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SPACE TRANSFER VEHICLE AVIONICS ADVANCED DEVELOPMENT NEEDS

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INTRODUCTION

President Bush on July 20,1989 announced the mandate to NASA to prepare a sustained planetary exploration plan for the 1990-2020 period. The plan covers the Mission to Planet Earth and S.S. Freedom programs during the 90's, return to the moon and creation of a manned Lunar outpost during the first decade and a manned outpost on Mars in the second decade of the 21st century. The task of moving explorers and their equipment and science experiments between the surfaces of the Earth and the Moon and Mars will place a heavy demand on the performance, reliability, maintainability and flexibility of the transportation system. In order to effectively meet these demands, early designs will focus on the Lunar mission needs. The resulting space transfer vehicle core system will first obtain flight experience by flying Planet Earth, precursor and other unmanned planetary missions followed by manned Lunar and then, evolve to the more complex manned Mars missions before 2020. This approach maximizes the commonality and synergism between the Planet Earth, Lunar and Mars missions and brings the challenge of transportation for the exploration initiatives well within the reach of orderly technology advancement and development.

PROJECT DESCRIPTION OVERVIEW

The assessment of preliminary transportation program options for the exploration initiative is underway. The exploration initiative for Lunar and Mars is outlined by mission phases in Figure 2. A typical Lunar/Mars Outpost technology /advanced development schedule is shown in Figure 3. An aggressive and focused technology development program is needed as early as possible to successfully support these new initiatives. This paper will describe the avionics advanced development needs, plans, laboratory facilities and benefits for an early start.

The Lunar transportation system consists of the Lunar transfer vehicle (LTV) and the Lunar excursion vehicle (LEV) shown in Figure 4. Although designed to be reusable, the LTV will initially be expended in order to deliver heavy payloads during the early emplacement phase. In the steady state mode, the LTV is based at Freedom. Reusable personnel and cargo vehicles will begin operation after initial emplacement operations and continue through outpost consolidation. Once Lunar exploration begins, up to two flights per year will be conducted from Freedom to the Lunar surface.

The LTV is a dual-purpose, 1-1/2 stage design consisting of a propulsion / avionics module core and aerobrake,four expendable main propellant tanks and a Lunar transfer crew module (LTCM). A common vehicle is used for both cargo and piloted missions to the Moon. The LTV with four engines at 20,000 pounds thrust each has engine out capability. The aerobrake is a rigid, spherical, sector-truncated cone structure made of composite materials covered with advanced Shuttle-type thermal protection system (TPS) tiles. The peripheral segments of the aerobrake are attached to the LTV core and aerobrake centerpiece at Freedom and the combination is checked out. The LTV core/aerobrake is then mated to the four propellant drop-tanks and cargo modules are added to complete the Lunar transfer vehicle. Windows and control displays allow the crew to control rendezvous and docking operations. The environmental control and life support system (ECLSS) is a Freedom-derived two gas, open-loop system. Power comes from advanced fuel cells located on the LTV. The module has a galley, zero-gravity toilet, and limited personnel hygiene provisions. The lunar transfer crew module (LTCM) attaches to the LTV and provides support for the crew. Systems operate for 4 days on the trans-Lunar leg and up to 7 days on the inbound leg to earth including a standby period while in Lunar orbit for the nominal Lunar missions. Shuttle-type medical supplies are provided. The LTCM fits within the aerobrake wake envelope of the LTV on return from the Moon and can accept up to a 5-g deceleration.

The LEV consists of a propulsion / avionics module and Lunar excursion crew module (LECM).The propellant system is sized for 30 days on the Lunar surface.The LEV employs common main engines; integral cryogenic thrusters; advanced fuel cells with battery back up for electrical power; advanced, redundant avionics software; and communications systems with the LTV. LEV landing legs and pads are provided with height control for both landing pad and unimproved landing areas. Multiple communications capabilities for LEV to LTV, Earth, Freedom, Lunar surface, and communications satellites are provided. Automated rendezvous and docking for both LLO and LEO are also provided.The LEV is normally based on the Lunar surface, covered by an environmental shelter, ready for launch and rendezvous with the LTV in the steady-state mode.The LECM, which shares common systems design with the LTCM, transports four crewmen. LECM systems are quiescent except for 4 days during descent/ascent missions. Power comes from fuel cells in the LEV during missions and from the surface support system during quiescent periods on the Moon. The LECM has no airlock; operational EVA's are normally not required. For early Lunar missions and contingencies, EVA's are supported by depressurizing the module. Repressurization gas is provided for two contingency EVA's with options for more if necessary. The LECM can fly at least five Lunar missions with checkout, maintenance, and resupply either in Lunar orbit or on the surface. Figure 5 shows a typical Lunar transfer operations. The vehicle will be capable of launching a crew to other Lunar areas, as the exploration program expands.

Figure 6 shows the Mars transfer operations. The complete Mars vehicle, ready for departure from Earth orbit, consists of a Mars Transfer Vehicle (MTV) with expendable trans-Mars injection (TMI) stage and a Mars Excursion Vehicle (MEV). The Mars vehicles require assembly and launch processing in LEO at Freedom. Assembly of the TMI stage and final joining of the TMI stage to the rest of the vehicle occurs near the station in a co-orbital position. Assembly is performed by robotic postitioning / manipulator arms. EVA is needed only for contingencies and possibly for inspection tasks. The cargo mission uses only the TMI element of the MTV and two MEV's. The MTV is boosted to Mars transfer trajectory by the TMI stage, which consists of a core module with five engines and up to three additional strap-on tank modules.The strap-on tanks are the same configuration as the core module tanks.When this stage has completed its job, it is jettisoned. The MTV has a large aerobrake for Mars aerocapture.The brake may optionally be returned to Earth by the trans-Ear The aerobrake is identical in shape and size to the aerobrake used by the Mars excursion vehicle but uses heavier structure.The MTV crew module is a single pressurized structure with an internal bulkhead to provide redundant pressure volumes. The crew is provided private quarters and exercise equipment, appropriate for the long (up to 3 years) mission duration. Space suits are carried for each of the crew; these suits accompany the crew to the Mars surface and back.

The MEV separates from the MTV before the Mars arrival and uses its own aeroshell for Mars orbit capture. After both vehicles are captured, the vehicles rendezvous and berth together. The crew transfers to the excursion vehicle for the Mars surface mission and the MEV separates from the MTV for descent to the surface. The crew pilots the MEV from the crew module during descent so that the ascent stage can be immediately activated in the event of an abort. The ascent stage is positioned on the descent stage for liftoff, either from a landing abort or for normal ascent. The MEV descends from Mars orbit to the Mars surface, supports the crew on the surface for up to 20 days, and returns the crew to Mars orbit for rendezvous with the MTV. After a brief checkout of the transfer vehicle, the trans-Earth burn is initiated at the first available opportunity.

The MTV using four advanced space engines that are the same as those used for the Lunar Transfer Vehicle returns the crew to Earth. It has long-duration crew accommodations for the transfers from Earth to Mars and return. It also includes an Earth capture crew vehicle (ECCV), a small Apollo-shaped capsule designed to aerobrake the crew either to low Earth orbit (LEO) or directly to Earth's surface.

The Lunar/Mars Initiative advanced development program will require the development of many systems for the Space Transfer Vehicle as shown in Figure 6A. This paper will highlight an approach for the development of the avionics systems and their associated laboratories and facilities.

AVIONICS ADVANCED DEVELOPMENT CRITERIA / CONCEPT

The criteria and the concept for an avionics advanced development program are shown in Figure 7. Technology and advanced development efforts are performed only where necessary to assure that mission performance can be validated and insight gained to confirm design approaches and reduce uncertainties.Interface standards are established early and problems discovered and solutions worked out in a lower-cost environment prior to the start of full-scale hardware development. The applications of these criteria to all phases of the transportation systems development is critical not only to the Lunar Outpost but also to the development of the Mars Outpost requirements. Technology development provides hardware and concept demonstration early in the life of a vehicle program in order to validate performance,operations and cost. A focused technology program schedules confidence into the follow-on advanced development demonstrations that supports key milestones. This approach helps management choose from identified design alternative or operational concepts. Technology identification, prioritization and planning begins with conceptual studies and trades, continues to support preliminary design and evolves to full scale hardware development and operations with demonstrations keyed to major decision points.

The key to success is the tight management program control,authority and responsibility under the program manager,with implementation shared by the organization able to perform the invention,development,demonstration,and implementation with credibility.

Based on past experience a major challenge of the new initiative will be to define and stablize system interface requirements between parallel development programs which historically change between each major system during and after the program development phase. The Lunar and Mars Outpost will each require several parallel development programs i.e. ETO,Freedom accommodations, space transfer vehicles and surface systems. The Lunar/Mars transportation system will have parallel development efforts ,i.e. STV,LTV,LEV,and lunar ballistic hoppers.Technology and advanced development,if structured properly, can provide a way to tie down interface requirements before multi-program/contractor interface changes become major issues.

AVIONICS ADVANCED DEVELOPMENT EXAMPLE NEEDS

Avionics advanced development needs are summarized in Figure 8 and are described on Appendix 1 quad chart formats with the description, major tasks, major drivers / benefits, and current technology identified.

The performance examples from the lunar initiative studies include; vehicle avionics(8A), vehicle software (8B), vehicle health management(8C), and autonomous self test and checkout(8D). The Operations examples include: automated vehicle assembly(8E), automated rendezvous and docking(8F), vehicle flight operations simulations(8G) and autonomous landing(8H).

ADVANCED AVIONICS DEVELOPMENT DEMONSTRATIONS

Laboratory and flight demonstrations needed by program phase are shown in Figure 9.

ADVANCED AVIONICS LABORATORY PHILOSOPHY AND OVERVIEW

Historically, R&D laboratories have been designed to develop and test a particular vehicle with limited usage during the early design phase. Consequently, design cycles were encountered for laboratory tools during phases A, B, and C of the vehicle development. Often software designs were rewritten several times before final hosting on the targeted computers simply because of the incompatibility of computer systems. The advancements in workstation capabilities (size, speed and software support systems) makes it conceivable to string together much of the Lunar and Mars vehicle avionics design process not as a cyclic process but as an evolutionary process. The design concept for a new avionics laboratory must recognize the existing and evolving capabilities of computer systems to formulate and integrate all phases of the avionic systems design . As the focal point of the Lunar/Mars advanced transportation avionics facilities, a new advanced avionics laboratory is envisioned as a generalized resource facility providing both existing and new programs with a complete set of tools for the design, development and testing of avionics systems. This laboratory concept should have the following capabilities as described in Figure 10.

The proposed concept shown in Figure 11 is designed to handle the large problem domain of the lunar initiative in real time. It is essential that the laboratory not only handles real-time operations.It must also function as a modeling laboratory, subsystem testbed and implicitly to provide system validation and verification as the Lunar and Mars vehicles design, development and testing progresses.

The philosphy for the proposed laboratory design will be to support the space transportation systems from cradle to grave. This begins with the initial modeling, progresses through real time integration of remote subsystems, to the validation and verification of the avionics system design,and finally sustained flight mission support. Each component in the laboratory design has some commonality to most life-cycle phases of the Lunar and Mars project with the intent of maximizing utilization and minimizing redesign. The four laboratory design phases are summarized in Figure 12 and discussed in more detail in Appendix 2.

BENEFITS OF ADVANCED DEVELOPMENT

Figure 13 lists the benefits of an advanced avionics development program and laboratory. Advanced development clearly validates design approaches and provides confirmation of performance specifications before costly design commitments are made. The proposed development laboratory will reduce development time and risks and provide data for the early resolution of issues and problems. Hindsight has shown the value of timely demonstration data in the support of cost effective decisions throughout the life of a program. The avionics development laboratory will be a new tool for the design and development of avionics systems that will provide continuous and evolving support to all program phases. The laboratory will form the common ground from which problems are identified and will increase confidence in safety, reliability and mission success.

SUMMARY

The avionics development laboratory and the Lunar/Mars Initiative advanced development program will provide a comprehensive approach to the complex issues and problems in the development of an avionics system (Figure 14). The program will be applicable to all program elements and will provide operational validation of all external vehicle interfaces affecting the avionics system. Innovative approaches will be required to reduce program costs and still maintain a high degree of manned and unmanned safety. The multi-use laboratory will be adaptable to all program phases and will support both vehicle and program interfaces. The laboratory will support the increases in productivity necessary for the efficient conduct of the Lunar/Mars Initiative program.

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WELCOME

SPACE TRANSPORTATION AVIONICS
TECHNOLOGY SYMPOSIUM

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* Significant inputs provided by MSFC's STV Study Contractors

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AGENDA

- PROJECT DESCRIPTION OVERVIEW
- AVONICS ADVANCED DEVELOPMENT CRITERIA / CONCEPT
- AVIONICS ADVANCED DEVELOPMENT NEEDS / EXAMPLES
- ADVANCED DEVELOPMENT DEMONSTRATIONS
- ADVANCED AVIONICS LABORATORY PHILOSOPHY / OVERVIEW
- BENEFITS OF AVIONICS ADVANCED DEVELOPMENT
- SUMMARY

Appendix 1 - Avionics Advanced Development Needs

Appendix 2 - Avionics Development Laboratory Support Phases

Exploration Initiative

Lunar

Robotics
- Site Selection/Verification

Emplacement
- Emplacement of Initial Surface Habitat
- Excursion Vehicle Support
- Science Experiments Emplaced

Consolidation
- Habitation Enhancements
- Expanded Science
- Mars Systems and Operations Support
- In-SITU Resource Demonstration

Operation
- Steady State Operations
- Expanded Lunar Science

Mars

Robotics
- Site Selection/Verification
- Support System Design

Emplacement
- First Human Landing and Return
- Emplacement of Initial Surface Habitat
- Demonstrate Water Production/Extraction
- Local Science and Exploration

Consolidation
- First Human Extended Stay-Time on Mars
- Habitation Enhancements
- Regional Science and Exploration

Operation
- Steady State Operations
- Expanded Mars Science

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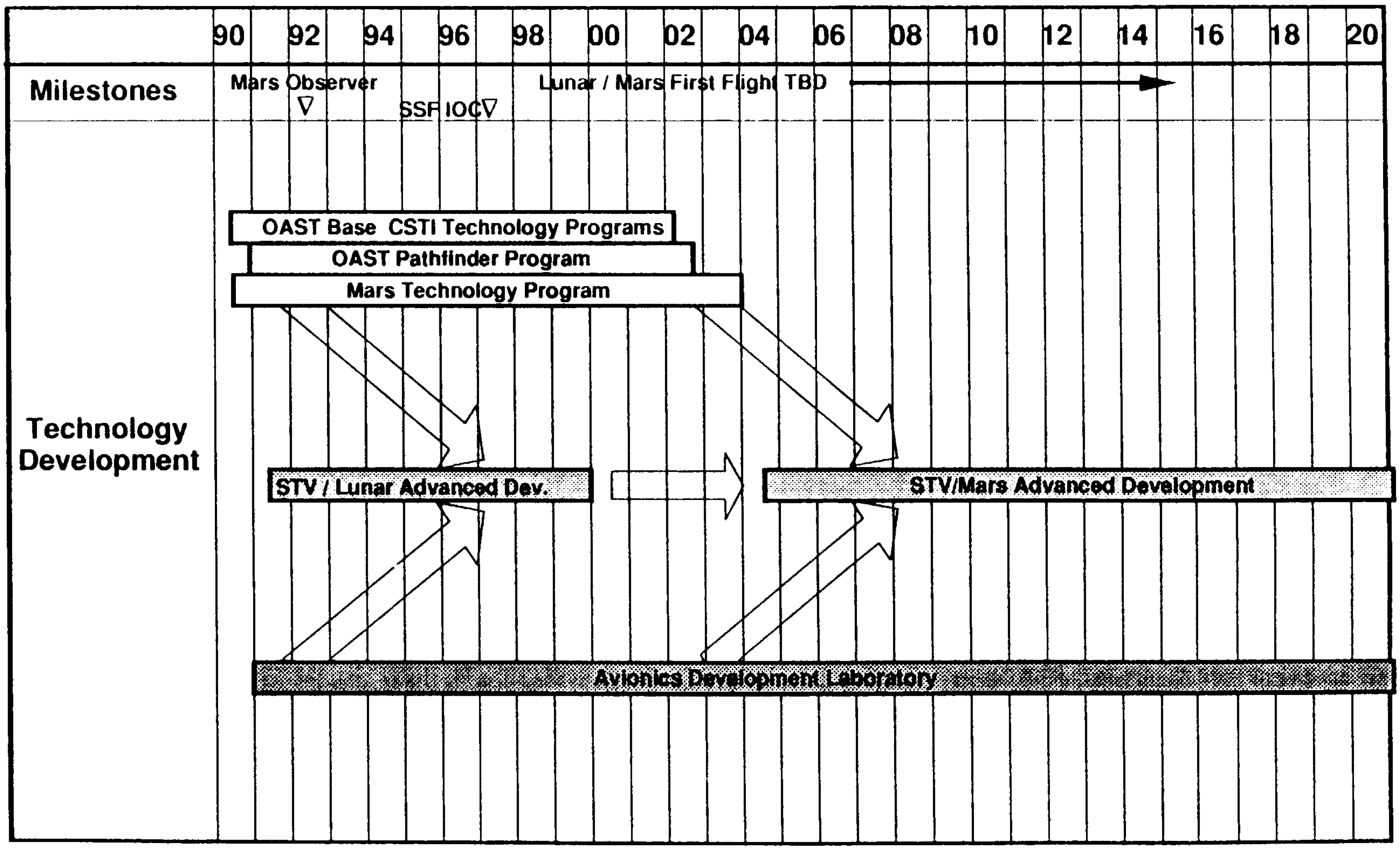
LUNAR / MARS OUTPOSTS TECHNOLOGY / ADVANCED DEVELOPMENT



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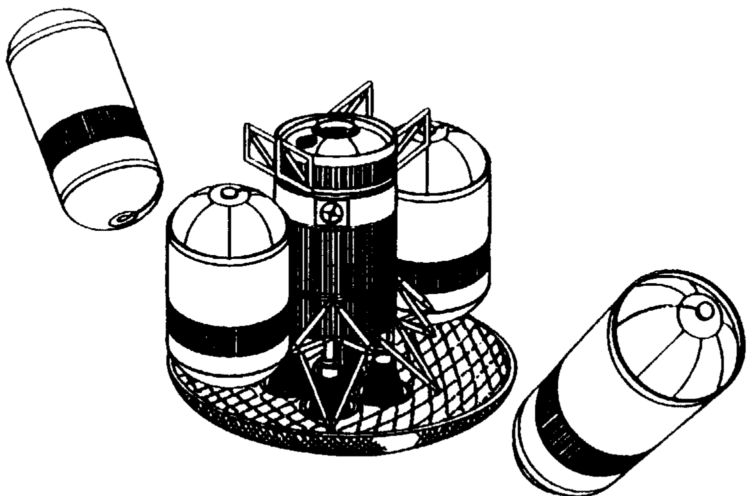
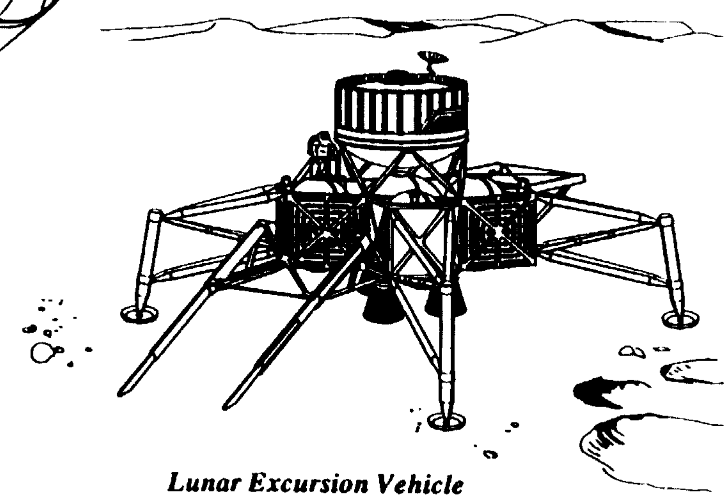
Typical Lunar Transportation System

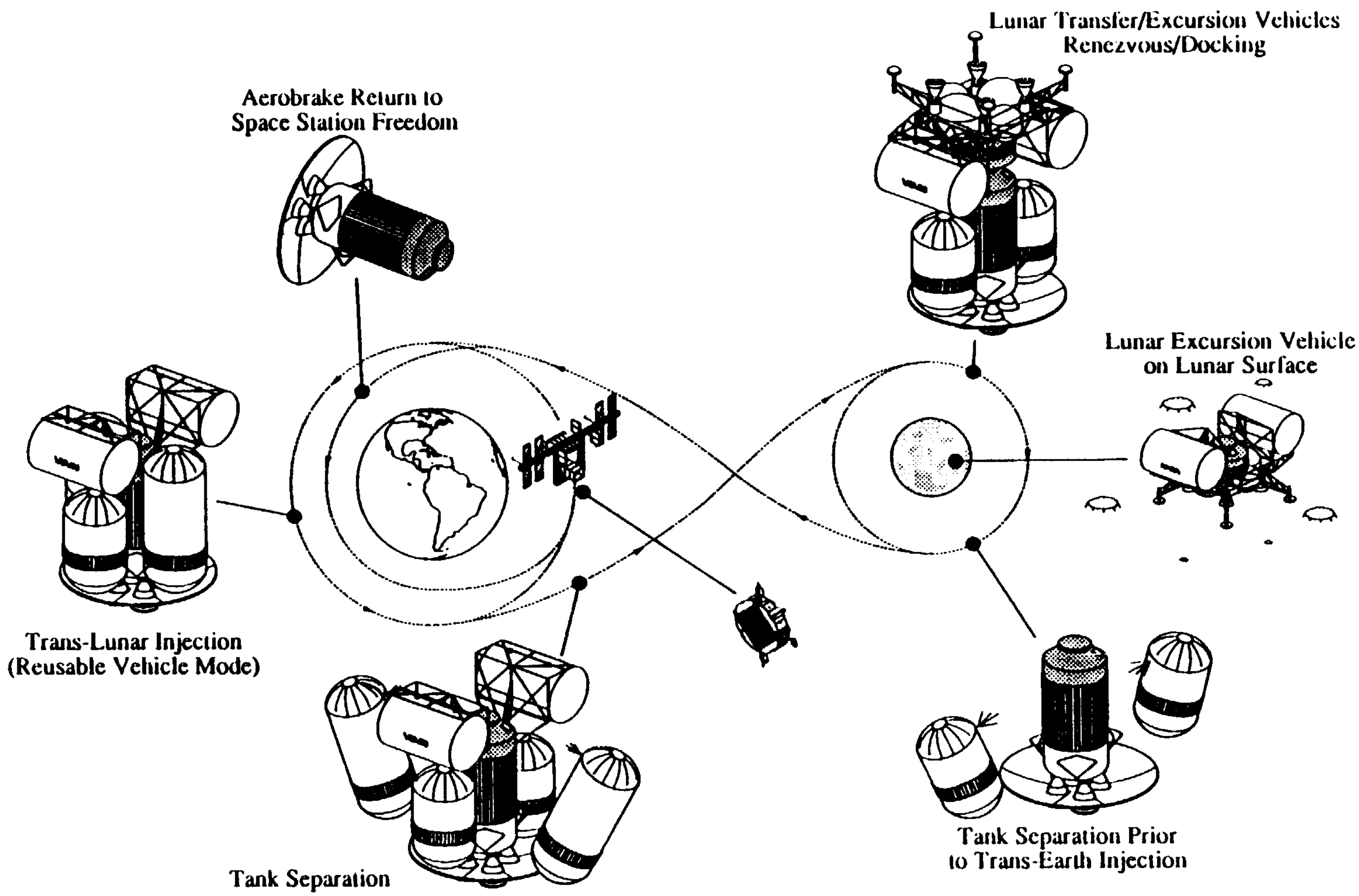


Lunar Transfer Vehicle (LTV)



Lunar Excursion Vehicle (LEV)

Lunar Transfer Operations



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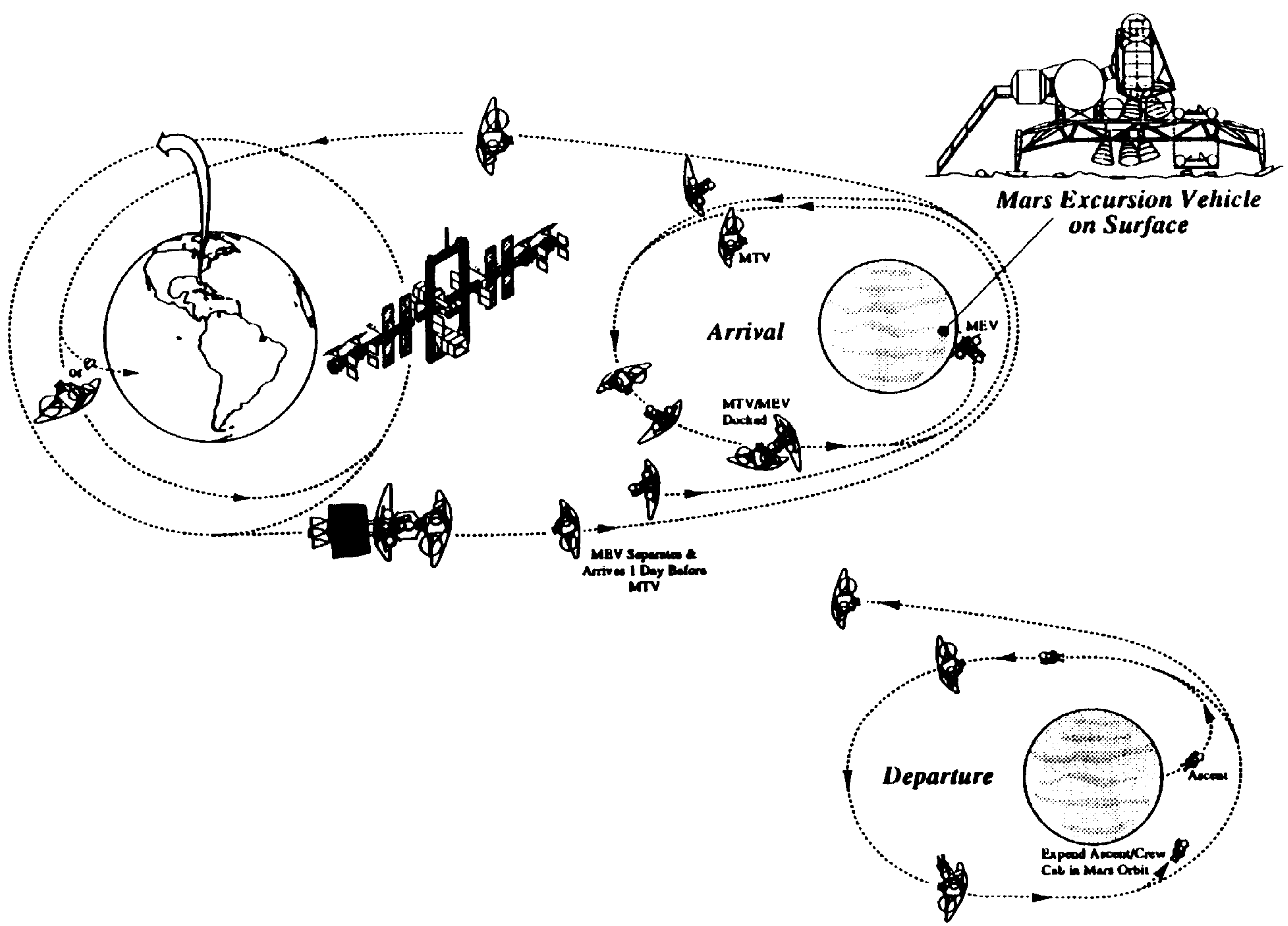
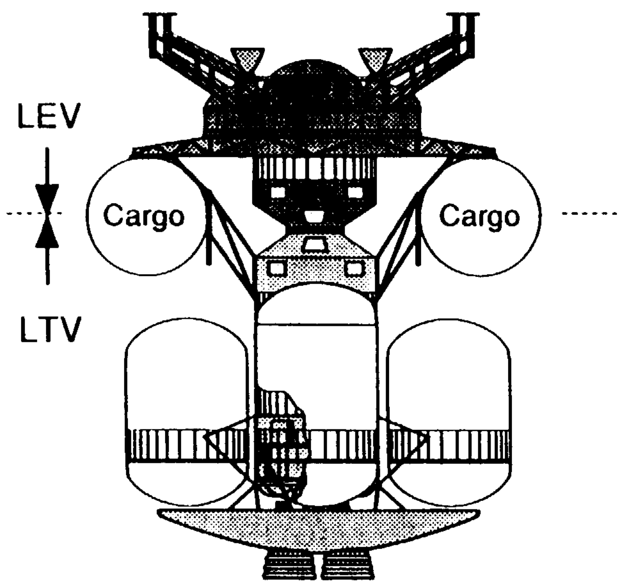
Mars Transfer Operations



Vehicle, Advanced Development & Technology

Vehicle



Advanced Development	Technology
• Space Transfer Vehicle Engine	●
• Advanced Cryo Storage and Transfer	●
• Cryo Auxiliary Propulsion	●
• Aerobrake	●
• **Avionics**	●
• Vehicle Structures	●
• Radiation Protection	
• ECLSS	
• Vehicle Assembly	●
• Vehicle Flight Ops.	

AVIONICS ADVANCED DEVELOPMENT CRITERIA / CONCEPT

CRITERIA

- Perform Technology / Advanced Development Efforts Where Necessary To:
  - Meet mission requirements
  - Make missions easier or less expensive to accomplish
  - Help reduce uncertainties or gain insight to confirm an approach
  - Discover problems and work out solutions in a lower-cost environment, prior to start of full-scale hardware development.

CONCEPT

- Technology and Advanced Development:
  - Provides hardware / concept demonstration
  - Supports early configuration / concept selection
  - Provides results available to support vehicle / program options at PDR, CDR and early operations phase
  - Provides operations validation
  - Provides performance validation
  - Provides cost validation
  - Provides common core avionics test bed for all vehicles
  - Managed within the project office
  - Implemented by government labs, prime contractors and subsystem / component contractors

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AVIONICS ADVANCED DEVELOPMENT NEEDS

	LUNAR	MARS	OMV/ROBOTIC SERVICER
PERFORMANCE			
• Vehicle Avionics	X	X	X
• Vehicle Software	X	X	X
• Vehicle Health Management	X	X	X
• Autonomous Self Test & Checkout	X	X	X
OPERATIONS			
• Automated Vehicle Assembly	X	X	X
• Autonomous Rendezvous & Docking	X	X	
• Vehicle Flight Operations Simulations	X	X	X
• Autonomous Landing	X	X	

ADVANCED AVIONICS DEVELOPMENT NEEDS VS LABORATORY / DEMONSTRATION

AVIONICS SYSTEMS NEEDS	DEVEL/PHASE LABORATORY					DEVEL/PHASE FLIGHT DEMO				
	A	B	C	D	OPS	A	B	C	D	OPS
VEHICLE AVIONICS	X	X	X	X	X			X	X	
VEHICLE SOFTWARE	X	X	X	X	X				X	X
VEHICLE HEALTH MANAGEMENT			X	X	X				X	X
AUTONOMOUS SELF-TEST & CHECKOUT			X	X					X	X
AUTOMATED VEHICLE ASSEMBLY			X	X	X			X	X	X
AUTONOMOUS RENDEZVOUS & DOCKING		X	X	X				X	X	X
VEHICLE FLIGHT OPERATIONS SIMULATIONS			X	X					X	X
AUTONOMOUS LANDING		X	X	X				X	X	X

ADVANCED AVIONICS LABORATORY PHILOSOPHY

An advanced avionics laboratory for on-orbit transportation should have the following capabilities to :

- Evaluate concepts and technologies employed in vehicle design through extensive use of software tools.
- Conduct rapid prototyping (hardware and software) of concepts for evaluation.
- Conduct sub-system simulations to explore performance, e.g., dynamics, flight code validation, calibration, etc.
- Conduct end-to-end simulations containing a mixture of simulated, emulated and prototype avionics systems.
- Conduct integrated hardware-in-the-loop simulations for the purpose of validation and verification.
- Conduct real-time mission monitoring, analysis and mission support.

UPPER STAGES

ADVANCED AVIONICS LABORATORY OVERVIEW

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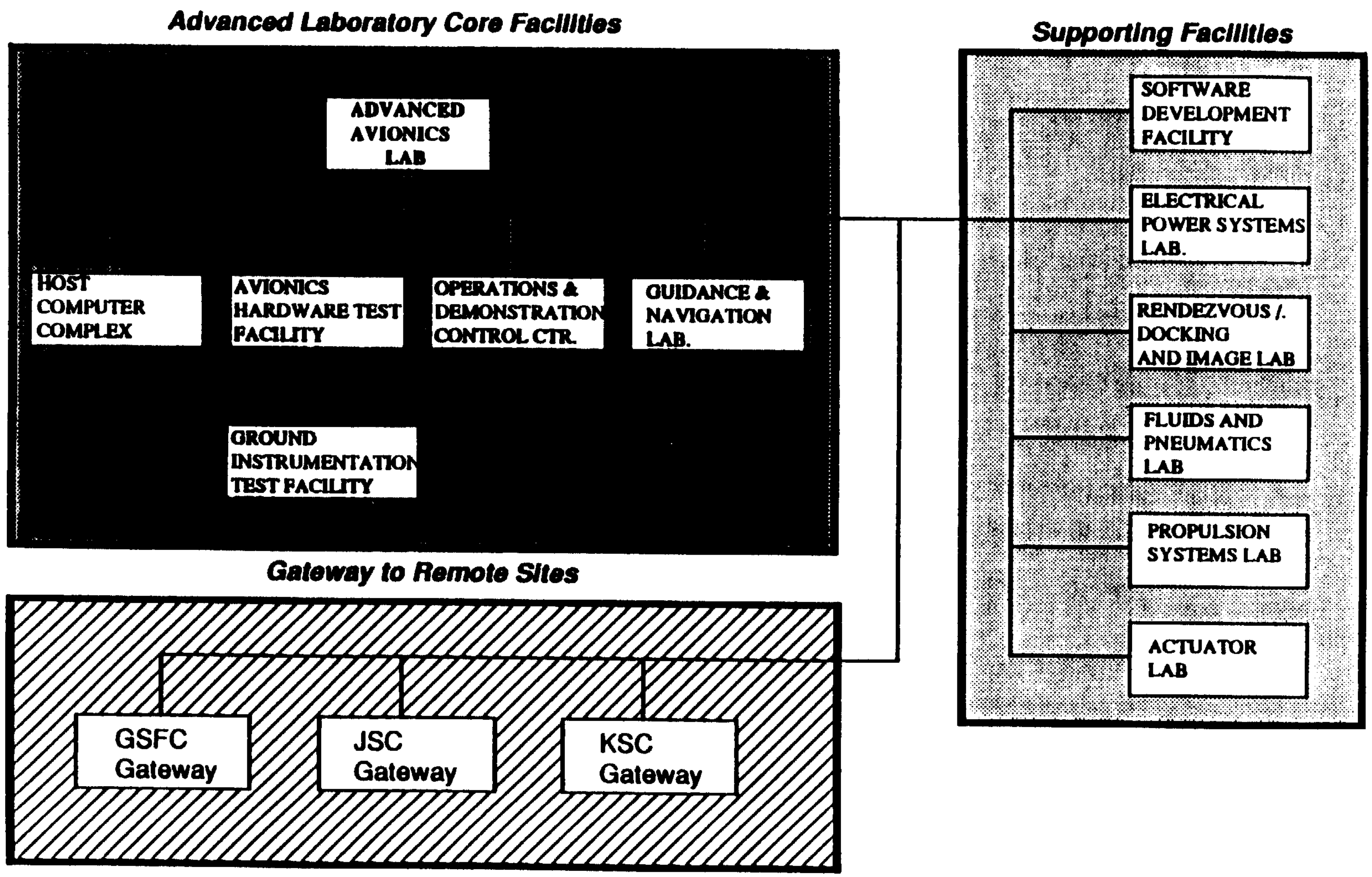

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PHASES OF AVIONICS SYSTEMS DESIGN SUPPORTED BY A LABORATORY

Phases A: Preliminary Analysis

- Systems Analysis
- Modeling and Simulation
- Concept Development

Phase B: Design Definition

- Refine Avionics Design Concept
- Establish Performance Requirements
- Define High Risk or New Technologies
- Define Data Management System

Phase C/D: Design/Development

- Specify Avionics System
- Design Components
- Design Operations
- Qualify Components
- Validate System
- Verify System

Phase E/F: Production/Operations

- Support Training
- Support Ground Operations
- Support Flight Operations
- Preform Software Maintenance
- Perform Hardware Maintenance

BENEFITS OF ADVANCED DEVELOPMENT / INTEGRATED AVIONICS LABORATORY

Advanced development:
- Validates design approaches
- Demonstrations provide solid points for design
- Enables confirmation of performance specifications

Integrated Avionics Laboratory:
- Reduces development time, provides early resolution of design issues and problems
- Key overall systems design, development & operations tool
- Aids productivity - "doing it right the first time"
- Reduces program cost, schedule & technical risk

Value
- Timely demonstration data for cost effective decisions throughout the life of a program

Advantages / Payoffs
- "Common Ground" for design, development, test, manufacturing and operations
- Proof of concept
- Continuous and evolving support to all program phases as requirements and designs mature
- Reduced unforseen / unpredicted test problems and failures
- Increases confidence in safety, reliability and mission success

SUMMARY

- Operational Validation of External Vehicle Interfaces
- Provides Early Demonstration of Redundancy Management Concepts
- Philosophy Applicable for all Program Elements
  - Components & Subsystems
  - Systems Performance & Integration
  - Vehicle Performance & Integration
- Innovative Approach Required
  - Reduce Program Costs
  - Manned & Unmanned Safety Paramount
- Multi-use Laboratory:
  - All Vehicles - LTV, LEV, Crew Module
  - Intra- and Extra-vehicle & Program Interfaces
  - All Program Phases - Concepts, Design, Integration, Test, Validate
- Increase Required in Productivity
  - User Friendly Capabilities Designed-in
  - Demonstrate/Verify System Concepts in Phases A & B
  - Autonomous Mission Operations
  - Self Monitor-Test-Validation Mandatory

APPENDIX 1 - Avionics Advanced Development Needs (Quad Charts Descriptions)

VEHICLE AVIONICS (Fig 8A) - Vehicle avioncs is defined as the data management system (comprising the computers,data storage, bus architecture),electrical power distribution, navigation and flight control sensors/effectors, propulsion control, communications and tracking, environmental control, vehicle sensors and associated interfaces required to support the mission.Figure 8A defines the need for integrated avionics systems which must be developed for exploration vehicles. These systems require new technology and the technology application must be initiated early in the conceptual design program and evolved through the Lunar/M.ars flights. The design and development of design methodologies supports fault tolerant architectures with the use of expert systems and neural networks to improve system level reliability and resiliency.
Advanced software development, production and maintenance techniques are an integral part of the evolving system development, simulation, test and validation environment The benefits of lower cost operations, high reliability and confidence and flexible configurations, for testing and flight operations mandate an increase in avionics technology. New technology is mandatory for advanced methodologies, analysis and concepts within 2-3 years, followed by advanced simulation and testing one year later and operational testing beginning in 1995.

VEHICLE SOFTWARE (Fig.8B) - The vehicle software consists of the operating system,fault detection, isolation, and recovery algorithms, and all application software required to perform all mission operations.The integrated design and development of lunar vehicle software is key to meeting the cost, safety, reliability, and flexibilty requirements of these missions. This involves determining mission specific operating system requirements, and early identification of hardware/software interfaces.Prototype system development is followed by integration of the software operating system with breadboard hardware to evolve the avionics system. The system safety of both manned and unmanned operating modes must be determined and limitations understood. The new technology schedule will develop operating system requirements in 2 years, followed by design of the fault tolerant operating system the following year. The operating system will then be verified functionally on the hardware simulator after an additional two years of operating system integration with the hardware system.

VEHICLE HEALTH MANAGEMENT (VHM)Fig.8C) - VHM directs built-in-test (BIT) and diagnostic tests to support on-orbit assembly and integration. It also supports equipment reconfiguration due to faults and/or fault prediction during all operational phases. A major design feature will be integrated, indigenous, health monitoring on key vehicle systems. This avionics capability is the major key to space based transfer and excursion vehicle reuse with a minimum maintenance goal.This approach partitions component, subsystem and system level information, handles intermittent, time variant, and multiple faults, and provides trend analysis from the onboard vehicle sensor complement.This approach results in a level of redundancy management that is required for the evolutionary program which has not been achieved to this day.The goal is to provide "designed in", autonomous vehicle system integration and checkout, with significant reduction in today's required mission operations and human resources.The increased reliabilty, fault tolerance, system reconfiguration and flexibility will require additional onboard computer and software resources.The technology development schedule includes definition of computer resources within the next year, development of the simulation and stability scenarios the following year,vehicle monitoring system partition one year later, and system level demonstration of the fault reporting methodologies in 1995.

AUTONOMOUS SELF TEST AND CHECKOUT (Fig. 8D) - Autonomous self-test and checkout consists of BIT hardware and software that is utilized during all mission phases.BIT is typically executed during system startup and operates in the background during normal operations. The unmanned Lunar reflight checkout and ascent preparations without a crew present and minimum maintenance goal provide the most significant drivers for Lunar vehicle autonomous self test and checkout. This capability must be incorporated as an integral part of the vehicle concepts and designs. Similarly Freedom and any other future orbital nodes require minimum resource allocation for assembly, repair, servicing, mission to mission turnaround, and flight recertification.These support elements emphasize the need for autonomous reconfiguration with minimal work load on the flight crews. This technological advancement will reduce costs and increase reliability by reduction of multiple supporting hardware checkout units and their continuing operational usage; in the factory, at KSC, at Freedom and on the Lunar surface. Current tactical aircraft technology has progressed significantly in this application but only limited useage has been implemented in space vehicle applications.

VEHICLE ASSEMBLY (Fig.8E) Most candidate vehicle designs require on-orbit or node assembly for the initial stage reasssembly for reuse flights. Even in the minimum maintenance scenario, servicing, repair, replacing expended propellant tankage for reflight, recertification and payload integration will be required. These individual elements are large in size and /or mass, 45 ft. (xx m) dia. aerobrakes, and 4.3 x 30 m propellant tank assemblies with individual masses up to 48 t assembled to a 30m core. The building blocks are delivered to Freedom for man tended or telerobotic final assembly, test and flight certification. The goal is to minimize on-orbit time and crew resources requirements, minimize the number of earth to orbit flights in the recurring operations mode, and provide a simple and reliable assembly operation. The operational baseline uses the OMV as a tug around Freedom to transfer the major elements, and the telerobotic servicer and Freedom remote manipulators to locate, position, interface, and integrate the multiple elements. Fluid, gas, commodity, plumbing, electrical and, data interfaces are mated by the IVA crew controlling the servicer/manipulator and assembly fixtures, EVA is used only when essential or in contingencies. NDE inspection techniques and other related technologies such as avionics and software, automated test and checkout are combined to simplify the orbital timelines. A balance between cost and complexity is maintained with a focus on safety and successful mission completion for orbital and lunar surface applications. Current STS SPAR arm applications, AI based DRPA initiatives, (DITA), and NASA flight telerobotic servicer provide examples of the technology foundation for this effort.

AUTOMATED RENDEZVOUS AND DOCKING (Fig. 8F), The Lunar/Mars missions share the requirement for automated rendezvous, closure, docking, and mating in low earth orbit, lunar and planetary orbits for unmanned missions. The resultant systems must also provide for primary on-board crew control using the same systems with appropriate man-machine interfaces. The technology requirements include mission techniques, GN&C algorithms, appropriate ranging parameters, sensors, crew display and control, and automated power, control, and consummable disconnects for transfer and interfacing between vehicles. Technology requirements are also derived from the mandatory crew display, control and command interfaces. The major drivers include the remote unloading, transport and proximity operations of unmanned ETO deliveries and transport to Freedom, and the LLO rendezvous operations involving combinations of manned and unmanned lunar transport and excursion vehicles. The key benefits include precision control systems for terminal docking and mechanical,and electrical systems integration. The major tasks include operations analyses, determination of safety technologies and sensor candidates, design of reusable quick disconnects, and the design of alignment and terminal latching devices. The current technology base for manned and unmanned vehicles includes demonstrated techniques and hardware from Gemini, Apollo, Skylab, and Shuttle with emerging technology from Freedom, OMV, Pathfinder and CSTI which provide proximity, ranging, guidance algorithms and basic AI technology.

VEHICLE FLIGHT OPERATIONS (Fig. 8G) The long duration Lunar missions present new challenges in operating complex, multiple vehicle and planetary surface stations which challenge the command, control, communication and human flight control resources. Increased lunar mission vehicle autonomy is needed for potential six month low lunar orbit transfer missions, with onboard management information processing, storage and manipulation of data for normal and contingency mission operations. The command role in individual vehicle operations will be with each vehicle while the flight control team on the ground, at station, or on the lunar surface are in support mode. The major drivers in the expanding operations technologies are the very high costs per flight due to personnel -intensive mission reconfiguration software, changing mission planning documentation, simultaneous operations of several flight elements, and multiple round the clock mission support teams. Mars missions will extend flight durations from months to years and will tend to increase operational costs exponentially.

AUTONOMOUS LANDING (Fig. 8H) Both Lunar and Mars unmanned excursion vehicles and surface hoopers will require autonomous onboard landing control and site selection. Closed loop terminal descent control form hover to touchdown is required. Communication time delays from the moon or Mars to earth make it impractical to attempt remote control of the final landing sequence. For manned missions, a safe override of the autonomous system must be provided. Autonomous landing is required for early cargo delivery and mission contingencies.

VEHICLE AVIONICS

DESCRIPTION

- Define, Develop, & Demonstrate Highly Fault Tolerant Avionics Architectures Capable of Automating Real-Time Mission & Vehicle Management Functions
- Provide Advanced S/W Development System
- Develop & Demonstrate Advanced Vehicle Subsystem Monitoring Capability For All Phases of Mission

MAJOR DRIVERS/BENEFITS

- Enabling Capability For Space Based Vehicles
- Redline Determination Increases Reliability & Probability Of Mission Success
- Reduces Turn-Around Time
- Reduces Dependence on SSF
- Reduces Software Maintenance Costs

MAJOR TASKS

- Determine Integrated System Requirements Including Data Thru-put
- Coordinate With & Incorporate Aerobrake GN&C Development Efforts
- Test & Demonstrate Key Components & Subsystems
- Simulations & Ground Testing of Integrated Systems

CURRENT TECHNOLOGY

- IUS & Centaur Basis - Ground Based Systems
- SOTA Has Neither Required Level Of Internal Reliability Nor Fault Isolation Capability
- Inflexible To Modifications & Requires Intensive Manpower For Flight Validation
- CSTI (Autonomous Systems) & Pathfinder (Autonomous Rendezvous & Docking) Provide Basic R&D in Expert Systems and Related AI Development

VEHICLE SOFTWARE

DESCRIPTION

- Provide Avionics Hardware Operating System
  - Deterministic
  - Validatable
- Support Development, Integration & Execution Of Software Algorithms
- Software Must Design-In Hardware Observability and Control

MAJOR DRIVERS/BENEFITS

- Safety - Vehicle, Mission, Crew
- Reduce Software Development Risk
- Support Self-Test & Checkout
- Increase System Reliability
- Demonstrate & Validate Hardware Testability

MAJOR TASKS

- Determine Mission Operational Requirements
- Classify Hardware/Software Interfaces
- Develop Prototypes For Avionics Lab Hardware
- Develop/Integrate Operating Systems With Breadboard Hardware
- Proof Of Concepts

CURRENT TECHNOLOGY

- Embedded Systems Use Ad Hoc Real-Time Executive (Even With ADA & CASE Tools)
- Hardware/Software Integration Is An Afterthought
- Only Door to Moderate Visibility of Hardware From Software

VEHICLE HEALTH MANAGEMENT

DESCRIPTION

- Diagnose / Handle All Faults
  Intermittent, Time Varying, Multiple
- Provide Redundancy Management Through Dynamic Reconfiguration
- System/Subsystem/Component Partitioning
- Health System Reconfiguration

MAJOR DRIVERS/BENEFITS

- Usage of Onboard Computer Resources
- Reduced Mission Operations & Costs
- Reliable, Reconfigurable & Fault Tolerant System
- Autonomous Integration & Checkout

MAJOR TASKS

- Identify Computer Resources/Requirements
- Develop Simulation / Testability Scenarios
- Develop/Verify VHM System Partitioning
- Develop Fault Reporting Methodologies

CURRENT TECHNOLOGY

- VHM Added On, Not Designed In
- Primitive Or No Long-Mission Real-Time Fault Recovery

AUTONOMOUS SELF TEST & CHECKOUT

DESCRIPTION

- High Coverage Built-In Self Test
- Autonomous Integration C/O
- Vehicle Sensors & Health Monitoring
- Autonomous Redundancy Management
- Predictions of Impending Failures

MAJOR DRIVERS/BENEFITS

- Low Cost Assembly/Mating/Ops At SSF
- Limited Resources For Repair During Mission
- Minimal Orbital Node Support Services
- Safe & Predictable Reconfiguration Behavior
- Predict Impending Failures - Crew Safety

MAJOR TASKS

- Integrate Requirements With VHM and Automated Assembly Technologies
- Develop Methodology For Predicting
- Develop Methodology & Database Methods For Measuring/Storing Performance Trend Data
- Standardization Of Mech./Elec. Interfaces (Vehicle & With SSF, OMV & Telerobotic Servicer)
- Paperless Procedures

CURRENT TECHNOLOGY

SOTA Is Limited

- ALS Paperless System "Goal"
- Aircraft Technologies
- Few Relevant Applications

VEHICLE ASSEMBLY

DESCRIPTION

- Develop Techniques and Components For Automated Assembly And Checkout
- Focus Generic I/F Technologies to Lunar Mission Applications
  - Vehicle Assembly
  - Aerobrake Assembly/Inspection/Test
  - Propellant Transfer
  - Crew Module Refurb, Installation & Verification
  - Vehicle/Payload On-orbit Integration

MAJOR DRIVERS/BENEFITS

- Massive Elements, Many Missions
- Complex Interfaces

- Minimize EVA and SSF Crew Impact
- Simplify On-Orbit Operations
- Reduction in ETO Traffic

MAJOR TASKS

- Design Standardization
  - Docking/Grappling Mechanisms
  - Vehicle Element Interfaces
- Define I/F Verification & Checkout Methods
- Quality Inspection Techniques & Procedures
- Devise Basic Operational Techniques
  - Manned Control
  - Manned Supervision
  - Autonomous
- Control System Implementation
- Flat Floor Simulations & Tests

CURRENT TECHNOLOGY

- None For Manned Systems

AUTOMATED RENDEZVOUS, DOCKING AND MATING

DESCRIPTION

Develop Capability to Rendezvous, Dock, & Mate Payloads in Low Earth And Lunar Orbits

- Develop Mission Techniques & Hardware
- Develop GN&C Algorithms
- Develop Range & Range Rate Sensors
- Demonstrate Automated Rendezvous & Docking in Flat Floor Simulations

MAJOR DRIVERS/BENEFITS

- Unloading of Unmanned ETO Transports
- Transport Payloads To LEO Node & Assemble
- LTV/LEV Operations in LLO

- Fine Control of Terminal Docking
- Electrical & Fluid Integration

- Minimize Node Support Services
- Increased Safety, Reliability, & Efficiency
- Reduced Cost & Human Risk

MAJOR TASKS

- Operations Analyses
- Hazard & Safety Analyses
- Focus Generic Technologies To Lunar Initiative Needs
- GN&C Development
- Sensor Definition
- Electrical & Fluid Service Connectors
- Latches, Utilities, Docking Structure
- Electronic Simulations
- Scaled Floor Simulations
- On-Orbit Demonstrations (OMV/SSF Testbed)

CURRENT TECHNOLOGY

- Active Piloted Vehicles (Skylab/CSM, ASTP)
- Teleoperation/Robotics (STS/SPAS)
- SSF Experience Base in AI Techniques
- OMV Develops Autonomous Rendezvous
- Pathfinder To Develop Generic Components
  - Proximity Radars & Laser RangeFinders
  - GN&C Algorithms
  - Docking Mechanisms
- CSTI Developing Basic AI Technology

VEHICLE FLIGHT OPERATIONS

DESCRIPTION

- Advanced Missions Involve Unique, Complex And Lengthy Mission Scenarios
- New Levels of Vehicle Autonomy Required To Achieve Required Safety, Survivability, & Cost
- On-Board Management, Manipulation, & Storage of Huge Data Quantities

MAJOR DRIVERS/BENEFITS

- Enabling Capability For Mars Missions
- Comm Occultation on Lunar Backside
- Simultaneous Operations of Several Major System Flight Elements
- Many Missions - Flight Times In Months/Years
- Complex Maneuvering & Control Requirements
- Reduced Costs for Mission Planning, Flight & Ground Crew Training, & Ops Support

MAJOR TASKS

- Analyses of Ops Requirements
  - LEO Build-up & Departure
  - Lunar Orbit, Landing, Take-off
  - Lunar Surface Activities
  - Return to LEO, Aerobrake, &SSF Recovery
- Develop New Ops Methodologies & Levels of Autonomy Required For Mission Phases
- Software Development & Test

CURRENT TECHNOLOGY

- SOTA is Manpower Intensive Mission & Payload Operations - Ground Based
  - Extensive Training & Rehearsals
  - Data Interpretation By Ground Crews

AUTONOMOUS LANDING

DESCRIPTION

- Safe Autonomous Landing At A Site In A Preselected Area
  - Terrain Recognition / Avoidance Slopes, Crevasses, Boulders
  - Propellant & Timeline Management
- Safe Override For Manned Missions

MAJOR DRIVERS/BENEFITS

- Required For Early Cargo Delivery
- Communication Time Delays
- GN & C and Vehicle Response
- Safety - Abort to Orbit

MAJOR TASKS

- Similarity Of Manned & Cargo Versions
- Sensor Technology, Selection & Development
- Adaptability To Emerging GN & C Algorithms
- Conceptual Simulations
  - Terrain Recognition & Anomalies
  - Propellant Slosh / Vehicle Dynamics
  - Impact System Dynamics

CURRENT TECHNOLOGY

- None Directly Related
- Aerodynamic / Earth Surface Systems
  - STS Landing System
  - Autonomous Land Vehicle Developing Related AI
  - Automated Landing For Commercial Aircraft Established Runways & Flight Paths

APPENDIX 2 - Avionics Development Laboratory Support Phases

Life Cycle Example:(Design Phases A & B)

The phase A/B of the LTV and LEV avionics system designs are critically sensitive to; the robustness of the design, the definition of system/subsystem interfaces and to the overall definition of requirements. One of the keys to overall enhancement of the engineering productivity during this phase is the ability to build system and subsystem models that are accurate representations with the capability to accommodate expected performance dispersions. This is important to reduce design cost and program risks, because of the increasing desire to accommodate changes in lunar mission requirements and provide future operational flexibility and robustness. Figure 12 A illustrates the relationships, tasks and data flows of the preliminary design phase.

In this laboratory concept, workstations are used to develop technical databases consisting of: system simulations, flight computer code, flight computer requirements, procurement specifications, and analytical test tools. This activity uses both Computer Aided Engineering (CAE) and Computer Aided Software Engineering (CASE) tools to develop advanced early prototype lunar vehicle design concepts. The early development of a prototype design concept facilitates the validating of the individual and combined system requirements. The form of early prototyping should be close, but not identical to, the actual targeted flight system with high resolution models used to complete any desired system simulation. The advantages of this approach is to; develop early interfacing and timing requirements for the lunar flight systems; develop, code and test design tools; enhance the interface between G&NC designers and flight software design and initiate manned crew interfaces in the overall concepts.

Figure 11 illustrates the interfaces between the laboratory and other program elements. The development of a distributed relational database is necessary to support the early system design phase. The inputs consist of: structural data such as a Nastran model, a solids model that provides elemental data for multi-body simulations and animations, the mission profile defining the time line and guidance parameters, and propulsion system models. The output from the laboratory consists of the performance estimate and interface control. The performance estimate gives dynamic animation results from the system simulations relating to the mission profile. More detailed results such as RCS specific impulse / performance profiles and TVC actuator power usage can also be derived. This level of performance data provides subsystem designers the parameters necessary for component design and analysis. The attributes of an early detailed design can be summarized as follows;

I.) The concurrent design of the subsystem requirements critical to the operation of the avionics system.

ii) Early validation of mission performance in the context of robust design requirements.

iii) Early validation of procurement specifications critical to subcontract control.

Given adequate avionics research and development, this approach to design will allow faster more efficient preliminary design with significantly fewer design alterations downstream.

Avionics Preliminary Design (Phase A/B)
The first step in supporting the detailed design phase of the LTV and LEV is the hosting of a replica of the avionics systems including models of subsystem components and flight computers. The resultant simulation can be run real time to verify the flight software design and redundant architectures before any hardware is integrated into the loop. The interfaces shown in Figure 12 A/B Advanced Laboratories utilization summary by program phase connect workstations through specialized I/O boards designed to meet a typical flight bus standard.

Avionics Detailed Design: Distributed Processing (Phase C)
The second step, illustrated in Figure 12 C/D, is to replace the distributed simulations with subsystem hardware. At this stage there are two types of hardware interfaces: remote laboratory interface such as the Propulsion Laboratory, and lunar vehicle avionics subsystem interfaces such as the Inertial Measurement Unit. Interfaces with remote laboratories will be required to detail requirements such as data acquisition. A special case may be the Rendezvous and Docking Laboratory where the real-time dynamics of LTV docking with Freedom and LTV/LEV rendezvous and docking in LLO can be studied to the point of validating the LTV and LEV GN&C designs. The IMU is an interesting example in that the six-dof motion can only be partially imposed on the hardware via the rate table. It is necessary to inject the six-dof data stream into the IMU processor at rates that can exceed 1000Hz, hence the additional link between the IMU (processor) and the simulation workstation. This type of interface is necessary to enable validation and verification of the IMU software. The actuation subsystem is another interesting case. Although the actuation subsystem will be identical to flight hardware, it cannot be considered representative for closed loop simulations simply because it is not coupled with the rocket engine. A simulation of the actuator response coupled to the main engine will still be required as part of the workstation simulation running in parallel . to test the power bus integration.

It is important to note that the communication bus will become a replica of the LTV/LEV avionics buses. This is desirable if the

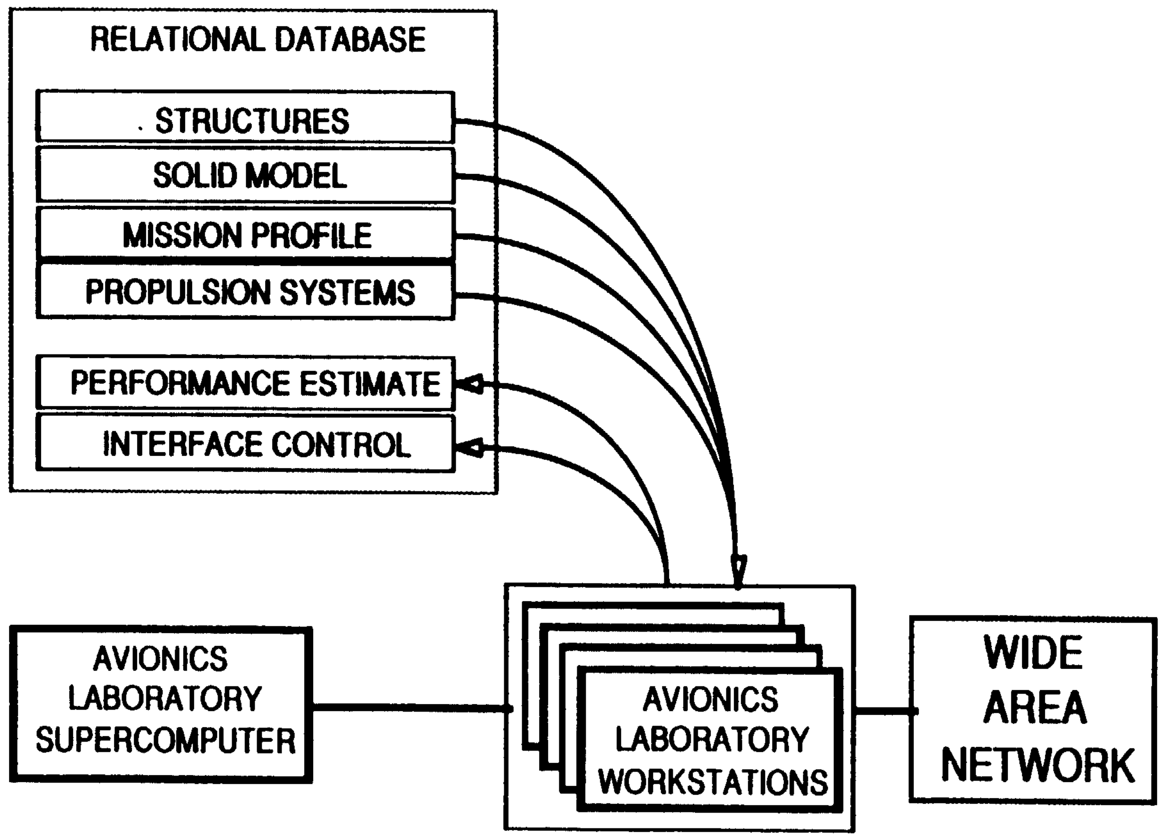
Propulsion Laboratory interface is viewed as the Propulsion Data Acquisition Unit, and the Rendezvous and Docking Laboratory is viewed as a proximity sensor. The subsystem bus interface is integral with the subsystem itself, so sensor simulation can be transparently replaced by the IMU.

Avionics Detailed Design: Hardware in the Loop (Phase D/E)
The third and final step, illustrated in Figure 12 E/F, is to complete the laboratory development for Flight Software Validation, Verification and mission support. The major additions to the laboratory include: complete subsystem integration, relocate the simulation into a flight system processor (the Data Acquisition Test and Simulation Unit - DATSU), interface test and ground support workstations, and interface the operations support system linked to other NASA center facilities. A specialized DMA monitor is included for Flight Code verification. One of the attributes of this Flight System architecture should be its ability to preform self-test. A complete end-to-end simulation can be performed to validate performance in any situation that could include environmental tests or even tests in orbit. Because the Flight System is cloned in the Avionics Laboratory, the results can be validated by comparison. To complete the test requirements, the Test Support Workstation is included for subsystem control and data acquisition. For example, because RCS solenoids have a limited life cycle, it is often necessary to isolate them during phasing tests. The Test Support Workstation controls the isolation and monitors the thruster signals. There are multiple trades which can be performed concerning functional allocation between the Test Support Workstation and the DATSU. With the growing emphasis on built-in-test, many of these test functions can be allocated to the DATSU.

Detailed Design: Flight Software Validation & Verification
One of the attributes of the Lunar Flight Systems architecture should be its ability to perform self-test. A complete end-to-end simulation as shown in Figure 12 G/H, Avionics Validation / Verification, can be performed to validate performance in any situation that could include environmental tests or even tests in orbit. Because the Flight System is cloned in the Avionics Laboratory, the results can be validated by comparison. To complete the test requirements, the Test Support Workstation is included for subsystem control and data acquisition. For example, because RCS solenoids have a limited life cycle, it is often necessary to isolate them during phasing tests. The Test Support Workstation controls the isolation and monitors the thruster signals. There are trades to be performed concerning functional allocation between the Test Support Workstation and the DATSU, with the growing emphasis on built-in-test, many of these test functions can be allocated to the DATSU.

As an example of the flexibility of the proposed Lunar avionics laboratory distributed system outlined in this paper, the following reconfiguration could be accomplished. The Avionics Simulation Workstation used during the design phase, could become the Ground Support Workstation. Using this workstation, data is extracted from the 'Relational Database' and the Mission Data Load computed (autopilot gains etc.). This data is combined with the mission flight software to form the software loads for the LTV and LEV which is then tested real time by the LTV/LEV Flight Systems. The Ground Support Workstation maintains the 'Performance Estimate' using both test data and the hypothesized telemetry data stream from the Flight System. Because the telemetry data set can be substituted for real time mission data, the Ground Support Workstation can support mission operations without modification. The Lunar operations example illustrates how systems integration of the avionics disciplines can yield increased productivity. The success this proposed system approach is predicated in part upon the development of fast workstations and flight computers, user friendly software and modern guidance and control methodologies. The "womb to tomb concept for the Lunar vehicle systems starts with concept definition and continues uninterrupted through sustained Lunar mission support for both manned and unmanned missions.

AVIONICS PRELIMINARY DESIGN

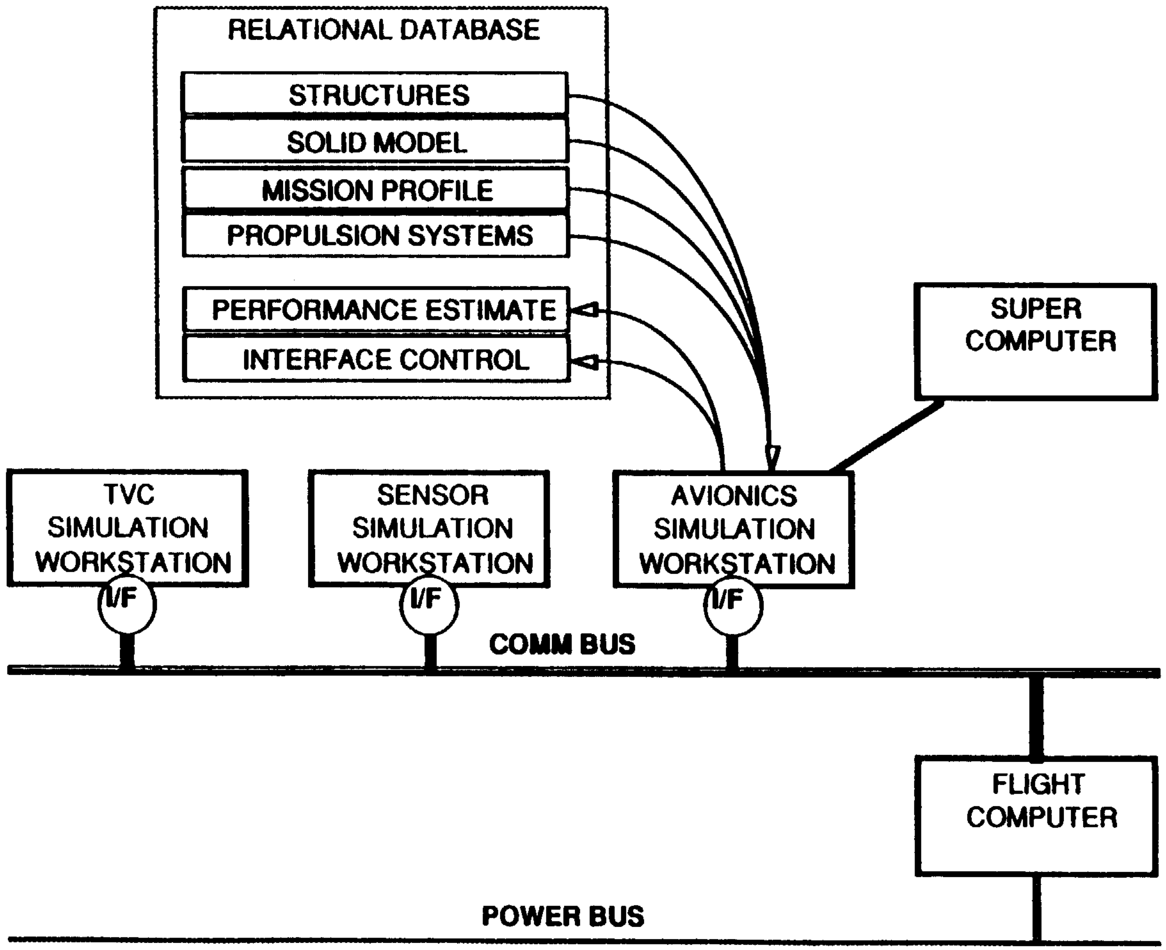


AVIONICS PRELIMINARY DESIGN

- CONCURRENT DESIGN
  - SYSTEM AND SUBSYSTEM INTERFACES MUST BE DEFINED EARLY IN THE PROGRAM IN ORDER TO ENSURE ALL REQUIREMENTS ARE ESTABLISHED
  - A RELATIONAL DATABASE COMMON TO ALL ELEMENTS OF THE PROGRAM IS REQUIRED TO ENSURE DATA PRECISION
  - EARLY DEFINITION OF AVIONICS PERFORMANCE RELATIVE TO MISSION REQUIREMENTS WILL CLARIFY SYSTEM AND SUBSYSTEM REQUIREMENTS. THIS WILL FACILITATE A ROBUST AVIONICS DESIGN

- PERFORMANCE VALIDATION
  - ACCURATE SYSTEM AND SUBSYSTEM MODELS ARE DEVELOPED TO FACILITATE GN&C DEVELOPMENT AND TEST
  - ACCURATE PERFORMANCE ANALYSIS IS ESSENTIAL TO ENSURE PERFORMANCE REQUIREMENTS WILL BE MET (ROBUST DESIGN)
  - EARLY PERFORMANCE VALIDATION IS REQUIRED TO ENSURE ACCURATE SUBCONTRACTOR REQUIREMENTS ARE ESTABLISHED

AVIONICS DETAILED DESIGN



AVIONICS DETAILED DESIGN

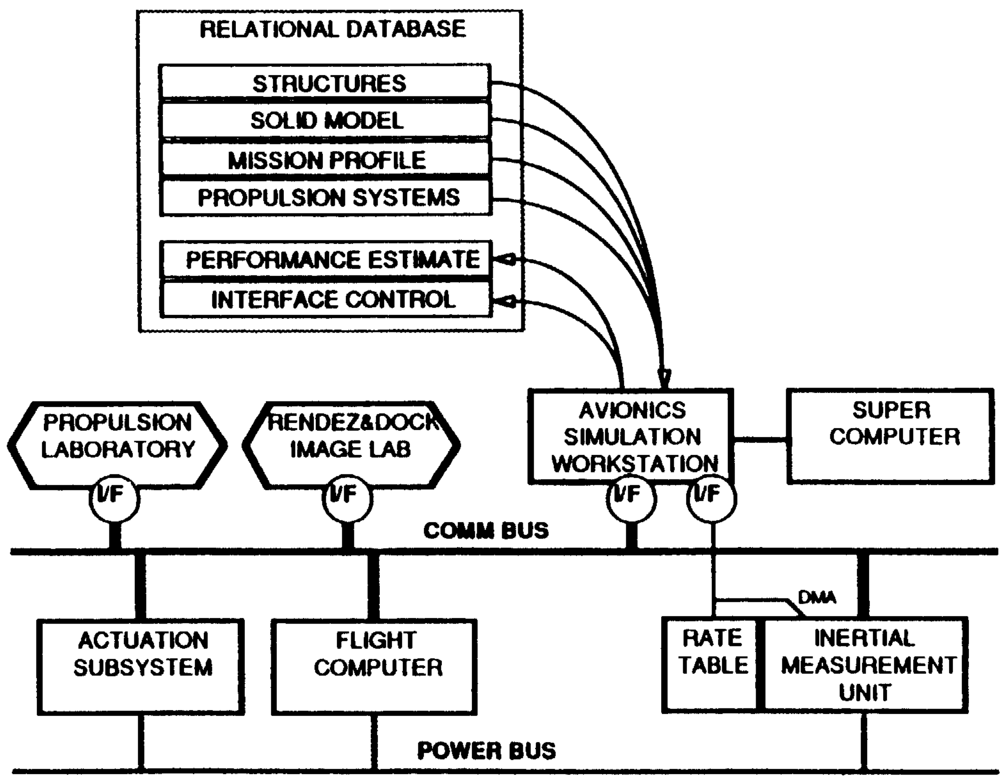
- AVIONICS SYSTEM FLIGHT ARCHITECTURE
  - THE FLIGHT COMPUTER, COMMUNICATIONS BUS AND POWER BUS ARE DEVELOPED AS THE FLIGHT SYSTEM BACKBONE
  - THE SUBSYSTEM MODELS ARE INTEGRATED INTO THE COMMUNICATIONS BUS TO VALIDATE SUBSYSTEM INTERFACES
  - THE GN&C CODE IS REHOSTED TO THE FLIGHT COMPUTER

- AVIONICS SYSTEM REAL-TIME PERFORMANCE
  - REAL-TIME PERFORMANCE IS VALIDATED DURING THE DETAILED DESIGN PHASE. THIS INCLUDES:
    - REDUNDANCY PERFORMANCE
    - SUBSYSTEM REDUNDANCY
    - BIT REQUIREMENTS
  - HARDWARE REQUIREMENTS ARE VALIDATED EARLY IN THE PROGRAM
  - MARGINS OF SAFETY ARE ESTABLISHED EARLY

UPPER STAGES

Space Transportation and Exploration Office

AVIONICS DESIGN: HARDWARE-IN-LOOP



12E

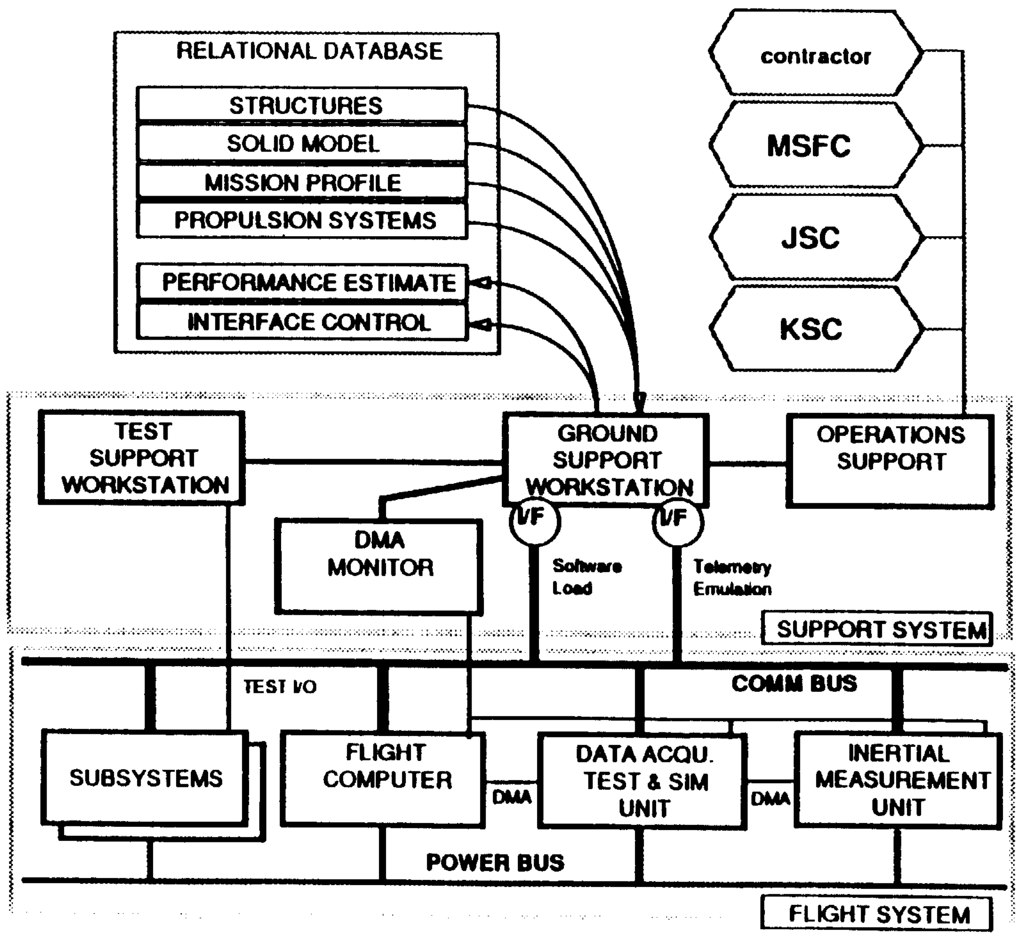
AVIONICS DESIGN: HARDWARE-IN-LOOP

- INTEGRATION OF HARDWARE INTO THE REAL-TIME SIMULATION
  - SUBSYSTEM SIMULATIONS ARE REPLACED TRANSPARENTLY BY THEIR HARDWARE / SOFTWARE EQUIVALENTS
  - SUBSYSTEM PERFORMANCE IS TESTED IN A REAL-TIME ENVIRONMENT TO ENSURE ALL REQUIREMENTS ARE MET
  - THE REAL WORLD IS SIMULATED TO CLOSE THE LOOP THROUGH THE INERTIAL MEASUREMENT UNIT
- INTEGRATION OF REMOTE LABS INTO THE REAL-TIME SIMULATION
  - A REAL-TIME ENVIRONMENT IS PROVIDED TO MEET MORE SOPHISTICATED REQUIREMENTS
  - REMOTED LABS CAN BE INTEGRATED IN AN IDENTICAL FASHION TO REAL LIFE

UPPER STAGES

Space Transportation and Exploration Office

AVIONICS VALIDATION & VERIFICATION



AVIONICS VALIDATION & VERIFICATION

- REPLICATE THE AVIONICS FLIGHT SYSTEM
  - DEVELOP THE FLIGHT SOFTWARE LOAD ON THE GROUND SUPPORT WORKSTATION
  - INTEGRATE THE REAL WORLD SIMULATION INTO THE FLIGHT SYSTEM TO PROVIDE A COMPLETE SELF-CHECK CAPABILITY USING DIRECT MEMORY ACCESS (DMA)
  - INTEGRATE A DMA MONITOR TO VERIFY THE SOFTWARE LOAD PERFORMANCE
  - INTEGRATE A TEST SUPPORT STATION FOR HARDWARE CHECKOUT

- OPERATIONS SUPPORT
  - INTEGRATE THE GROUND SUPPORT WORKSTATION INTO OPERATIONS SUPPORT
  - USE THE SELF-CHECK RESULTS FOR PRE-FLIGHT VALIDATION
  - USE THE REPLICA FOR IN-FLIGHT SUPPORT AND TELEMETRY COMPARISON
  - USE THE REPLICA FOR POST-FLIGHT ANALYSIS