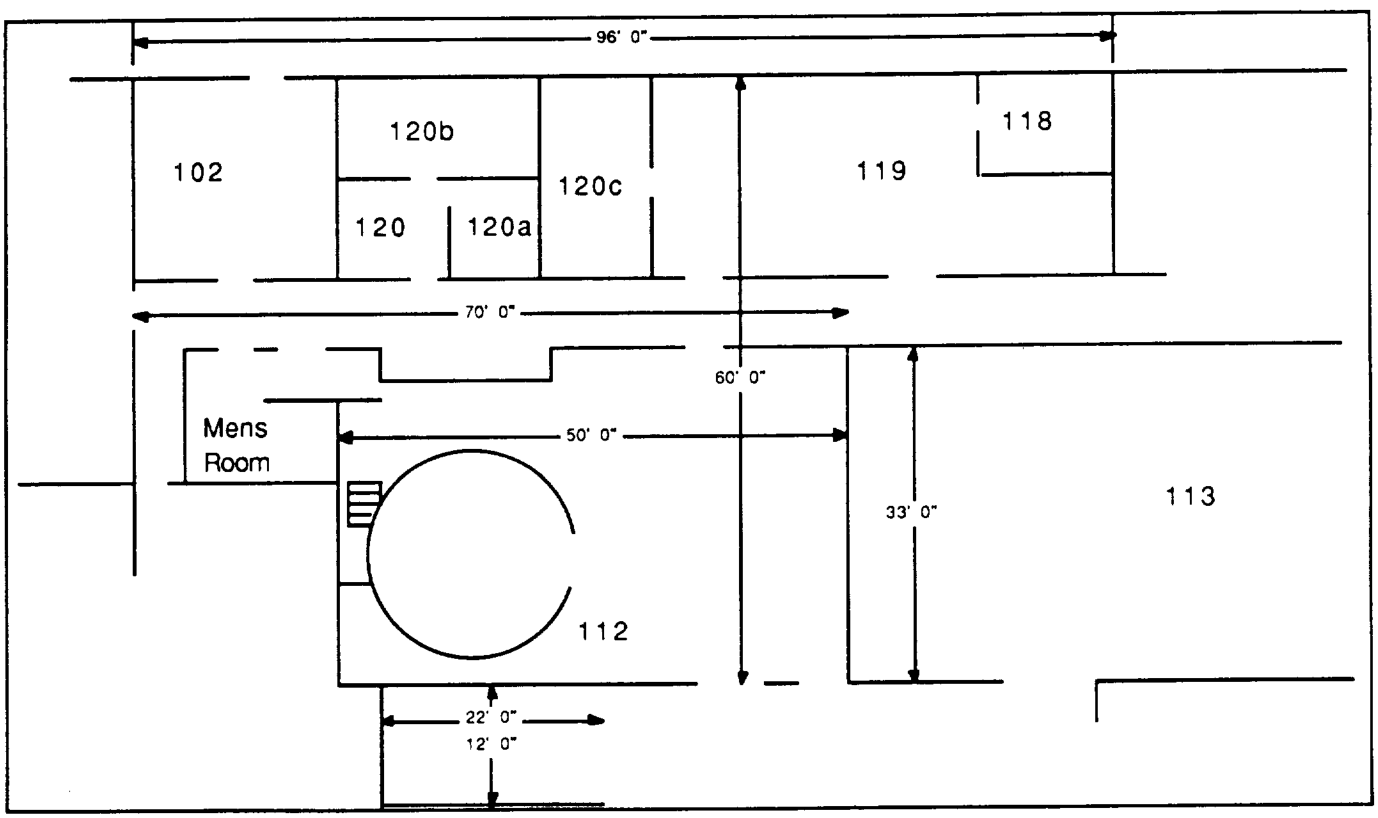


FIGURE 7.2-2. DESIGNATED GBT AREA, MSFC BUILDING 4476, FIRST FLOOR

A change to this area is already in work, but the completion dates do not support the current Phase 1 IOC date of August 1990. This proposed change has three options. The "A" option was used in this study.

A general GBT layout is shown in Figure 7.2-3. Detailed layouts of existing labs at GDSS were used as a basis for this preliminary plan. Volume II contains these layouts and a list of the "lessons learned" during their implementation and use.

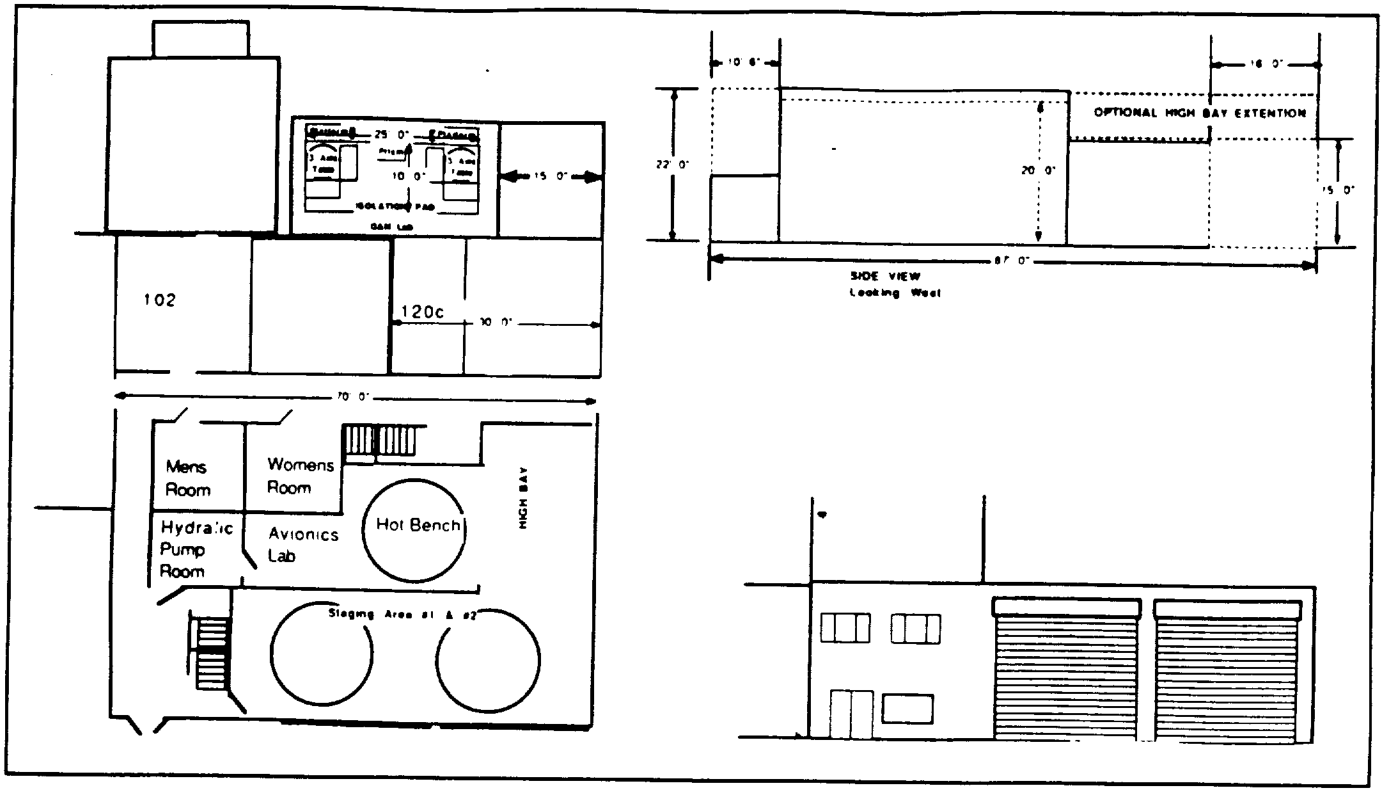


FIGURE 7.2-3. BUILDING 4476 PROPOSED 1ST FLOOR PLAN

7.2.1 MSFC BLD 4476 OPTION A MODIFICATIONS

These modifications can be summarized as:

1. Removal of Centrifuge and other obsolete structure & equipment.
2. Extend portion of the South wall to enclose weather enclosure.
3. Relocate South Main Entrance and enclose old entry area
4. Remodel and enlarge 2nd floor Mezzanine area.
5. Add Hydraulic pump room.
6. Add Women's Restroom.

7.2.2 PROPOSED GBT FACILITY MODIFICATIONS

Some modifications to Building 4476 in addition to those currently being considered in Option A are recommended. Figure 7.2-3 contains several views of the modifications. Table 7.2.2-1 outlines these modifications and summarizes their basic rationales.

TABLE 7.2.2-1

NO	DESCRIPTION	RATIONALE
1	Southern High Bay Extension with 2 large access doors.	1. Provides access to High Bay and staging areas #1 & #2.
2.	Northern G&N Lab Extension	2. Accommodates G&N labs & provides North Star LOS. Provides easiest method to provide isolation pads for 3 axis table.
3.	Northern High Bay Extension	3. Accommodates future "flow through" processing of modules & staging.
4.	Mezzanine Modification	4. Optimizes main processor areas to resources (shortens distance to Hot Bench & staging areas by placing main processor on mezzanine.

7.2.3 PROPOSED GBT SPACE ALLOCATION

The original Target GBT floor plan approached 10000 square feet and featured a two story layout. The candidate site offered about one third of the space unmodified. Optional add-ons bring the usable space to around 5000 square feet and optimizes the usefulness of the 2nd floor area.

7.2.3.1 DEMONSTRATION, CONTROL & PROCESSING CENTERS

Figure 7.2.3.1-1 shows a general spatial allocation of the mezzanine. The GBT Primary Processor, Control Processor, Mass memory and hard copy printing devices will be housed in the GBT Processing Center upstairs and adjacent to the Demonstration & Control Center. Both areas will have independently controllable environments designed to properly accommodate the data processing equipment, staff and visitors. Attention will be given to provide a view of high bay and staging area operations. Windowed partitions will be utilized to provide the designed view of the Processing Center and downstairs working areas while maintaining the controlled equipment. The Demonstration area will accommodate up to 20 visitors in a design which permits a good view of the large screen monitors, projection screens and main control console. Individual control of the Demonstration Center temperature and lighting is imperative.

Safety provisions for rapid egress from the mezzanine require two stairways. Provisions to protect the Primary Processing Center from fire and intrusion should be provided. A Halon system should be investigated.

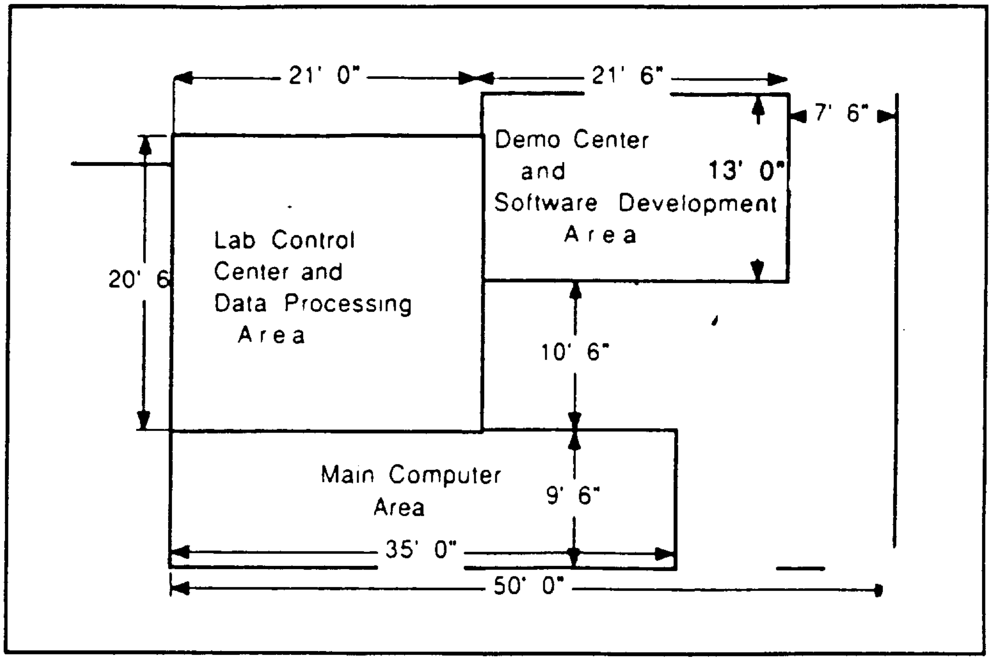


FIGURE 7.2.3.1-1 MEZZANINE LAYOUT

7.2.3.2 AVIONICS HARDWARE TESTBED (HOT BENCH) AND STAGING AREA

Basic to the design of the GBT is its capability to evaluate candidate hardware in a closed-loop, simulated operational environment. The Target configuration will have the ability to interface with prototype hardware at both the box and system level. A Primary full capability test bed will be supplemented with staging area equipment capable of preliminary open loop and closed loop testing. The staging areas will enable a parallel and more efficient use of the GBT facilities. The large roll up type of doors will facilitate easy access to the two staging area test stations. The staging areas are adjacent to the upstairs processing facilities as well as electrical and hydraulic power sources. The space allocated for the Hardware Testbed and staging areas was sized to accommodate a prototype flight segment of 15 ft. diameter and 15 ft. height.

7.2.3.3 GUIDANCE & NAVIGATION

Several requirements drove the location and configuration of this GBT resource lab. The future configuration of this lab called for dual 3-axis tables. The 10x25x10 foot isolation pad accommodates these units and the associated optical alignment equipment. The size of the pad and the ability to have a line-of-sight access to the North Star for alignment dictates the location within an addition on the north side of Bldg. 4476.

7.2.3.4 PLACEMENT OF OTHER GBT RESOURCES

Due to the fluid nature of the already planned facility modifications and the August 1990 Phase i IOC, specific placement of the other GBT resources is felt to be premature. Temporary facilities will have to be provided while Bldg. 4476 is being modified.

8.0 GROUND BASED LAB PHASE 1 COST ESTIMATES

Table 8.0.-1 gives the ROM costs associated with the Phase 1 GBT. Note that these costs do not reflect any fees or expenses associated with procurement. The hardware and software prices are "list prices". Software development costs reflect only a flat hourly cost.

HLVC MAST Costs	Description	COST
CORE		
Hardware		
Main Processor System	Concurrent (Goldrush/Scirocco	$252,100
Main Control Processor System	Masscomp (MC6755-4 CPUs)	$186,000
Graphics Monitor/processor		$15,000
Mass Memory		$111,250
Hard Copy Processors	2-Lasers, 1 HS line printer	$12,000
Software		
Main Processor Operating System		$3,000
Multi Tasking Graphics Executive	Dataview	$20 000
Fortran System		$3,000
C3 Ada System		$30 000
Program Executive & Menus	1000 hrs	$47 980
Simulatioin Program & Menus	2200 hrs	$105,556
Simulation Model Data & Menus	2200 hrs	$105 556
Mission/Vehicle/Enviroment Models	2400 hrs	$115,150
Software Development Aids & Menus	240 hrs	$11 515
Inter-Lab Connections & Menus	160 hrs	$7,677
Element Total		$1,025,784
Avionics Hardware Test Bed		
Hardware		
Master Input/Output Interfacing Unit		$116 000
Local Terminal/Monitor		$20 000
PCM DeCom & Data Processor		$60 000
Vehicle Bus Analyzer		$45,000
Network/Bus Interfaces		$4 300
Benches & I/O Hardware		
Benchmark Hardware		
G&N Sensors	INU #1	$1 300,000
Flight Control Processor	INU #1	
SubSystem Controller	RVU #1	$500,000
Data Processing System	MDU #1	$250 000
Flight Control Sensors	RGU &AA #1	
Data Bus Interfacing Unit	DBIU (Orbiter/SRB)	
Remote Data Unit	RDU	$250,000
Software		
Inertial Sensor Models	INU #1 (160 hrs)	$7,677
F/C Processor Models	INU #1 (160 hrs)	$7,677
S/S Controller Models	RVU #1 (160 hrs)	$7,677
DPS Models	MDU #1 (160 hrs)	$7,677
F/C Sensor Models	RGU &AA #1 (160 hrs)	$7,677
Engine Controller Models	EIU #1 (200 hrs)	$9,596
Cross-Channel Communications	120 hrs	$5,758
Synchronization & Skewing	80 hrs	$3,838
Instrumentation	160 hrs	$7,677
LRU Evaluation	1200 hrs	$57,576
PCM DeCom & Data Reduction		
Element Total		$2,668,130

Display Center		
HARDWARE		
Graphics Processors (4 each)	(same as S W Dev Lab)	
Large Screen Monitors (2 each)		$10,000
Hard Copy Processors		$6,000
Projectors		$550
Video Recorders (2 each)		$3,000
Network/Bus Interface		
Projection screens		$600
Demo Center Furniture		$2,000
Software		
Graphics Programs	1000 hrs	$48,000
Graphics Tools		$27,000
Element Total		$97,150
Software Development Lab		
Hardware		
Workstations (4 Units)	Compacts 386	$80,000
Archive Storage		
Graphic Printer		
Network/Bus Interface		$20,000
Software		
Software Development Tools		
Data Dependancy Analysis		$30,000
Element Total		$130,000
Combined Element Totals		$227,150
Guidance & Navigation Lab		
Hardware		
3 Axis Table		$560,000
Enviromental Chamber		
Test Controllers (3 Units)		$60,000
Input/Output Interface Unit		$50,000
Optical Alignment Equipment		$10,000
Printers (2 Units)		$10,000
Inertial Test Set		$50,000
Misc Test Equipment		$10,000
Software		
Inertial Sensor Evaluation Models	400 hrs	$19,192
Table Control		$15,000
Operating System/Drivers		$50,000
Integrated Testing S/W		$100,000
Element Total		$934,192
TOTAL GBT PHASE 1 Development Costs		$4,855,256

TABLE 8.0-1 PHASE 1 GBT COSTS

9.0 SUMMARY AND CONCLUSIONS

The purpose in defining the philosophy, objectives and desired functional capabilities of the Ground Based Testbed was, of course, to provide a basis for implementation planning. Successful implementation will be judged upon the GBTs ability to provide timely and cost effective support to Shuttle C, STV and other emerging programs. Figure 9.0-1 reviews the basic functions provided by the GBT. The other factor which can not be neglected is funding for the implementation and operation of the GBT. All of these factors will be summarized in this section.

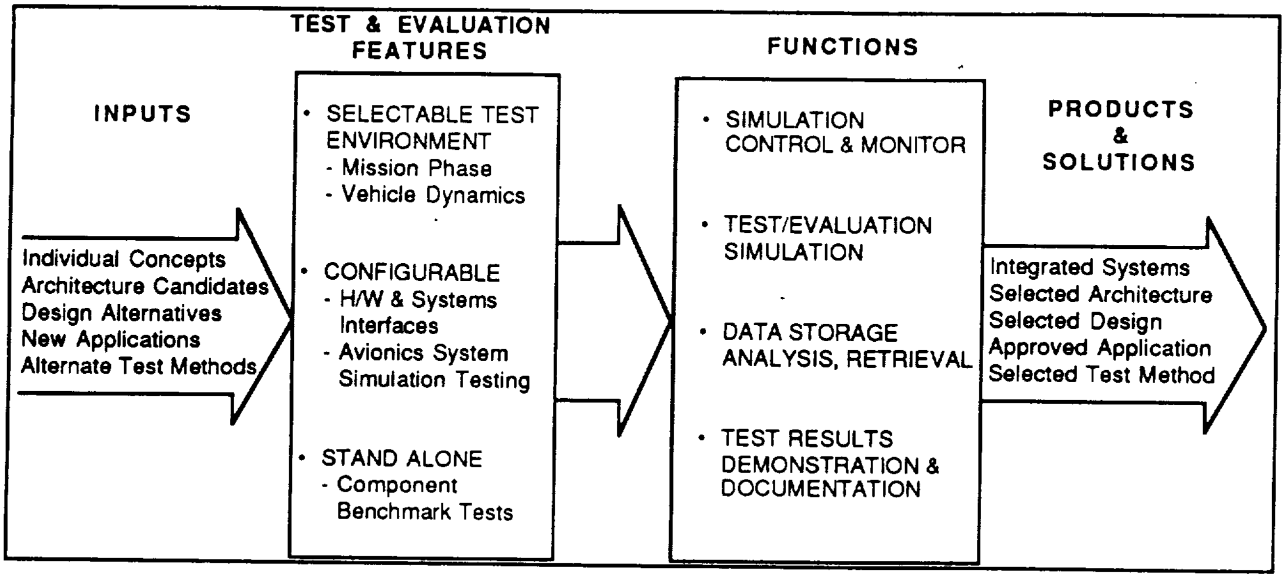


FIGURE 9.0-1 GBT FUNCTIONS

9.1 GBT FUNCTIONAL DESIGN

To perform the Functions and provide the Test and Evaluation Features shown, the GBT design evolved into several functional elements. These elements in turn were sized to support specific program driven capabilities and requirements. The development of element capabilities was paced by projected funding levels and prioritized program support requirements. Where possible, provisions were made to use existing, related test and evaluation resources. These provisions, in most cases, not only provide an earlier operational capability, but also extend the original resources capabilities and effectively extend its operational life.

The primary functional elements of the GBT are shown in Figure 9.1-1 and will be discussed in the following paragraphs.

9.1.1 GBT CORE

The GBT has been described as spanning the test continuum from pure simulation to hardware performance evaluation. Common to each extreme is a flexible, high through-put core processor.The GBT core has a main processor which is functionally divided into the primary processor and the avionics system simulator. The primary processor function includes running the simulation of the test vehicle dynamics, the mission environment and all other interfacing elements to the vehicle avionics system.The avionics system simulation function includes running the simulation of the test vehicle avionics system. This includes the monitor and control of all interfaces to real hardware being tested or run on the Avionics Hardware Test Bench.

Selection of this processor was one of the most important and far reaching design decisions of the study. The unit chosen combined an excellent cost to performance ratio with a software and hardware migration path capable of supporting the rapidly expanding simulation demands of the immediate future. Initially sized with a through put in excess of 150 Million Instructions per Second, (MIPS), this expandable core processor has the software tools and I/O ports to support the GBTs current and future Real-Time simulation requirements.

The four other main elements of the GBT core are the Main Control Processor, Mass Storage Unit, Hard Copy Processor and Interconnecting network/buss structure. The Main Control Processor is primarily tasked with the allocation and control of GBT resources. It controls most of the various busses and networks running throughout the GBT and supervises use of the Mass Storage and Hard copy Processor. While functionally a part of the GBT Core, the Main Control Processor will probably reside in the Main Control and Demonstration center.

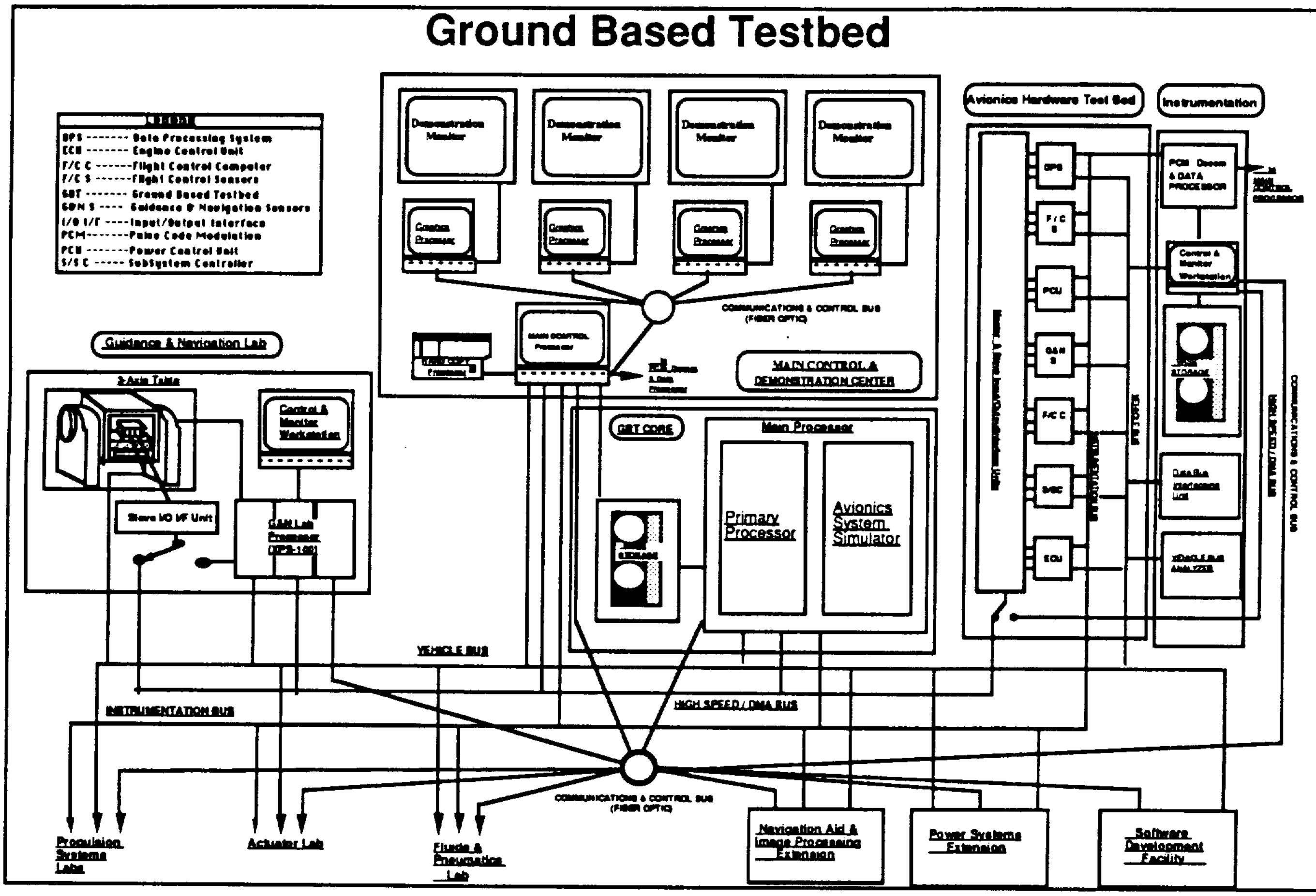


FIGURE 9.1-1 GROUND BASED TESTBED TARGET CONFIGURATION

9.1.2 MAIN CONTROL & DEMONSTRATION CENTER

Within this element rests the primary control and allocation of all the GBT resources. Central to its function is the Main Control Processor that is linked to all the available resources by an extensive inter / intra lab communications network. The Main Control Center and Demonstration Center are collocated because of their complementary functions. The Demonstration monitors may be used to supplement the status displays available to the core's Main Control Processor. The graphics processors will also supplement the Main Control Processor in controlling parallel operations going on within the GBT.

The Demonstration Center primarily consists of four graphics processors driving four large screen monitors. The graphics processors are used to develop display and other support type graphics. Working with the large screen monitors, the processors can reproduce demonstration graphics depicting anything from real-time test parameters to reproduction of demonstration graphics.

9.1.3 AVIONICS HARDWARE TEST BED

The Avionics Hardware Test Bed is the third major segment of the GBT Target Configuration. It contains the interfacing units, busses and harnesses necessary to accommodate the GBT Benchmark hardware. The benchmark hardware is a collection of current avionics units which, when connected to the required interfacing harness, comprise a fully functional avionics system.It provides a real world performance standard to which the candidate hardware can be compared. The Avionics Hardware Test Bed therefor facilitates development and evaluation of new avionics systems,and components by providing a high fidelity, native environment in which they can be tested.

9.1.4 GUIDANCE & NAVIGATION RESOURCE LAB

The G&N Lab is one of the most important resources available to the GBT. Though capable of fully independent operation, in an acceptance test procedure role, its primary value is in closed-loop simulation of an integrated avionics system. The precision 3-axis table can supply all necessary stimuli, except acceleration, to evaluate the best inertial elements of the HLCV era. The Slave I/O interface box will provide the local real-time interfaces to accommodate such testing.

9.1.5 INSTRUMENTATION RESOURCE LAB

The Instrumentation segment is a subset of the Avionics hardware test bed that permits local control and monitoring of the test bed hardware or units under test. It functionally duplicities an instrumentation ground station and is equipped to analyze vehicle bus traffic.

9.1.6 SOFTWARE DEVELOPMENT FACILITY

A major design driver is the architecture of the user friendly software that yielded the efficient and highly compatible interface for potential users. The cost effectiveness of GBT usage rests squarely on its accessibility and its ability to accommodate several tasks in parallel. This translates to a modular set of software tools, tailorable to specific applications and executed with data that bounds the required performance regimes. The tailoring and selection of appropriate performance data is accomplished by a menu driven linkage process.The Software Development Facility will initially be located in the Main Control and Demonstration Facility while the basic GBT operational and benchmark software is being integrated. As the GBT phases into operation, the function of this element will shift to the primary user interface. It will become the site where users will assemble the modularized software tools and simulations into the desired testing regimes. The Software Development Facility will also host the building of the demonstration graphics.

9.1.7 NAVIGATION AID & IMAGE PROCESSING EXTENSION

This GBT extension is scheduled for Phase 2 implementation. It is designed to provide developmental support for the autonomous rendezvous and docking aids in the near term and approach and landing systems for the far term Fly Back Booster. See HLCV Second Quarterly Review, Thursday 22 September 1988 for details.

9.1.8 POWER SYSTEMS EXTENSION

This GBT extension will be capable of testing new technologies in Power Systems components and architectures. This Phase 2 extension will support not only the normal evaluation of candidate power system sources and architectures, but will be focused on EMA power supply development and testing.

9.1.9 FLUIDS & PNEUMATICS LAB

This GBT extension facility contains the hardware and special test equipment needed to test the new Fluids and Pneumatic architectures and components. The Fluids & Pneumatics Lab contains flow and pressure sensing equipment, pressure regulation equipment, electronic valves, a facility processor, a VME bus input/output interface chassis, and bottled fluids and gases.The extension facility shall have thick safety walls and a pressure pit for this high pressure LN_2. The facility shall also be capable of running remote when operating with the high pressure.

9.1.10 ACTUATOR LAB

This resource lab will provide a dynamic performance evaluation facility primarily aimed at larger, fast response actuators used in Trust Vector Control systems. With the emergence of large numbers of clustered engines as a solution to the heavy lift booster requirements, EMAs are gaining popularity. The advantages of being able to link the Power Systems and Actuator Labs together via the GBT is seen as an attractive Phase 2 capability.

9.1.11 PROPULSION SYSTEMS LABS

MSFC has long been the site of propulsion system development and test. The GBT would provide a way to combine the existing,high fidelity,.propulsion system hardware emulations and simulations with the avionics system simulations to provide integrated, end to end testing. Particularly useful will be the capability to evaluate control system performance using the clustered engine configurations of the future.

9.2 GBT IMPLEMENTATION

From the beginning, it was recognized that the Ground Based Test beds capabilities would be tied to meeting current program system testing requirements. The GBTs role was to encompass vehicle simulation and testing needs from inception to the Preliminary Design Review (PDR). Looking at the projected vehicle developmental schedules, it was all too clear that the first operational GBT capabilities would have to be focused on the critical developmental problems. If vehicles like the Shuttle C or STV were to be supported prior to their PDRs the GBT must be at least operational by August 1990.

Software model development is another key factor in the implementation plan. Fidelity of the vehicle dynamic and system models is critical to establishing the GBT as a valuable program development resource. This usually requires actual hardware being used to develop and verify the fidelity of the respective software models. Availability of similar hardware often proves to be another pacing element. The basic GBT hardware and software design is modular and thus can be changed easily to accommodate different requirements. The early phases of implementation require the building of a specific number of these basic modules to satisfy a limited number of needs. To satisfy a greater set of requirements relatively few new modules are required.

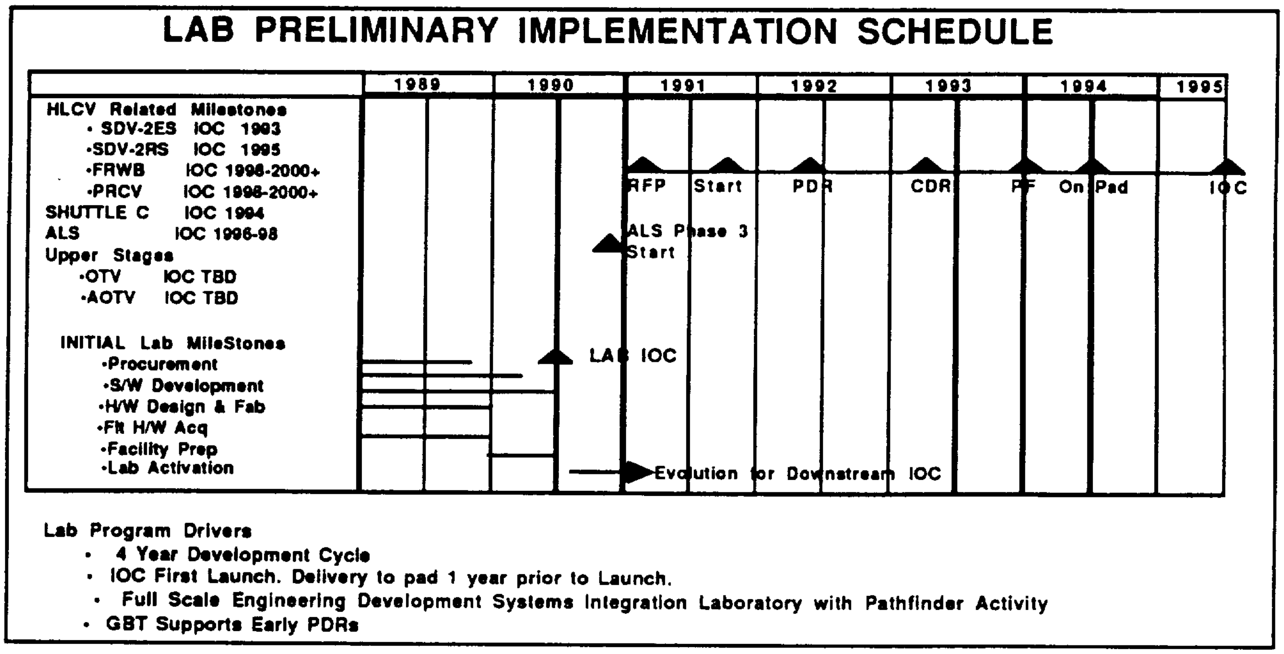


FIGURE 9.2-1 IMPLEMENTATION SCHEDULE

Figure 9.2-1 shows an early implementation schedule and its assumptions. One of the most difficult problems of the implementation schedule, shown earlier in figure 1.2-2, is the amount of work to be done in the first phase. Between February 1989 and August 1990, over 60% of the total task must be accomplished. This is not consist with the relatively low front end funding guidelines that were provided for this study. Figure 9.2-2 shows this problem graphically.

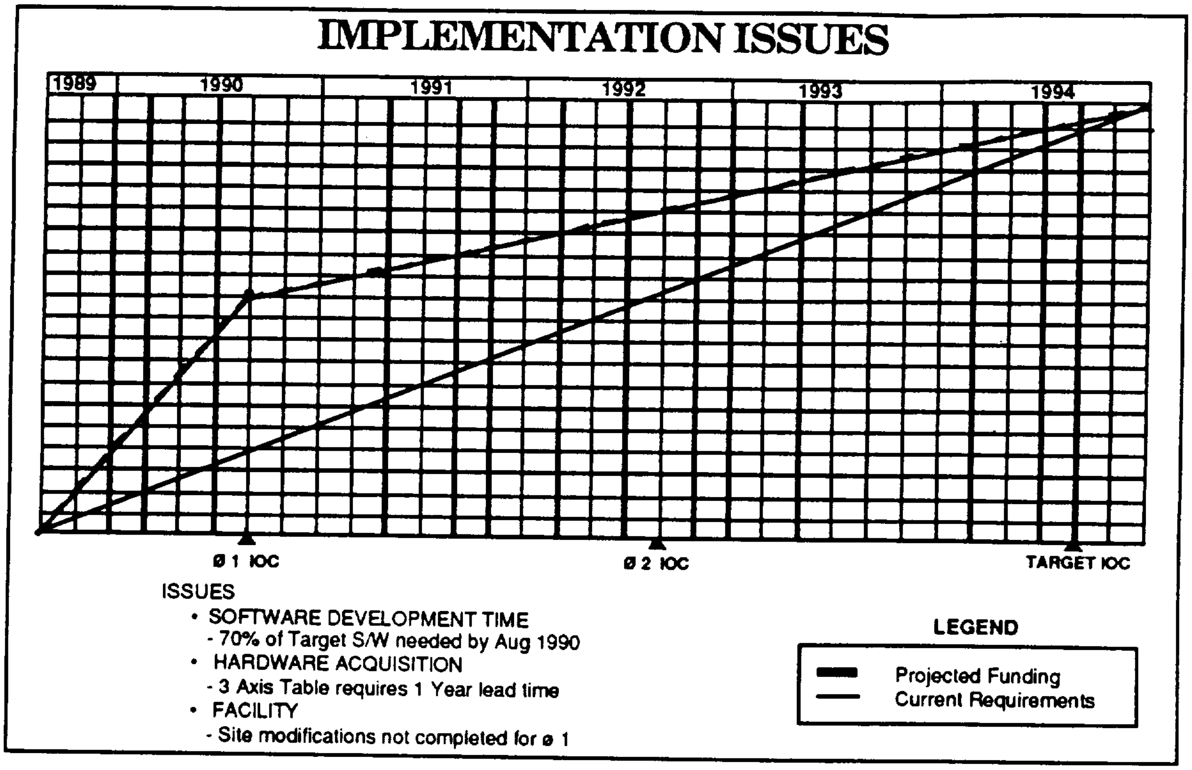


FIGURE 9.2-2 PROJECTED FUNDING LEVELS VS TASK

9.3 GBT FUNDING

The bottom line for GBT success is being able to supply the most cost effective and useful test facility at the time when new programs need it the most. This implies that the projects are willing to pay their way and plan for such usage initially. This idealistic form of funding must be recognized as supplemental to basic level of funding needed to initially implement and later maintain GBT operations. Internal Research & Development projects are also a source of funding. This type of function typically accelerates the application of useful, new technologies and test concepts upon which later major programs are built.

Table 9.3-1 shows a summary of the element costs associated with the Phase 1 Ground Based Test Bed. Note that these are ROM costs with no wraps. More up to date, loaded costs are available in the Final Report Addendum.