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NATIONAL SPACE TRANSPORTATION SYSTEM (NSTS) TECHNOLOGY NEEDS

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DAVID L. WINTERHALTER
DIRECTOR, SYSTEMS ENGINEERING AND ANALYSIS DIRECTORATE

KIMBERLY K. ULRICH
ORBITER PROJECT MANAGER
SHUTTLE ORBITER DIVISION
SYSTEMS ENGINEERING AND ANALYSIS DIRECTORATE

TELEPHONE: (202) 453-2488

ABSTRACT

SHUTTLE AVIONICS NEEDS

The National Space Transportation System (NSTS) is one of the Nation's most valuable resources, providing manned transportation to and from Space in support of payloads and scientific research. The NSTS program is currently faced with the problem of hardware obsolescence, which could result in unacceptable schedule and cost impacts to the flight program. Obsolescence problems occur because certain components are no longer being manufactured or repair turnaround time is excessive. In order to achieve a long-term, reliable transportation system that can support manned access to space through 2010 and beyond, NASA must develop a strategic plan for a phased implementation of enhancements which will satisfy this long-term goal.

The NSTS program has initiated the Assured Shuttle Availability (ASA) project with the following objectives: eliminate hardware obsolescence in critical areas, increase reliability and safety of the vehicle, decrease operational costs and turnaround time, and improve operational capability. This project in part will insure the development of an evolved Space Shuttle which will be the primary implementation vehicle for advanced technologies for the next 30 years.

The Shuttle avionics system, which controls most of the flight critical subsystems, is a primary candidate for upgrades and enhancements. The development of enhanced avionics is a critical step in the ASA process and certain goals must be addressed early in the program to obtain the most efficient and low cost design. This phased implementation plan can be broken into four phases spanning over a 32-year period. Phase I (1984-1991) will complete the design and incorporate the upgrade programs that have already been funded through the NSTS program. Phase II (1992-1997) will incorporate upgrades mandatory to keep the system on-line and functional (obsolescence changes and safety critical changes). Where budget allows, non-mandatory upgrades that will improve operational turnaround and performance will be considered. Phase III (1998-2007) will scope the total NSTS needs and be targeted to accommodate new missions (Lunar Base, Mars, Advanced Launch Systems, etc.). Phase IV (2008-2016) will primarily concentrate on keeping the Shuttle operational by replacing obsolete components. The Shuttle will be approaching lifetime limitations near the end of Phase IV; therefore, further advanced technology should be funded under other programs, such as MARS, Next Manned Transportation System (NMTS), etc.

It is imperative that future vehicles (NMTS, Shuttle C, etc.) be considered in the design of any new system. These programs must benefit from the new technology development incorporated into the Shuttle. There is also a potential reciprocal situation where a planned NSTS upgrade is based on a "pathfinder" activity in another program. Some high level goals that will be addressed are as follows: 1) determine long-term effects of new enhancements throughout the ASA process, 2) consider hardware and interface commonality with other programs where applicable (i.e., Space Station, Shuttle C, Crew Escape and Rescue Vehicle, Orbiter Maneuvering Vehicle, etc.), and 3) capitalize on new technology development (autonomous systems) to reduce labor intensive operational procedures that currently exist.

In summary, the strategy for ASA will be to first meet our mandatory needs--keep the Shuttle flying. Non-mandatory changes that will improve operational capability and enhance performance will then be considered if funding is adequate. Upgrade packages should be developed to install within designated inspection periods, grouped in a systematic approach to reduce cost and schedule impacts, and allow the capability to provide a Block II Shuttle (Phase III).

INTRODUCTION

This paper addresses a preliminary plan to meet near and long-term avionic needs of the Shuttle Orbiter program. Since the Shuttle is the only operational manned vehicle, it will be the vehicle for implementing advanced technology development. Long-term goals, such as advanced expendable launch systems (i.e., Shuttle C) and the NMTS will be a design consideration for new systems during the Shuttle life cycle. The ASA program will provide the necessary improvements to keep the vehicle operational through its life cycle, which is estimated to be through the year 2020. However, there is a point where advanced technology is no longer relevant to the ASA program and will fall under other designated programs such as the Lunar Base, Mars, NMTS, etc. New facilities required to develop or verify new design concepts, such as development avionics laboratories, will be funded through the institutions budget or the specific programs that need this new technology.

Also, Shuttle needs in terms of ASA will be addressed. New technology development that can be utilized for Mars missions or the NMTS will be discussed in broad terms, not directly under the ASA program. Although orbiter avionics upgrades are critical, they will be in competition with other systems, such as Solid Rocket Boosters (SRB) and Space Shuttle Main Engines (SSME). The NSTS program may not be able to incorporate all changes that are beneficial, however, those that are affordable and offer the correct long-term benefits will be implemented. It should be noted that the ASA program is a contender for funding, but, has not officially been approved in the budget process. Other methods of funding may have to be considered.

AVIONICS SYSTEM OVERVIEW - LIMITATIONS AND CONSTRAINTS

The Space Shuttle avionics system plays an integral role in all phases of flight from pre-launch to post landing. This highly complex system is composed of over 300 Line Replaceable Units (LRU'S) connected to five General Purpose Computers (GPC) through a digital data bus network. The primary functions of the system are to provide ground checkout, performance monitoring, and control of the vehicle. The system architecture, through use of redundant hardware and complex software programs, allows for failures (fail-operational/fail-safe) without compromising the safety of the vehicle. The design and development of this vehicle took place during the 1970's; therefore, the capabilities designed into this system were significantly advanced compared to other systems utilized during this timeframe.

The avionics system interfaces with almost every subsystem on the vehicle; External Tank (ET), SRB's, SSME's, Flight Control, etc. Most functions such as guidance, navigation and control of the vehicle, communication and tracking, payload operations, vehicle attitude control, subsystem monitoring, and failure annunciation are performed by the Data Processing System (DPS). The DPS hardware composition and functions are shown in Table 1.

TABLE 1.

DATA PROCESSING SYSTEM

HARDWARE	***FUNCTION***	***UNITS***
General Purpose Computers	Central Processing	5
Digital Data Buses	Transmit Input/Output Commands	24
Mass Memory Units	Software and Data Storage	2
Multiplexer Demultiplexer (19 ORB, 4 SRB)	Convert and Format Data	23
Main Engine Interface Unit	Command SSME's	3
Multifunction CRT Display System	Monitor and Control Vehicle	4
Master Events Controller	Command signals to arm and safe pyrotechnics	2
Master Timing Unit	Provides precise frequency output for timing and synchronization	1

The DPS software is a sophisticated set of programs, which utilizes over 500,000 lines of code. These programs were developed using a combination of a specialized high-order language and assembly language to accommodate real-time space flight applications. The Primary Avionics Software System (PASS) is the principal software used to operate the vehicle. An independently coded backup software package is loaded into the fifth GPC and is mainly utilized if a generic failure causes PASS to become inoperative.

During ascent and entry phases of flight, the DPS is configured into four independent strings (two-fault tolerant) in a synchronized fashion, each string utilizing one GPC.

Redundancy is managed in both the software and hardware making this system stable and reliable. The Shuttle avionics system is one of the most sophisticated and integrated aerospace systems today. The Shuttle avionics architecture can be seen in Figure 1.

As with any complex system, the Shuttle avionics system has limitations. One of the primary limitations with the current system is the labor intensive requirement for flight operational readiness (i.e., software/hardware verification, I-Load verification, etc.). Also, highly complex designs for certain components necessitate a highly skilled person for repair and maintenance (long turnaround time). These limitations and others require certain upgrades to the ground and flight hardware to improve turnaround time and guarantee the flight manifest is met. As R&D laboratories invent new and more efficient electronic components, the avionics systems which are in use today become obsolete and parts are no longer manufactured.

While designing new LRU's to eliminate obsolescence, the opportunity exits to increase performance capabilities on the Shuttle program. However, this creates a paradox. The significant amount of time required to design, develop ("tailor" for specific requirements), and qualify a piece of hardware along with new technology development, causes a system to be obsolete before it is ever flown. These constraints and realities must be considered in new avionics systems designs during the ASA Program.

ASSURED SHUTTLE AVAILABILITY

The ASA program will be a phased implementation plan of enhancements to the vehicle with the following objectives in mind: eliminate hardware obsolescence in critical areas, increase reliability and safety of the vehicle, decrease operational costs and turnaround time, and improve operational/payload capability. This phased implementation can be broken down into four phases spanning over a 32-year period.

Phase I (1984-1991) will complete the design and incorporate the upgrade programs that have already been funded through the NSTS program. Additionally, budget has been requested to start new upgrades in fiscal year 1991. The current programs include the enhanced GPC, Inertial Measurement Unit (IMU), MDM, Star Tracker, Tacan, Mass Memory Unit (MMU), and the Master Events Controller (MEC). The major drivers behind these upgrade programs were obsolescence and maintainability (repair costs and turnaround time). Most of these enhancements will reduce weight, volume, power, and take advantage of new available technologies

SHUTTLE AVIONICS ARCHITECTURE: A HARDWARE-SOFTWARE CORE WITH PERIPHERAL HARDWARE

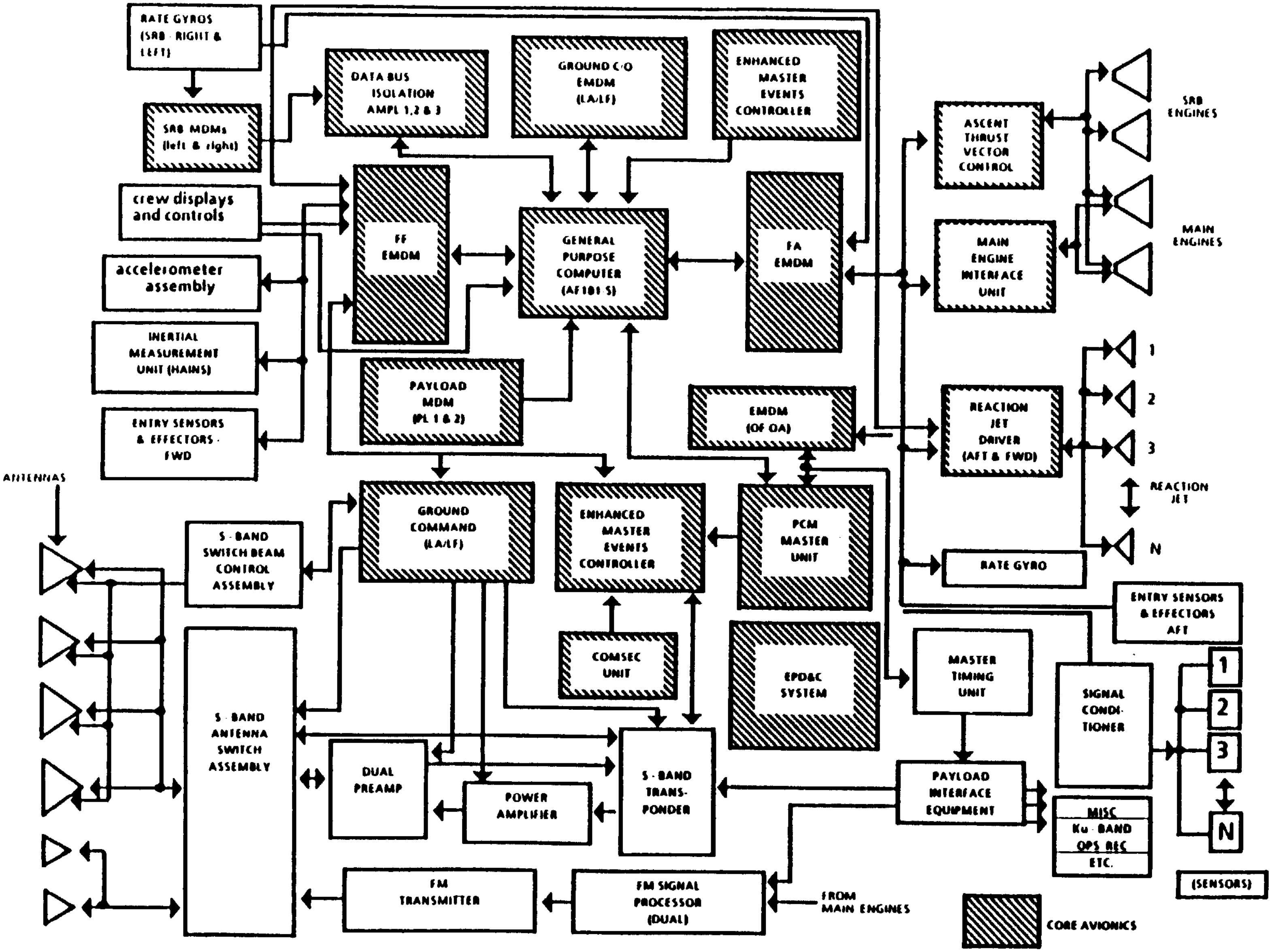

Figure 1

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to improve reliability and maintainability, thus, reducing the life cycle costs of the hardware. Additionally, enhancements to the new GPC's include increased memory capability and faster data processing. The new IMU's were enhanced with a better error detection capability reducing turnaround and software verification. Upgrades that are functionally "transparent" and require little or no changes to the software, such as the IMU and MDM, are attractive because of reduced program costs. Phase I will be completed by the end of 1991 when OV-105 becomes operational and significant work begins on items for Phase II of the implementation process.

Phase II (1992-1997) of the implementation process is very important relative to the designs chosen for new systems. The major upgrades that will be incorporated in this phase are those mandatory to keep the system on-line and functional (obsolescence changes and safety critical single-point failures). Other enhancements that may fall into this phase are those driven by economical factors (reduced life cycle costs) and desirable changes (non-mandatory performance improvements).

As in all programs, the project funding levels will require all potential candidate upgrades to be cost effective and beneficial to the overall NASA Agency, whether for obsolescence upgrades or operational improvements. The current redundancy and fail operational/fail safe features must be maintained with any new upgrade. Although the NSTS program should be cost effective, we must keep in mind that the NSTS's role is to be the implementation vehicle for new technology developments that make sense to implement. Likewise, the NSTS should not implement new technology that is not cost effective. To insure we are in step with the R&D programs, we should work closely with the Office of Aeronautics and Space Technology.

The proposed changes for Phase II presently being contemplated that are necessary because of obsolescence or will provide more capability are as follows: glass cockpit, electrical power distribution and control (EPD&C), Integrated Navigation System/Global Positioning System (INS/GPS), and integrated communications system. Some of these features will not only eliminate obsolescence, but will improve reliability and consolidate (reduce) the number of LRU's. These systems will also decrease weight and power, improve the performance of the vehicle, and lessen ground testing requirements substantially. Although obsolescence can be solved without incorporating integrated systems, integration will be advantageous and cost effective to the program in terms of reliability, performance, and ground turnaround. The architecture of these systems changes will be designed to accommodate a Block II Shuttle (Phase III) without a total system redesign. A Block II Shuttle concept will incorporate numerous enhancements that require significant modifications to the vehicle during an extended vehicle downtime and can only be accomplished with a fifth Orbiter sustaining 14 flights per year. Some candidates may require flight tests (INS/GPS) to assess the reliability of the system. These tests, whether ground or flight, will be identified and costed during the trade studies.

Non-mandatory upgrades that will improve operational turnaround and performance (weight savings, automated systems, etc.), generally require major mods to the vehicle or significant up-front funding. Some of the options that fall into this category are as follows: on-board verification and checkout, high power fuel cells, electromechanical actuators, automated flight design system, integrated flight status monitoring system, etc. If these upgrades are considered, it is imperative that comprehensive trade studies be made before significant funding is committed. More autonomous systems will eliminate the labor intensive requirements for flight readiness; however, limited funding will necessitate that all changes be compared on the basis of performance enhancements and safety improvements. Although non-mandatory changes are potential candidates for Phase II, budget constraints could push these options into Phase III.

The selection of Phase II upgrades must be given serious engineering forethought so the program does not get locked into the same labor intensive operational costs and turnaround time that exist today. Additionally, the Agency's credibility in costing projects is of great concern; therefore, a well thoughtout contractor proposal will be negotiated prior to Authority to Proceed (ATP). Planned NSTS upgrades could also be based on "pathfinder" activities in other programs, thus reducing costs. Commonality of hardware, system interfaces, software, and crew procedures should be considered where applicable in Phase II upgrades. For example, commonality will reduce manufacturing and testing costs.

Other factors relevant to mandatory and non-mandatory changes are structural and modification downtime. Upgrades will be selected and scheduled so that the flight manifest is not impacted. Flying with differently configured vehicles (hardware and software) is not cost effective in terms of crew training, facility upgrades, etc. Some configuration differences will be unavoidable; however, they can be drastically reduced if upgrades are grouped systematically or functionally with transparency to other areas. Costs can also be reduced if enhancements are made in interrelated groups such as glass cockpit, automated cockpit switches and controls, on-board crew training, on-board checkout and verification, assured orbiter return (crew unable to perform time-critical functions), health monitoring system, etc.

Costs for facility upgrades to the Shuttle Avionics Integration Laboratory (SAIL), Shuttle Mission Simulator (SMS), Mission Control Center (MCC), etc., will be considered when selecting enhancements. Upgrades in Phase II will be installed in OV-106 (assuming approval) in-line. Approval of OV-106 will allow modification periods in excess of three months after OV-106 is operational. The orbiter modification schedule is represented graphically in Figure 2.

The priorities for Phase II are to first implement mandatory changes (obsolescence and safety). If schedule and budget funds allow, examples of non-mandatory candidates that will be considered are automated flight design, on-board checkout and verification, and electromechanical actuators. Automated flight design and on-board checkout/verification will both reduce manpower requirements for flight readiness, thus fulfilling a highly desirable goal. Electromechanical actuators will improve reliability, turnaround time, performance, fault tolerance, as well as decrease weight and costs. In reality, changes such as high power fuel cells, electromechanical actuators, advanced EPD&C, and on-board checkout and verification will most likely be implemented in Phase III because of the required modification time.

Phase III (1998-2007) will scope the total NSTS needs and be targeted to accommodate new missions (Lunar Base, Mars, etc.). Additionally, some of the upgrades incorporated in Phase I will already be obsolete and require further redesign. Rather than upgrade specific LRU's, new advanced architectures should be considered for 1) evolving into a Block II Shuttle concept, and 2) be implemented in line to a new orbiter (i.e., OV-107). Any projects not funded in Phase II will have top priority.

Approval of a new vehicle (OV-106) will play a key part in the implementation of any upgrades requiring major modifications. Without a fourth vehicle, upgrades must be incorporated during the normal KSC flow and/or the planned 3-month structural inspection period in order to maintain the flight manifest. This could seriously reduce any major modifications made to the vehicle or upgrades will have to be implemented incrementally. If OV-106 is approved, this will allow individual vehicles to be scheduled for long periods of downtime to install major modifications.

The main objectives of Phase III are to progress into a more autonomous operational program and utilize previous upgrades and new technologies to develop a Shuttle Block II concept. In terms of ground processing, automation of a bad process is not necessarily good. The process must be analyzed for efficiency and possibly changed before it is automated. The advanced technology developed in Phase III will be geared toward requirements for the NMTS and mission requirements for Mars.

SHUTTLE PHASED IMPLEMENTATION PLAN

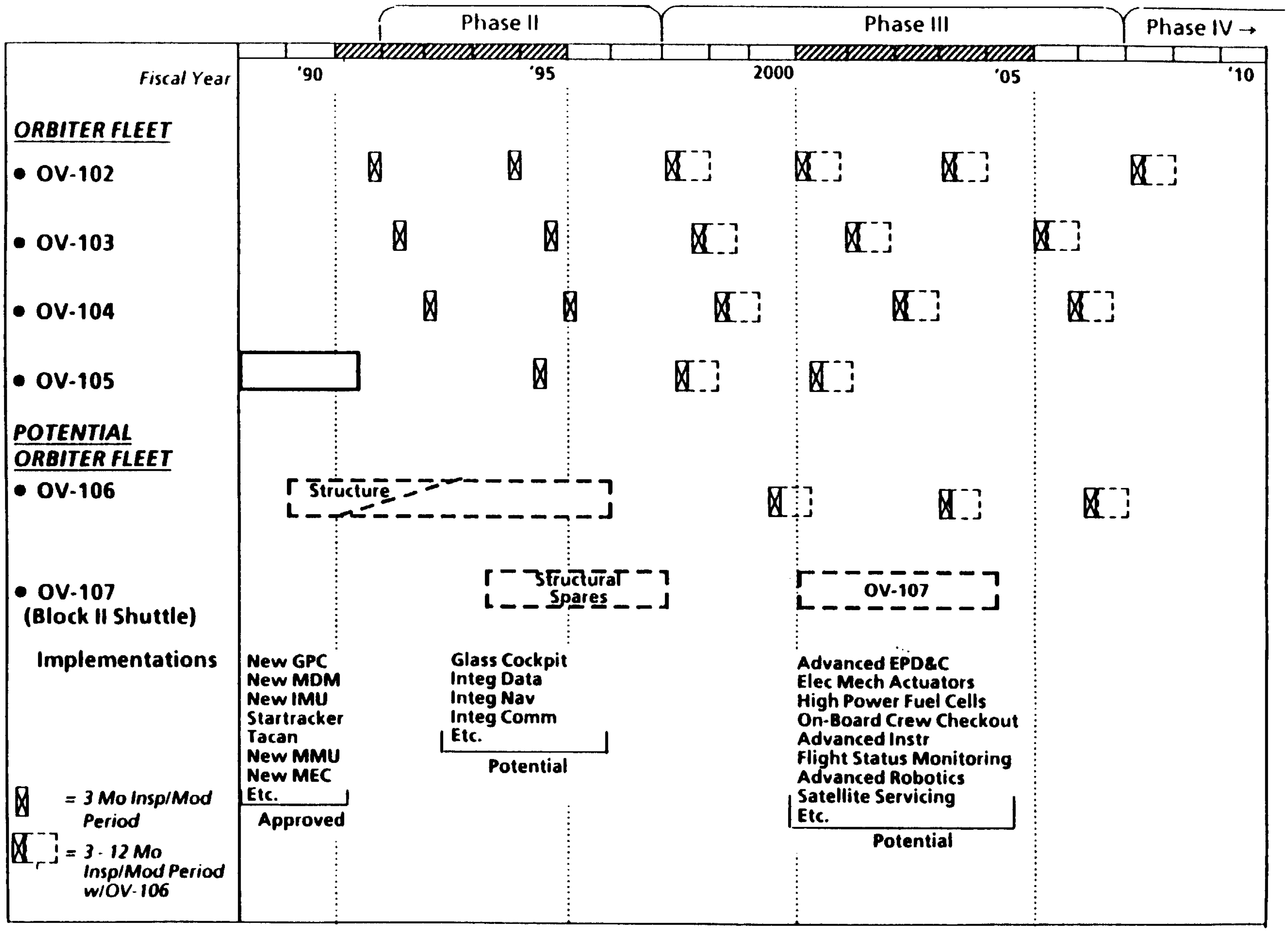

Figure 2

The autonomous systems in avionics such as rendezvous and docking, landing, and GN&C can be applied to the Mars program and advanced expendable launch vehicle (ELV) programs.

If a Block II Shuttle (OV-107) were initiated in 1998, studies for advanced avionics architectures must begin in 1995. This would allow five years for DDT&E before the hardware is installed (2001). Evolving into a Block II Shuttle will allow more capability to be designed into the avionics system. Upgrades will not require transparency to the existing architectures, such as those implemented in Phase II. Figure 2 graphically represents a potential plan for a future Orbiter fleet.

Potential candidates for this phase are as follows: advanced avionics laboratory (integrated Shuttle/Space Station), advanced avionics architecture (facilitate vehicle autonomy), satellite servicing (autonomous rendezvous, docking, etc.), advanced robotics (autonomous payload deployment). To obtain these sophisticated systems, investment in risk analysis and management systems (identify risks inherent in new avionics designs) and computer aided software engineering (artificial intelligence) will be required.

The integrated avionics laboratory is applicable to ASA and should be implemented early in this phase (1998) with trade studies performed in 1996/1997. This facility will combine the SAIL with the Multisystem Integration Facility (MSIF) for Space Station. This concept will reduce overall integration costs for space transportation systems and maximize use of center expertise for subsystem development and verification. It will also promote commonality of hardware between the two programs.

New facilities that are required for design and verification of new approved flight hardware/software systems (i.e., advanced architectures) will be provided through institutional funds. Such facilities could include a Data Management Systems Test Bed, Optical Avionics Laboratory, Systems Integration Laboratory, etc.

The Risk Analysis and Management System is another high priority candidate that should be initiated early in Phase III. This system can be utilized to identify and quantify risks associated with new avionics architectures in order to make cost effective, reliable, and safe upgrades.

Phase IV (2008-2016) will primarily concentrate on keeping the Shuttle operational (i.e., replace obsolete components from Phase II, minor upgrades). The Shuttle will be approaching lifetime limitations near the end of this phase; therefore, further advanced technology should be funded under other programs such as Mars, NMTS, or Advanced Launch Systems (ALS).

SUMMARY

The strategy for ASA will be to first meet our mandatory needs--keep the Shuttle flying. This requires that all upgrades due to obsolescence and safety have first priority. Non-mandatory changes to improve operational capability and turnaround will be incorporated when program funding can accommodate these upgrades.

The primary goals for ASA are as follows: eliminate obsolescence, reduce operational costs and turnaround time without impacting safety and reliability, increase performance, and enhance operational capability. Selection of new enhancements will be made based on cost and performance benefits. Limited funding will require that significant trade studies be made to determine the appropriate enhancements to implement, accurately negotiate costs, and understand the operational benefits/savings.

Upgrade packages should be developed to install within designated inspection periods, grouped in a systematic approach to reduce cost and schedule impacts, and allow the capability to provide a Block II Shuttle. Approval of follow-on orbiters is critical to allow sufficient time for major modifications. Commonality of hardware, software, crew procedures, and system interfaces between various programs, where applicable, is highly desirable.

The program should eventually evolve to a more autonomus operational concept eliminating costs and turnaround time wherever possible. NASA intends to retain its role as the leader of new technology development, and the Shuttle is a good base for implementing technology improvements.

It should be noted that avionics upgrades, although critical, will be in competition with other systems such as SRB's and SSME's. The NSTS program may not be able to incorporate all changes that are beneficial, however, those that are affordable and offer the correct long-term benefit will be implemented. Although the ASA program is supported by the Agency, it has not been officially approved in the budget process.