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CARGO LAUNCH VEHICLES TO LOW EARTH ORBIT

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Introduction

The National Space Policy signed by President Reagan on Jan 5, 1988, and the National Space Launch Program Report to Congress signed by President Bush on April 10, 1989, established the basis for assessing the nation's launch vehicle infrastructure. Consistent with the policies and time-phased strategies defined in these documents, reliable access to space will be provided through the use of a mixed fleet of launch vehicles, including the space transportation system (STS), existing expendable launch vehicles (ELVs) and new heavy lift launch vehicles (HLLVs). This will give the Nation the capability to meet the base program needs and accommodate the expanded requirements of human exploration of the Moon and trans-Mars through either a vigorous or a paced deployment of assets. The existing United States space infrastructure provides the launch capability to perform Lunar/Mars robotic missions, assemble Space Station Freedom (S.S. Freedom) and establish it as a transportation node for Lunar and planetary missions.

Current capabilities, augmented with HLLV systems will provide the balanced, flexible, and assured access to space necessary to meet current commitments and perform the bold new initiative recently outlined by the President.

Requirements

There are two primary space transportation capabilities required to support both base program and expanded mission requirements: earth-to-orbit transportation systems and space transfer vehicle systems. Table 1 depicts which existing and new earth-to-orbit (ETO) vehicles are required to support each of these mission requirements. It is evident from this table that current launch vehicles can accommodate the base program mission requirements. However, the expanded mission area will require new launch vehicles. Current ETO capabilities will need to be augmented with a HLLV for lunar missions and a growth HLLV for Mars missions.

Earth-To-Orbit Launch Vehicle	Civil Mission Requirements						
	Base			Expanded			
	SSF Assy/Logistics	Spacelab	Science/Planetary/ Observatories	SSF Accommodations	Precursors	Lunar	Mars
Existing:							
• Atlas					x		
• Delta					x		
• Titan			x		x		
• STS	x	x	x	x		x	x
New:							
• HLLV					x	x	
• Growth HLLV							x

Table 1. ETO Requirements

Base Program

Many types of missions are included in the base program: assembly, logistics, and crew rotation for the S.S. Freedom; servicing of satellites; Spacelab; delivery of communication, science, planetary, and observatory satellites in support of the science, application and technology programs; and mission to planet earth activities. The base program missions are manifested on a mixed fleet consisting of the STS and a stable of ELVs. Existing transportation systems have sufficient performance capabilities to support base program requirements.

Expanded Mission Area — Lunar/Mars Initiative

Robotic Missions

The ETO transportation system is required to support the launch of robotic missions prior to any piloted Lunar/ Mars mission. These robotic missions support the selection of outpost sites, location of potential resources, emplacement of navigation aids, and provide engineering data for the design, development, and operation of the outposts. These missions are also required to augment life science databases to ensure the health and safety of the crew, and to provide communications capabilities needed for the lunar missions. Table 2 shows the planned robotic missions, along with the ETO vehicles currently planned.

Destination	Mission (Flights)	Vehicle
Polar Orbit	Life Sat (10*)	Delta II
Lunar	Lunar Observer (2)	Atlas II
L_2 (Far Side)	Comm Sat (1)	Atlas II
Mars	Global Network (2)	Titan IV
Mars	Sample Return/ Local Rover (2)	Titan IV
Mars	High Res. Imaging/ Comm Orbiter (2)	Titan IV
Mars	Rovers (1)	Titan IV
Mars	Rovers (1)	Titan IV
Mars	Rovers (1)	Titan IV
Mars	Communication Sat. (1)	Titan IV

Note: *Two flights per year for five years.

Table 2. Robotic Precursor Missions

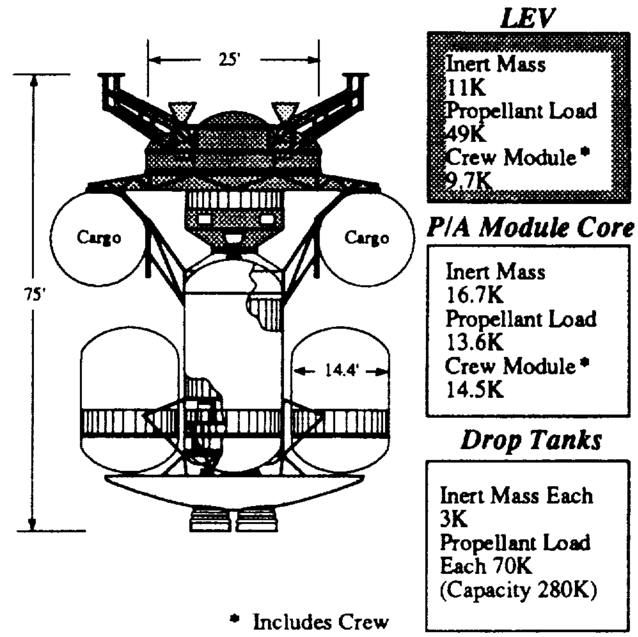


Figure 1. Lunar Transfer and Excursion Vehicles

Lunar Outpost

The mission requirements for the Lunar outpost are partitioned into three phases—the emplacement phase, the consolidation phase, and the utilization phase. The ETO transportation system must ferry vehicles, cargo, crew, and propellant to S.S. Freedom (220 nm altitude) in support of these Lunar outpost phase requirements. Reference capability for a new HLLV to deliver these various payloads to S.S. Freedom is a manifested mass limit of 135K to 157K per flight (with 25 ft and 15 ft diameter shrouds respectively). The LTV/Lunar excursion vehicle (LEV) shown in Figure 1, indicates that the aerobrake and the LEV (25 ft diameter) are the driving components for the large shroud size. The smaller 15 ft shroud provides an adequate volume for the 157K propellant delivery.

A capability to test and process the Lunar transfer vehicles at the S.S. Freedom is needed to meet the required cargo and piloted Lunar launches. Accommodation equipment must be ferried to S.S. Freedom beginning in the mid to late 90s to meet these launch dates for the Lunar outpost.

The mass requirement for payload delivery to S.S. Freedom for each mission in support of the Lunar outpost cover a range of 242K-440K. This mass range is driven by whether the vehicles operate in expendable or reusable mode, the mission is cargo or piloted, and whether Lunar LOX is being utilized. Mass requirements for piloted flights include cargo in addition to the mass of the crew. Approximately 70 to 75 percent of the mass delivered to LEO is LTV propellant. The 15 ft shroud HLLV with a 157K payload capability can deliver two LTV propellant modules to LEO. Initial delivery of an entire single LTV/ LEV mission requires two 157K and one 135K HLLV flights.

Mars Outpost

Establishing a permanent, self-sufficient base on the surface of Mars will follow an evolutionary path with emplacement, consolidation, and utilization phases similar to the Lunar outpost. Once again, the ETO transportation system must ferry the vehicles, cargo, crew, and propellant to S.S. Freedom in support of Mars outpost requirements. Additional growth of S.S. Freedom, beyond that required for the Lunar outpost, is required to accommodate MTVs in support of Mars missions beginning in 2015.

The growth HLLV for the Mars outpost requires significantly greater capability than the HLLV used to support the Lunar outpost. An ETO delivery mass of140t is utilized to manifest MTV payloads to be integrated at S.S. Freedom. The reference MTV (Figure 2) illustrates vehicle elements which must be delivered separately and assembled in orbit. The aerobrakes and the trans-Mars injection stage (TMIS) are elements driving the HLLV to a payload shroud of Figure 2. Mars Transfer and Excursion Vehicles 40 ft in diameter and 100 ft in length. Each fueled TMIS stage tank has a mass of 300K. Multiple flights of the growth HLLV will deliver all the elements and propellant of a complete MTV to LEO.

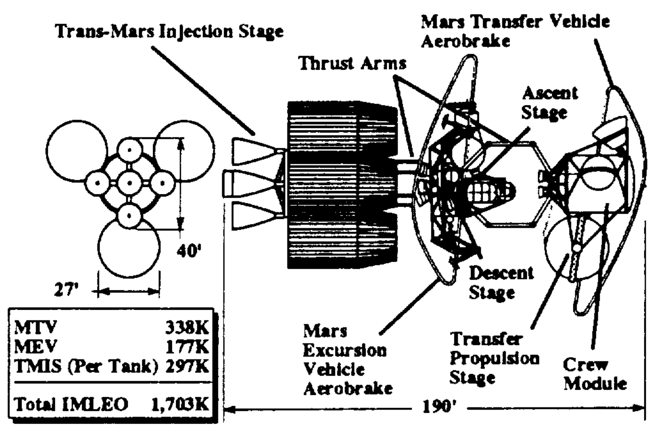


Figure 2. Mars Transfer and Excursion Vehicles

The mass requirements to S.S. Freedom to accommodate the Mars piloted outpost cover a range of approximately 1210K-1870K depending on the mission type and the year flown. Propellant for trans-Mars injection and trans-Earth injection constitute the majority of the mass to LEO.

Base and Expanded Model

A composite model of the projected range of mass-to-orbit requirements for the base and expanded (Lunar and Mars portions) programs is shown in Figure 3. Lunar mass delivery requirements more than double the total mass-to-orbit requirements by the turn of the century. When Mars missions begin in 2015, total mass delivery requirements more than double again. Figure 4 illustrates the number of individual payload elements delivered to LEO by payload mass range for the 1990 to 2020 time period. The payload mass range of greater than 65K (beyond the capability of existing space transportation systems) is a new requirement imposed by Lunar/Mars missions.

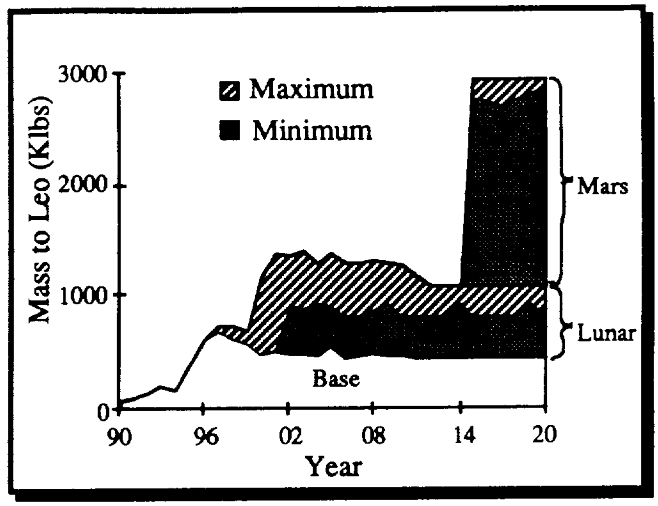


Figure 3. Composite Mission Model - Mass To LEO

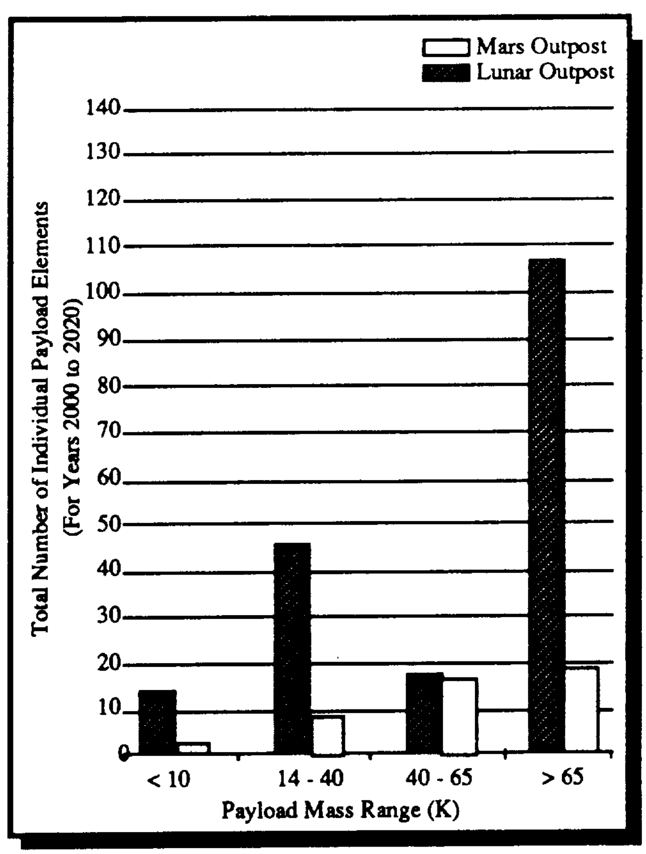


Figure 4. Composite Mission Model - Number of Payloads To LEO

Existing Systems

Earth to Orbit

EXPENDABLES. Three families of unmanned ELVs, Titan, Atlas, and Delta, are currently available to augment the STS. As shown in Figure 5, the capabilities of these ELV families have been enhanced over the past few years to meet increasing national needs. The Titan IV, Atlas II and Delta II are adequate to accomplish all robotic missions. Planned ELV flights through FY 1994 are shown in Table 3. Depending on total national needs in the time period of the robotic missions, Table 4 indicates a potential Titan IV launch rate problem (assumes continued Titan IV launches at the rates indicated). HLLV availability could alleviate ELV constraints by providing joint manifesting of some of these missions.

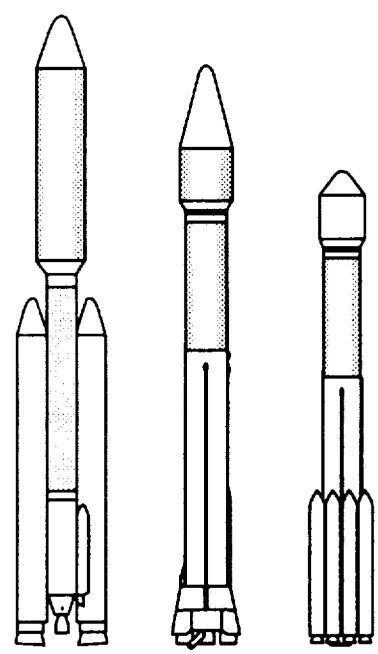


Figure 5. Expendable Launch Vehicle (ELV) Capabilities

Launch Systems	Flight Rates - Fiscal Years					
	1990	1991	1992	1993	1994	Total
Titan IV	5	7	5	6	5	28
Delta II	6	4	4	4	2	20
Atlas II	-	2	2	2	1	7
Totals	11	13	11	12	8	55

Table 3. Planned ELV Flights

New or Upgraded Transportation Capabilities

ETO Vehicles

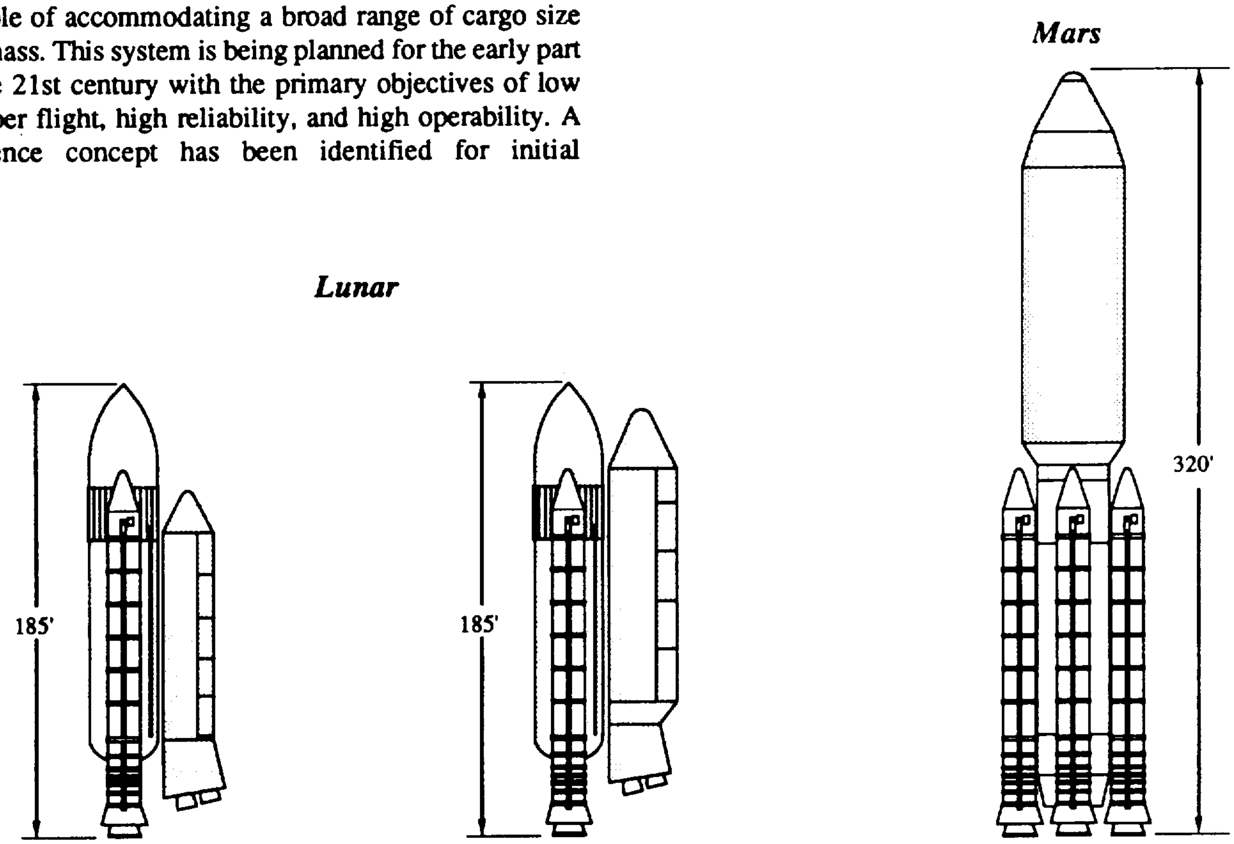
By the mid to late 1990s, ETO transportation systems will require a heavy lift capability to support the new initiative missions. The only heavy lift concept being considered prior to 1999 is the Shuttle-C, an unmanned Shuttle derived cargo vehicle. The Shuttle-C could support assembly of S.S. Freedom and its growth to a Lunar transportation node. At the turn of the century, the expanded requirements of the Lunar/Mars initiative will necessitate greater capabilities of unmanned, low cost launch vehicles such as ALS or derivatives of the STS. Lunar outpost ETO transportation requires significantly higher launch rates and lift capabilities than are currently available and could utilize the Shuttle-C, ALS, or a mixed fleet of both. Growth HLLVs will be required to launch the payloads, propellants, and space vehicles required for the Mars outpost missions.

SHUTTLE-C. The Shuttle-C is designed to be an unmanned launch system capable of reliably delivering heavy payloads to orbit. Shuttle-C is not a new system, but rather an expansion of our current STS program. It uses existing and modified STS qualified systems, such as ASRBs and a slightly modified ET with structurally enhanced interfaces. To minimize ETO launches, the 15 ft and 25 ft diameter shrouds will be utilized with a common expendable boattail (Figure 6). Lunar missions can be manifested in three launches for the early missions and two launches for the steady-state missions. The 15 ft configuration (157K capability) maximizes propellant and high density payload delivery to orbit. The 25 ft configuration (135K capability) is required to accommodate delivery of the large diameter LEV and aerobrake elements.

The ETO transportation requirements for the Mars outpost require a launch vehicle with an expanded payload volume and greater lift capability than that required for the Lunar missions. The growth HLLV (Figure 6) is capable of delivering 300K to S.S. Freedom with a payload envelope of 40 ft diameter and 100 ft length. Four ASRBs are used as first stage boosters. Five SSMEs in a recoverable propulsion/avionics (P/A) module are used on a 33 ft diameter core stage. After main engine cut-off (MECO), the core stage separates from the payload and a small kick-stage transfers and circularizes the payload at the required orbit. Following core separation, the P/A module separates from the core vehicle and returns to Earth for reuse.

ADVANCED LAUNCH SYSTEM (ALS). The ALS, a joint program of the U.S. Air Force and NASA, is being defined as a family of unmanned cargo launch vehicles capable of accommodating a broad range of cargo size and mass. This system is being planned for the early part of the 21st century with the primary objectives of low cost per flight, high reliability, and high operability. A reference concept has been identified for initial deployment to meet the ALS requirements. The Lunar and Mars requirements have been evaluated as a delta to the ALS reference program.

To minimize Lunar HLLV launches, the two booster vehicle is used (Figure 7). Each Lunar mission can be manifested using two ALS flights. The payload weights shown are net payload to S.S. Freedom orbit with all circularization/stabilization and flight support equipment accounted for. In addition to the ALS vehicle, a transfer stage and uprated OMV are required to transfer the payloads from MECO to S.S. Freedom orbit. The most significant impacts of the Lunar initiative to the ALS program are those elements not currently in the program related to circularization/stabilization and the introduction of the two booster vehicle earlier than planned.

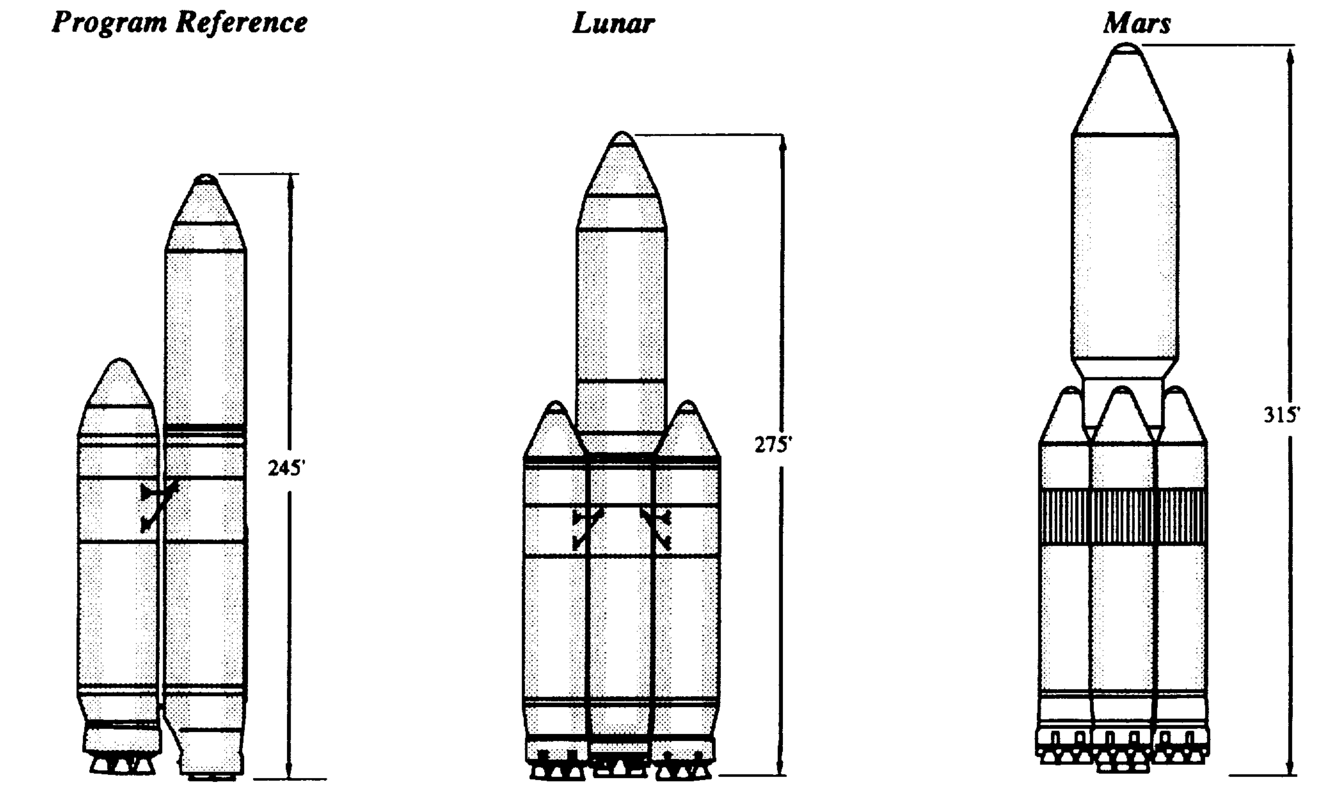


Net Payload	157K
Boosters	2 ASRB's
Core Stage	Standard ET
Core Propulsion	3 SSME's
Payload Envelope	15' Dia.
	82' Length

Net Payload	135K
Boosters	2 ASRB's
Core Stage	Standard ET
Core Propulsion	3 SSME's
Payload Envelope	25' Dia.
	90' Length

Net Payload	300K
Boosters	4 ASRB's
Core Stage	New 30' Dia.
Core Propulsion	Recoverable P/A
	w/5 SSME's
Payload Envelope	40' Dia.
	100' Length

Figure 6. Shuttle Derived Vehicles for Lunar and Mars Mission Requirements



Program Reference	
Net Payload	115K
Boosters	1 LOX/LH_2 w/6 STME's
Core Stage	LOX/LH_2
Core Propulsion	3 STME's
Payload Envelope	25' Dia. 100' Length

Lunar	
Net Payload	215K
Boosters	2 LOX/LH_2 w/6 STME's ea.
Core Stage	LOX/LH_2
Core Propulsion	3 STME's
Payload Envelope	33' Dia. 100' Length

Mars	
Net Payload	300K
Boosters	3 LOX/LH_2 w/6 STME's ea.
Core Stage	LOX/LH_2
Core Propulsion	3 STME's
Payload Envelope	40' Dia. 100' Length

Figure 7. Advanced Launch System (ALS) for Lunar and Mars Mission Requirements

Mars missions are accommodated using previously mentioned vehicles together with the three booster vehicle shown in Figure 7. This vehicle, which utilizes a 40 ft shroud, will accommodate the large elements illustrated in Figure 2. The MTV configuration can be manifested within seven ALS flights.

Advanced Avionics Technologies

Figure 8 indicates the time period allowed to develop a launch vehicle to meet the requirements for the lunar missions. PDR for the launch vehicle needs to be held at the end of 1994. At this time the technologies that will be incorporated into this design must reach the OAST designated level 5. By CDR in 1995 the level must reach 6 or 7.

Figure 9 indicates the time period to develop a launch vehicle to meet the requirements for the Mars missions. PDR would be scheduled for 2005 at which time the technology maturity should reach level 5 and level 6 or 7 by CDR in 2008.

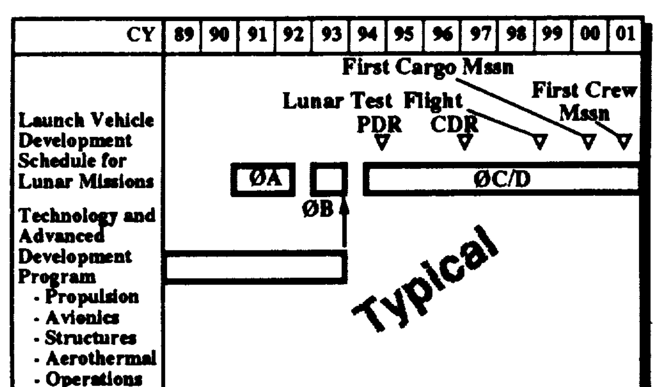


Figure 8. Launch Vehicle Development Schedule for Lunar Missions.

Since the launch vehicle for the lunar missions needs to be developed in the near term, the various technologies required for this vehicle will be the ones discussed in the following paragraphs.

Current launch vehicles were designed for performance, and incorporate the technology from their design era. They typically cost about $3600/lb of payload to orbit. Figure 10 shows we can reduce this cost for an HLLV

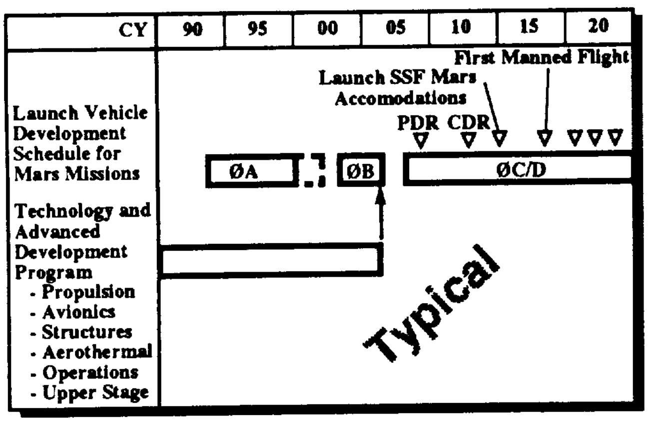


Figure 9. Launch Vehicle Development Schedule for Mars Missions.

payload by the economy of large payload capability, through the use of LO_2/LH_2 propellant to eliminate the need for a core second stage, and by rate and quantity effects to achieve less than $1000/lb before adding the advantage of technologies.

Further cost reductions for a new launch vehicle must come from incorporating appropriate new and applied technologies to reduce the recurring operations costs of manufacturing and launching. These are producibility improvements provided through new methods of manufacturing low cost engines, structures, automation of integration and launch processes, and higher reliability of the launch vehicle and its support equipment.

Figure 11 illustrates the cost of an existing technology "strawman" vehicle relative to current launch vehicles and the desired goal. The allocated cost difference to achieve the goal is shown for each technology area. This allocation was calculated using a sophisticated estimation and cost-savings software model that calculates technology savings and their synergistic effects (both positive and negative) upon vehicle/operations costs.

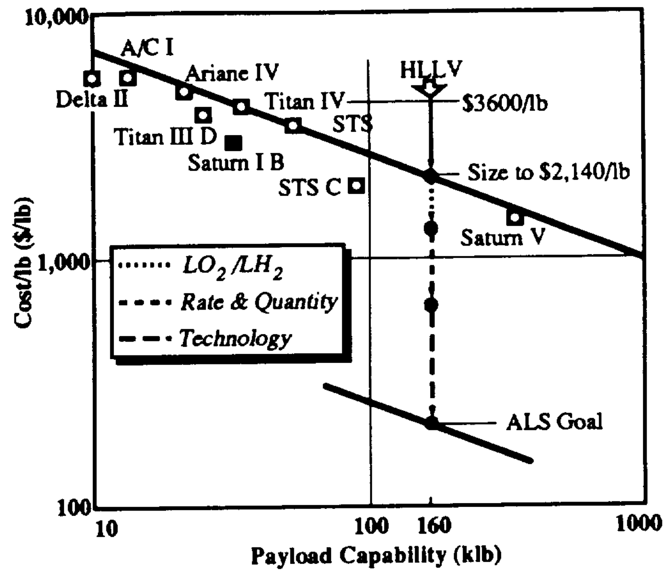


Figure 10. Identification of Target Cost Savings For Technology Developments

Figure 12 shows the degree of cost savings already achieved by technology demonstration/implementation on existing ELV programs.

Technologies have been ranked according to cost-reduction potential and consideration of their overall benefit to a new launch vehicle concept as shown in Table 4. The top nine in the list have the most significant cost savings.

The next grouping of two technologies have relatively lower cost savings but represent high schedule impacts.

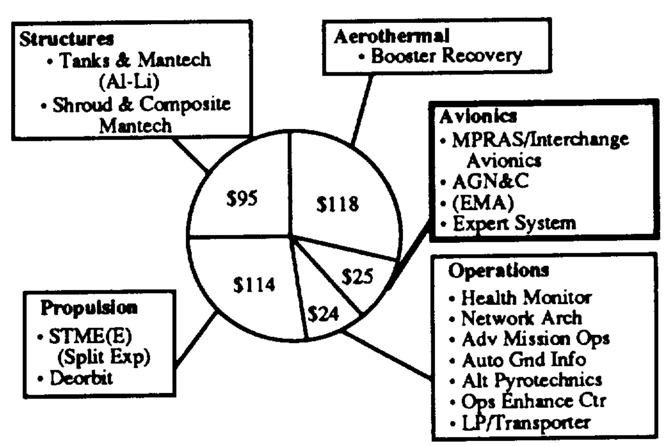


Figure 11. Focused Technology Contributes to Reducing the Cost to-Orbit

The next group of is generally ranked according to cost savings. Items like manufacturing technologies, or expert systems, make larger benefits available in other areas.

Items in the fourth group, of lesser cost impact, affect turn around times and resiliency to failures, and are important. The maturity of each technology at the present time is shown at the top of Figure 13. Definitions for maturity level are derived from the NASA Office of Aeronautics and Space Technology technique for describing the technology development process. Progressively increasing levels and maturity represent advancement from generic base to a focus on specific program needs.

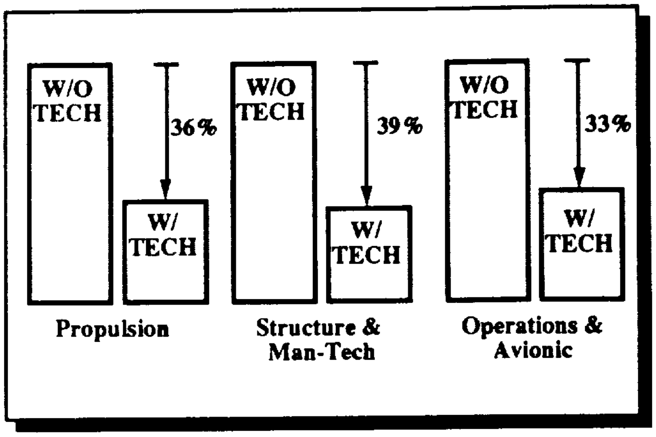


Figure 12. Projected Cost Savings for Each Technology Development Area

The avionics technology advancement must present an integrated approach to reducing launch system costs. Technologies are interrelated with each other and with the system development activity (see Figure 14). Interfaces between the various avionics elements within the vehicle segment and operations segment are recognized as big cost drivers. The different elements of avionics cannot be developed separately, then integrated, and provide any significant cost savings.

A multi-path redundant avionics suite (MPRAS) technology development is central to all launch vehicle avionics. All of the other avionics technologies, adaptive guidance, navigation, and control (AGN&C): electromechanical actuators with integrated electrical power supply (EMA): expert systems for decision-aid applications (ES): low-cost interchangeable avionics; and alternate pyrotechnics, exchange data with the MPRAS technology to achieve the benefits of an integrated approach. MPRAS, developed with an associated lab, can provide a test bed for demonstrating cost savings and technology feasibility.

Rank	Title	Contribution	Rationale
1	STME(E)-LO_2/LH_2 Gas Generator	Propulsion Cost	Major Cost Impact
2	STME(E)-LO_2/LH_2 Split Expander	Propulsion Cost	
3	STME(E) Vehicle/Engine Definition	Propulsion Cost	
4	Booster Recovery Module	Propulsion Cost (Booster Recovery & Eng Reuse)	
5	Expendable Tanks & Structures	Core & Booster Structures Cost	
6	MPRAS	Cost & Enables AGN&C and Vehicle Reliability	
7	Integrated Health Monitoring	Operations Cost, Engine & Vehicle Reliability	
8	Composite Payload Shroud	Shroud Structures Cost	
9	Interchangeable Avionics	Backup Avionics Cost	
10	Ops Facitilies Design-Ind Prep	Schedule-Preparedness for Assembly & Launch	Schedule Impact
11	Launch Platform/Transporter	Transporter Cost and Schedule	
12	Mantech-Automated Welding & NDE	Manufacturing Cost of Structures	Enables & Validates Other Technologies
13	Operations Enchancement Center	Validates Ops Cost & Procedures	
14	Expert Systems	Enables AGN&C, Health Mon, & Automated Ops	
15	Mantech-Composite Structures	Manufacturing Cost of Structures	
16	Advanced Mission Operations	Mission Planning Costs	Lesser Cost Impacts
17	AGN&C	Mission Planning Cost & Vehicle Robustness	
18	Network Architecture	Ops and Facilities (Computer) Cost & Schedule	
19	Solid Rocket Booster	Backup Propulsion Cost and SRB Reliability	
20	Electromech Act/Power Supply	Operations Checkout Cost	
21	Auto Ground Info Processing	Information Processing Costs	
22	Core Deorbit	Cost and Technology Risk Reduction	
23	Aero Data Bases	Supports Structure Cost Reduction	
24	Alternate Pyrotechnics Initiation	Operations Cost	

Table 4. Technology Prioritization Accounts for Cost and Risk Factors

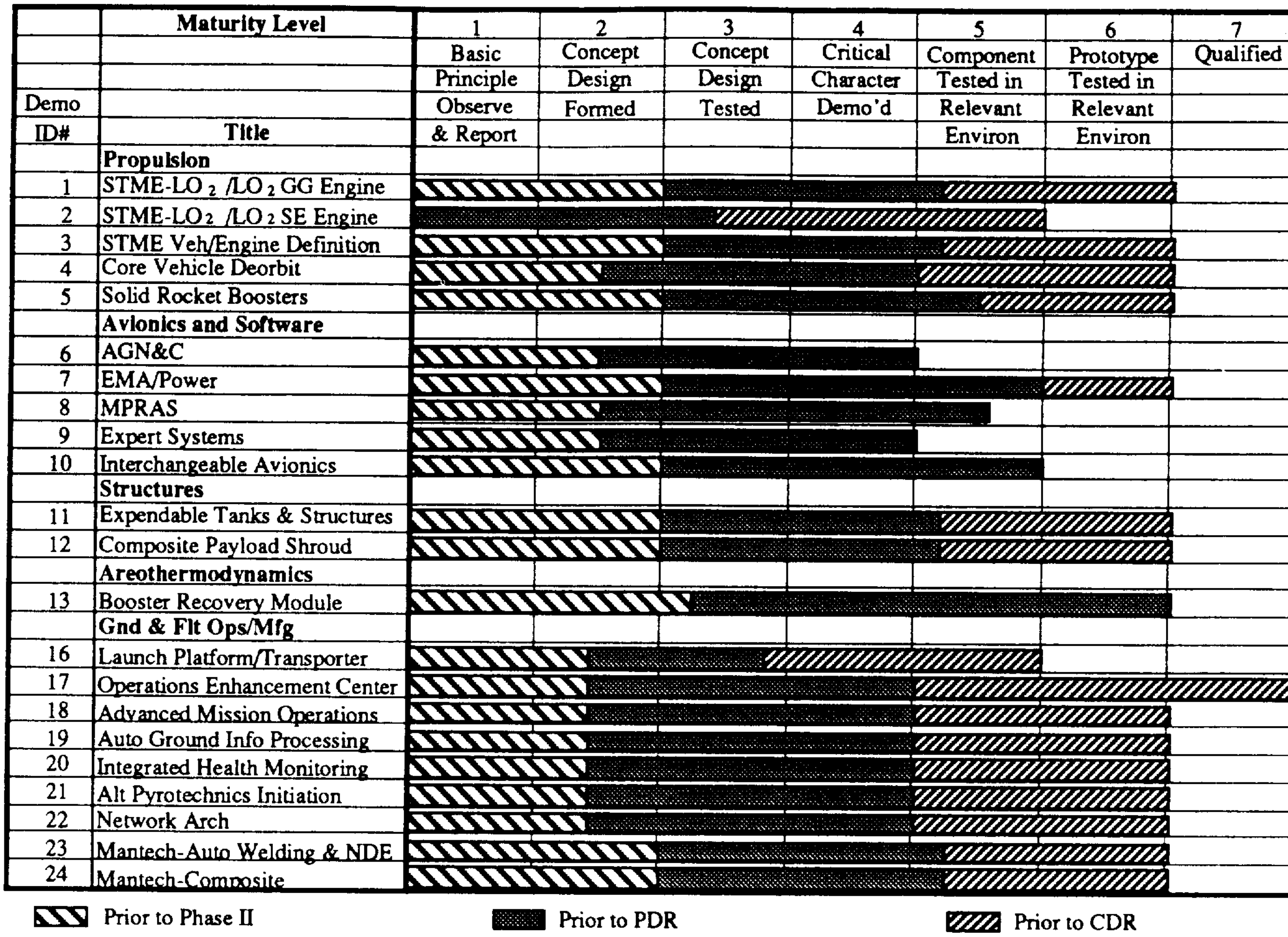


Figure 13. Technology Maturity Available by at least CDR.

Major Interrelationships
Among Technology Demonstrations

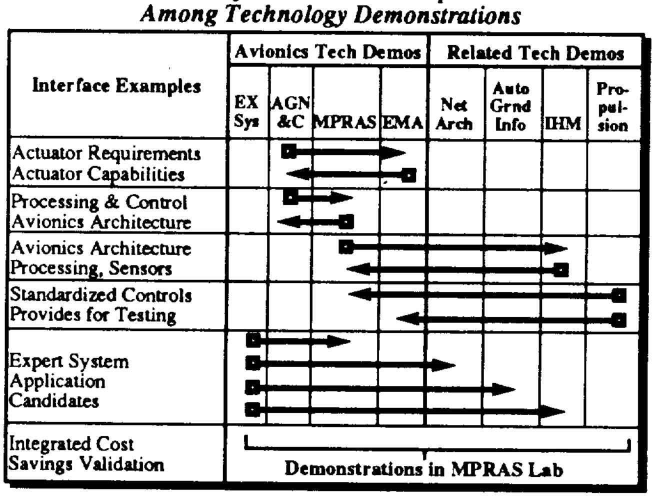


Figure 14. Avionics Technology Demonstrations Interact with Propulsion, and Opns Elements

Avionics technologies are included in ground and flight operations. These technologies are associated with automating information processing in the ground systems, more efficient facility designs, and development of a lower-cost launch platform/transporter.

Specific ground and flight operations technologies based on previous study results have been selected to achieve significant development cost or schedule reductions. These candidate technologies are shown in Figure 15, including their relationships with each other, and avionics and software technologies.

The entire ground operations system, including its manpower and facilities, should be optimized to support processing. Selected application of automation and robotics will further enhance operations.

The advanced mission operations goal is to reduce the off-line, but manpower-intensive, mission-peculiar planning to levels that support a standard mission. To provide timely and up-to-date information throughout the ground operations segment, the automated ground information processing technology development should develop electronic processing procedures and investigate and develop the electronic infrastructure to support their application.

The integrated health monitoring (IHM) technology is designed to reduce or eliminate the traditional test and checkout operations that require large manpower resources to perform and analyze procedures. With today's computing and correlation abilities provided by inexpensive electronic devices, the potential for cost reduction is enormous. IHM will also provide the resources to minimize post-failure stand-down. IHM must be built into all elements of the launch vehicle system, and, therefore, will be interacting with technology projects in all areas. IHM will provide requirements to ensure vehicle and operations systems will support the IHM architecture. Associated technology projects will feed system definition to IHM to allow its effective tailoring.

Finally, the network architecture and operating system technology area will tie the ground and flight operations systems together into an integrated system of networked computer workstations, that will reduce or completely eliminate the requirement for single-purpose special test equipment. Integration of operations system networks, automated information processing techniques will provide an architecture which supports highly efficient management and operations.

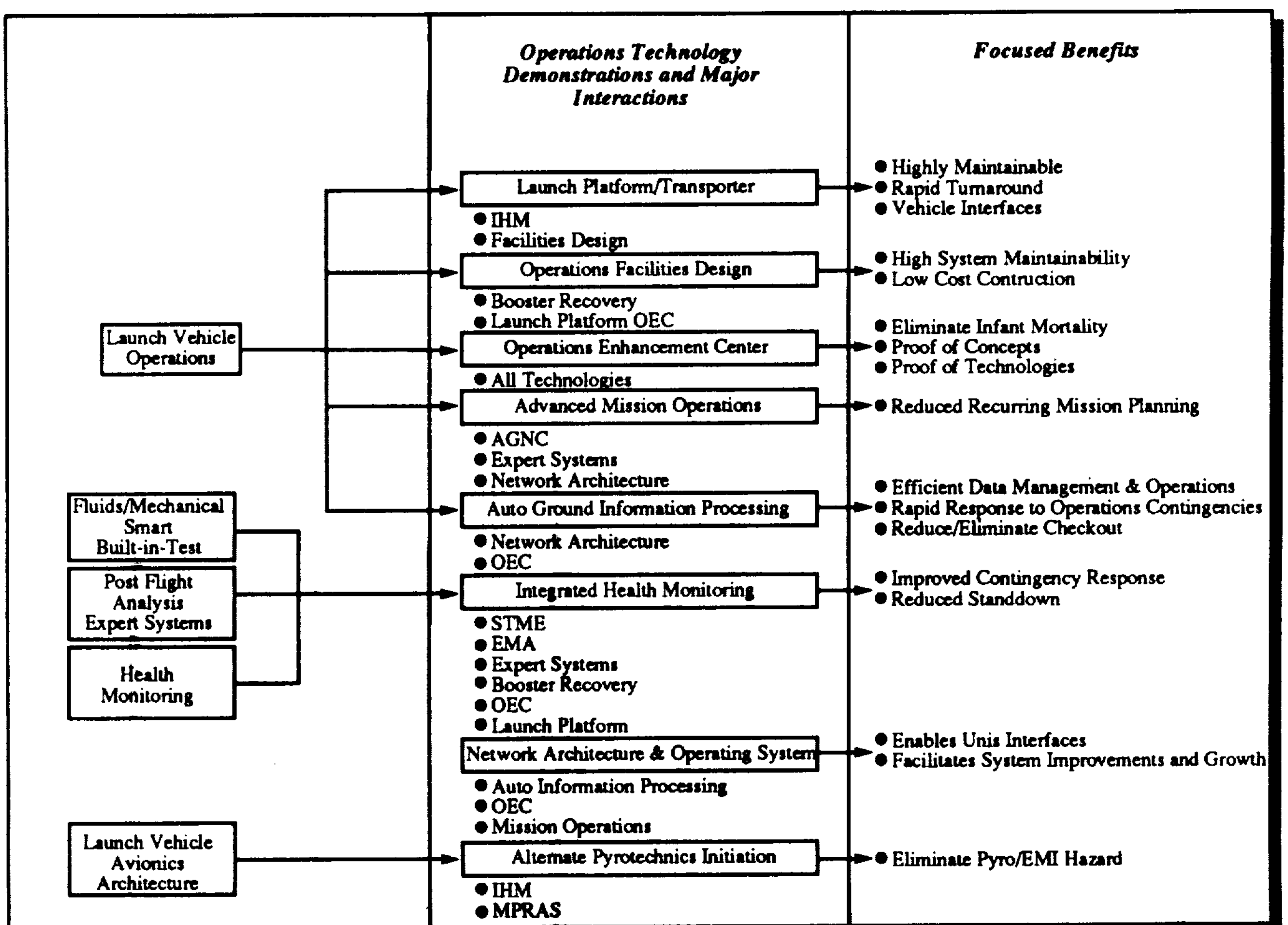


Figure 15. Operations Benefit Through Technology Focus and Integration.

Adaptive Guidance, Navigation, and Control (AGNC)

The objective is to develop a low life cycle cost (LCC), robust GN&C system and its integrated mission preparation system. One approach will be to automate as much of the interactive portions of the analysis as possible and provide a single integrated "package" (a work station environment) on which these tasks can be performed. This will reduce the cost and time associated with GN&C preparation for a new set of payloads/cargo for each mission. The other approach will be to make the on-board algorithms more sophisticated or adaptive so that they do not need as much preparation for a particular flight and can autonomously adapt to the unique conditions of each flight and payload. Both approaches have the goal of producing a GN&C design that is as robust as necessary. Such a system would be insensitive to all payloads/cargo combinations, weather and missions, and would never require mission specific analysis or changes. The preparation system and cost for such an ideal GN&C system would be minimal. Each approach would have to be measured to determine the breadth and depth of its preparation system and process. Robustness here is defined as a system's ability to accommodate new payloads/cargo or missions without changes. For example, a control system that can accept a payload weight range of 28,000 lb to 160,000 lb without any analysis or changes to any part of the GN&C system is more robust than a system that can only tolerate a range of 28,000 lb to 90,000 lb without changes.

Current costs of mission analysis for a unique payload are ten times the cost for re-flight of a similar payload to the same destination. From various analysis the flights in the model would carry a unique payload or a similar payload to a new destination. The use of AGNC will reduce the analysis task for any mission to less than that currently required for a re-flight. This gives the AGNC benefit shown in Figure 16. In addition, ground processing data has been analyzed and reductions in GN&C preparation that amounted to 10% of the overall ground processing task has been identified. The other potential benefit of AGNC, improved reliability, is not incorporated in the cost-benefit analysis.

Electromechanical Actuation (EMA) with Electrical Power Supply

An integral electromechanical actuation system coupled with an integrated electrical power supply (IEPS) system,

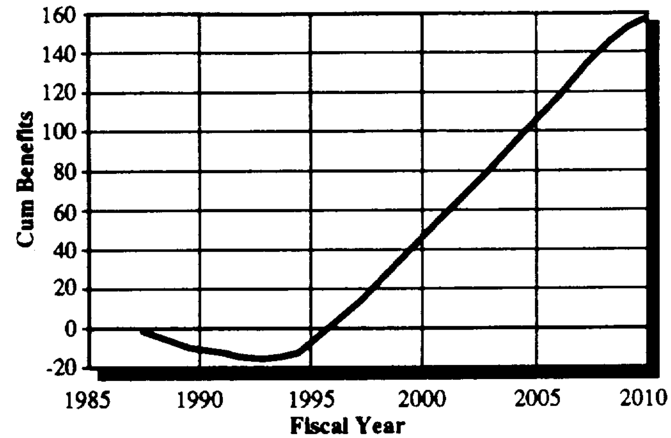


Figure 16. Adaptive GN&C Technology Cost Benefit Potential

can provide significant launch vehicle operations cost reductions. These cost reductions are attained through use of modular design, automatic checkout, and by the elimination of fluid actuation control.

EMA systems are being prepared as a viable alternative to the classic hydraulic fluid control approach. Previous trade studies indicate significant potential cost savings for launch vehicle applications. This is primarily due to the operational flexibility and minimum maintenance and support requirements associated with an EMA system. In addition, higher reliability, superior frequency response, simplified failure detection methods, and system adaptability to redundant design concepts are other advantages.

To successfully meet all the anticipated advantages of an EMA system, several key technology issues need to be resolved.

a. High-power motor/mechanical actuator design - While high-power assemblies have been used on ships and other terrestrial applications, we need to evaluate (and perhaps modify) the current designs for operation in the space environment and their ability to meet launch vehicle size, mass, and cost constraints.

b. The design of the high-energy power processors - These are required for either the electronic commutation of brushless DC motors, or the resonant processing for the three-phase induction motors. Along with the basic designs, we will require the supporting high-power component technologies that can be used to build the hardware.

c. High-density energy sources - The high peak-to-average power profiles common for EMA systems may require different energy storage and distribution options. Temporary energy storage in capacitors or different supplementary batteries may be required to minimize energy source mass and cost. The EMA/IEPS system is shown in figure 17.

POWER SOURCE. The primary power source must be able to provide continuous power from prelaunch activities through mission completion. Variations in peak power requirements during the mission will require a power supply concept to be robust and capable of supplying high energy rates on demand.

Power source technologies such as batteries (silver-zinc, lithium thionyl chloride) and other stored power sources (thermal and chemical) should be considered. Alternate power sources such as turbo alternators, gas generators, and auxiliary power units should also be evaluated. Power usage for more than 95% of mission time is approximately 55 amps/actuator. (There is a total of 20 actuators/vehicles.) However, during peak requiments-large EMA TVC activities-usage rate could exceed 150 amps/actuator. The 55 amps/actuator is based on an average actuator output power of 20 hp. The 150 amps/actuator is based on a peak actuator output of 50 hp. The above power is presumed to be provided at 270 Vdc. The 270 Vdc system is indicated for preliminary calculations only.

To accommodate these variations, options such as rechargeable energy storage capacitors and inductors or even thermal batteries could supplement primary batteries during peak energy usage.

Note that no new power supply technology issues need to be resolved for this type of application. However, technical issues for system integration, electromagnetic interference (EMI), thermal, and system performance concerns should be successfully demonstrated on a subscale basis for PDR to show confidence in the system concept.

Studies on prelaunch servicing and checkout tasks for ELV's and the Shuttle, shown in Figure 18, indicate potential savings of about 4000 hours for the ELV's and about 9000 hours for the Shuttle per launch, through replacing the hydraulic TVC and the pneumatic actuation system with an EMA system. The space shuttle data was obtained from Pan Am services which was under contract for shuttle processing. The ELV data was generated using GDSS launch cost data for the Atlas/Centaur.

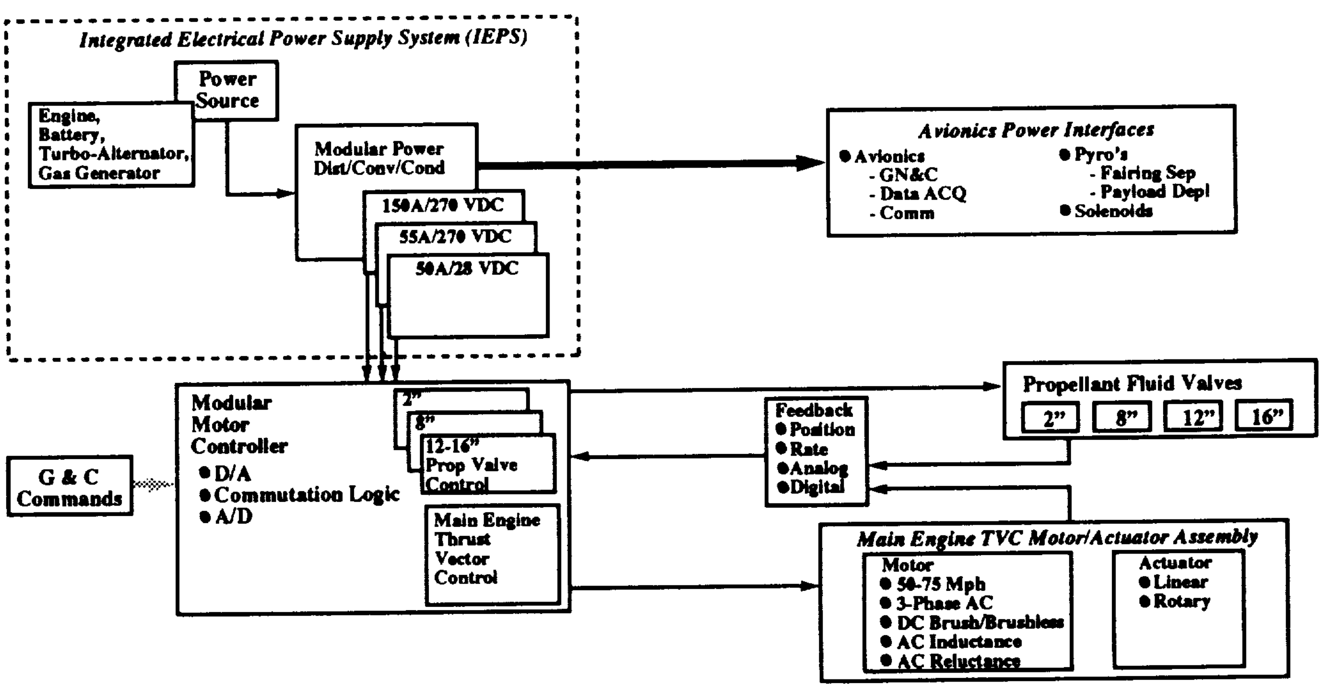


Figure 17. Alternate Configurations Assessment

The figures do not reflect EMA savings in the area of system fault isolation and corrective procedures when compared to a hydraulic system. Preliminary analyses show the TVC requirements to be similar to that of the space shuttle main engines (SSMEs), providing for potential saving of higher than 9000 hours per launch. Manpower savings are made in operations and ground support tasks. (*Replacing fluid actuation systems eliminates the need for regular and costly leak checks and contamination concerns.*)

The EMA system is sealed and storable. EMA/IEPS components are modularized and therefore easily replaceable. A requirement for complex ground support systems is also eliminated. The EMA/IEPS system will be independent and testable on demand, without a need for external support systems.

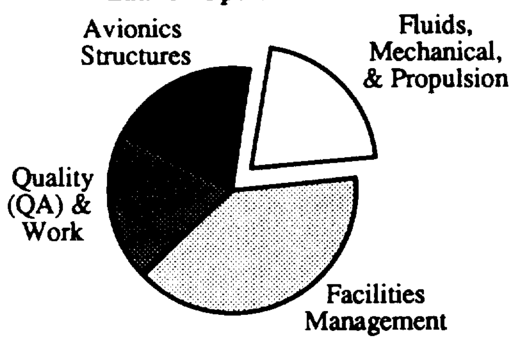
The ground processing benefits of EMA systems are realized by eliminating hydraulic and pneumatic systems. Studies of Centaur for Titan and Atlas/Centaur conclude that a 6% reduction in overall ground processing costs are possible. In addition, hardware savings and reliability improvements are probable. However, the cost-benefit analysis shown in Figure 19 excludes reliability improvements and includes only a small hardware cost benefit due to modularity and a philosophy of multiple subcontractor sourcing.

Multi-Path Redundant Avionics Suite (MPRAS)

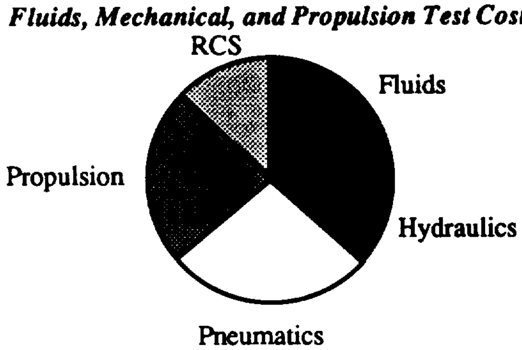
MPRAS provides the groundwork to integrate the entire airborne avionics system. It provides design standards that minimize life cycle and operations costs, while increasing reliability. The MPRAS architecture would make extensive use of bus techniques and common modules. Figure 20 shows a proposed architecture. It makes extensive use of busing techniques and common modules. Cost savings can be realized as shown in Table 5.

Potential Testing Cost Savings From Electromechanical Systems

Launch Operations Costs



Fluids, Mechanical, and Propulsion Test Costs



	HR	Savings Per Cent Used	Savings (HR)
Total ELV Launch Operations	91575		
Total F/M/P Test Time	19197		
Fluids	4928	10%	490
Hydraulics	2177	90%	1960
Pneumatics	5143	40%	2060
Propulsion	4616	20%	920
RCS	2333	<5%	0
			5430 HR
Equivalent Shuttle HRS			
Plumbing, Vent, and Drain	1069	20%	210
Hydraulics	1573	90%	1430
Propulsion	10099	40%	4040
ACS	2099	<5%	0
VAB Activities			5670
Pad Operations (35%)			3600
			9270 HR

Use of Electromechanical Valves and Actuators Can Reduce ELV Test Time by >5000 HR, and Potentially >9000 HR for the Shuttle or ALS.

Figure 18. Operational Cost Savings Derived From EMA Applications.

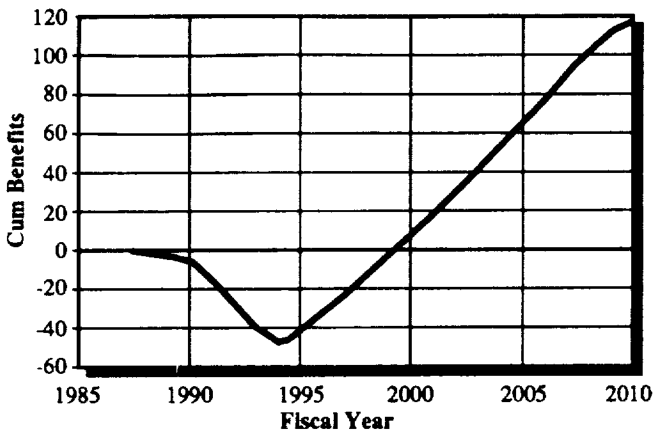


Figure 19. EMA Cost Benefits Potential

Future launch vehicles could include core and solid boosters or core with liquid boosters(s). To provide the processing required, a flexible architecture is paramount. Conventional triple modular redundancy (TNR) systems must be sized for the worst case. Growth potential must be planned to preclude the redesign of more complex vehicles and to maintain a simple integrated checkout concept. The flexible MPRAS architecture will provide the ability to add or delete liquid booster interfaces from the system as required and will be scalable to manned vehicles. One example of conventional design is point-

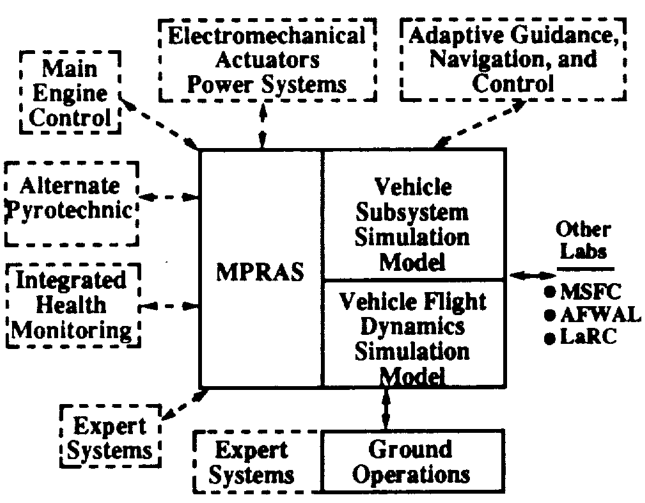


Figure 20. MPRAS: Integrated Avionics Approach To Reduce Costs

to-point harnessing, which can be reduced significantly with an appreciable cost reduction. The Centaur on Titan has approximately 100 yard-wired functions wired the entire length of the vehicle. A bus could reduce this harness by an order of magnitude.

Cost Savings Concepts

- Reduction of Hardware Cost
  - Common Modules
  - Standard Interfaces
  - Use of Data Buses
- Increased Reliability
  - Self-Test Modules
  - Redundancy
  - Reconfiguration
- Reduction of Operations Cost
  - Automatic Checkout
  - On-Board Data Processing
  - Mission Planning
  - Mission Analysis

Table 5. MPRAS Concepts Potential

A strawman MPRAS architecture that can be used as a point of departure is shown in Figure 21. The method of reducing launch vehicle life cycle cost is first to reduce hardware cost and improve reliability. This is done with very reliable common modules using standard interfaces and software produced in large quantities. For example, the common module processor may be used for guidance, signal processing, or as the engine controller, which reduces the number of unique processors in the system. This will reduce the number of avionic units required and with standardized back planes and buses, upgrades and expanded capability are possible, all producing cost savings. Also, the design is simple, reducing the complexity and increasing reliability.

Meeting the reduced operations cost goal is available through the additional processing of the MPRAS architecture. The cost reduction can be achieved by reducing the manpower required for launch support in the areas of propellant loading, health monitoring, avionic monitoring, calibration, and data evaluation.

A cost benefit analysis is shown in Figure 22. The major contributor to the cost savings is the avionics hardware cost reduction. This hardware reduction comes from the reduced amount of hardware required due to MPRAS and the lower cost of parts due to standardization and multiple sources of suppliers.

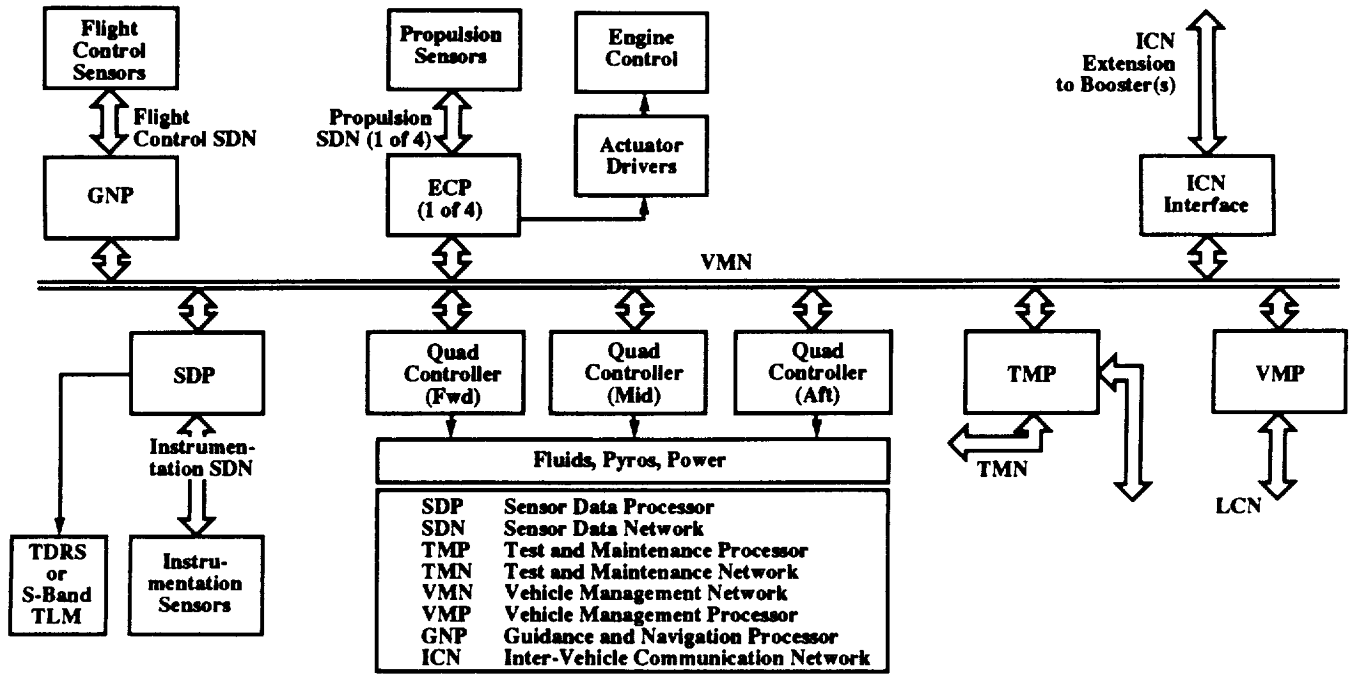


Figure 21. Distributed Architecture for Advanced Launch Vehicles.

Expert Systems for Decision-Aid Applications

Expert systems using artificial intelligence approaches provides effective individual and coupled decision aids for improved ground and on-board system autonomy and can reduce life cycle costs through efficient use of manpower.

Future launch vehicle program need to approach vehicle processing differently from in the past. Ground segment operations have been traditionally manpower-intensive.

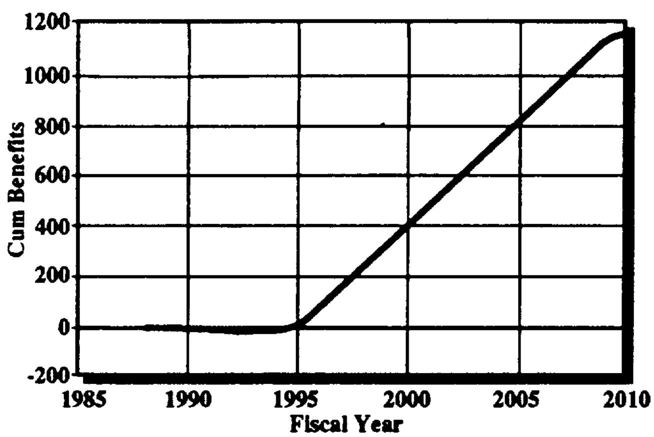


Figure 22. MPRAS Cost Benefits Potential

This is due to the many necessary checkout and prelaunch monitoring procedures that are set up and performed manually. Current pre-launch operations of expendable vehicles require a critical path of months will require a systematic approach to the automation of the ground operations to cope with the short turnaround processing schedule proposed.

An expert decision aid is a software approach to solving particular problems that are constantly changing and complex or adaptive in behavior, the opposite of an analytical problem that is basically deterministic. Examples of these types of problems are the re-scheduling of a vehicle checkout due to a damaged cable or determining if a system is indeed faulty given conflicting sensor readings. These heuristic problems require a depth of knowledge and experience (art rather than science) to form solutions quickly. Expert systems embody that collection of knowledge and experience in modular pieces that are rules and facts that describe the proper thought process for a given SE for circumstances arrived at by any path. It is this modular independence that makes expert systems attractive. The incremental improvement of knowledge and experience can be built and tested readily without re-testing the rest of the software system, unlike conventional software that is difficult to maintain in a day-to-day changing environment.

Experience from launch vehicle programs and past studies have shown that there are many opportunities in operations that reduce costs and improve autonomy, including:

- **Ground operations:** daily planning support and timely work-around decisions aids
- **Ground checkout:** autonomous procedural operations and control, standard trends, and redline monitoring
- **On-board systems:** monitoring, integration, and control recommendations
- **Launch day:** fly with fault diagnostics and decision aids
- **Postflight:** data reduction and analysis

Figure 23 shows that decision aids have the most potential for application cost savings in the Ground Segment (checkout, logistics, preparation, and maintenance) and the Control Segment (mission peculiar, mission planning, and mission control). The Control Segment has been further broken down into seven costs areas and estimates were made for the expert system savings anticipated in each.

Low-Cost Interchangeable Avionics

The goal of this technology development is to significantly reduce the cost of producing critical avionics components by specifically addressing relaxation of the stringent restrictions typically placed on performance-driven units, and promoting standardization between units.

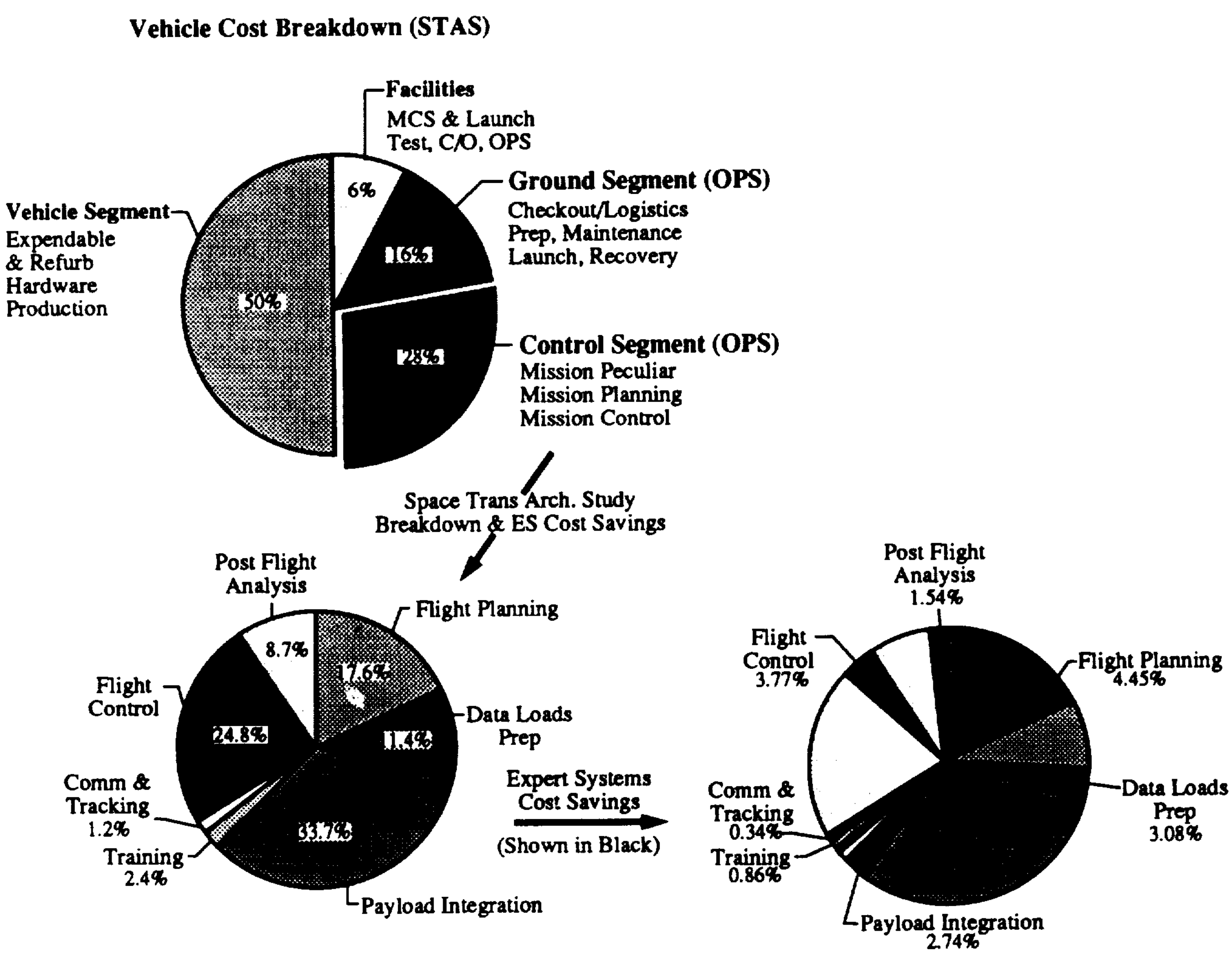


Figure 23. Decision Support Applications Contribution To Cost Benefits.

Figure 24 shows a proposed modular Inertial Navigation Unit (INU) with typical standard modules.

One of the primary goals of a new launch vehicle program is to significantly reduce the cost of putting a payload in low earth orbit. This goal is being pursued using the philosophy of a large, robust, highly-margined design. Because of this philosophy, the avionics size and weight are less critical to the overall vehicle performance. Also, the environments for the avionics packages can be made significantly less severe than for current launch vehicles. This is because the relatively large size of this vehicle allows for the placement of avionics packages in locations which have mild vibration, shock, and thermal environments.

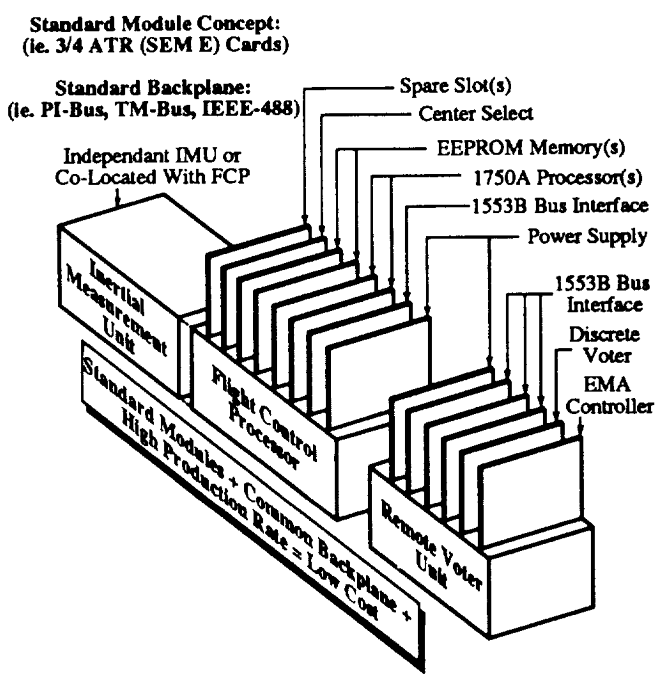


Figure 24. The Standardization of Common Processing Modules and Common Backplane

The relaxed environments allow for acceptable performance by using lower-cost instruments. For example, accelerometer capability is directly related to vibratory inputs, and gyro performance is heavily influenced by temperature extremes. By reducing these environmental extremes, performance requirements can be met at significantly reduced cost.

Automated Ground Information Processing

The objective of this technology development is to achieve cost savings through automation of key functions and interfaces in ground information processing.

The development should focus on creating an integrated paperless environment that ties together planning, procedure changes, quality assurance report (QAR) generation, and calibration tracking. This type of automation would ensure that the goal of providing short times between launches can be achieved.

Turnaround time requirements between launches demands streamlining operations to meet planned mission models. The approach for this technology development is to identify those areas in the ground operations cycle that can use automated information processing to provide cost savings and schedule enhancement. Figure 25 depicts an operations functional flow for a new launch vehicle program. While showing the entire operations functional flow, the figure separates the support and integration functions, and the control checkout and display functions. As illustrated, the support and integration function relies on input from the engineering design process and, through planning/scheduling and flow control process interfaces across the spectrum of ground operations.

One methodology would be to identify those functional interfaces that will provide the highest cost payoff by shortening delays in schedule during launch vehicle preparation. Current estimate indicates that the the two areas under "Preflight and Recurring Support," payload integration and engineering support, benefit significantly from automation. Three specific areas to analyze are: 1) procedures which include tracking and incorporating changes, 2) planning, and 3) calibration tracking. Associated with the planning process and procedures are the generation and disposition of QARs. Automated QAR disposition, with an emphasis on reducing the time required to work the QAR and hence, shortening delays in vehicle processing should be investigated.

Integrated Health Monitoring

An Integrated Health Monitoring (IHM) architecture design provides an automated means of observing the functional condition of critical vehicle hardware not only during flight, but also during production and ground

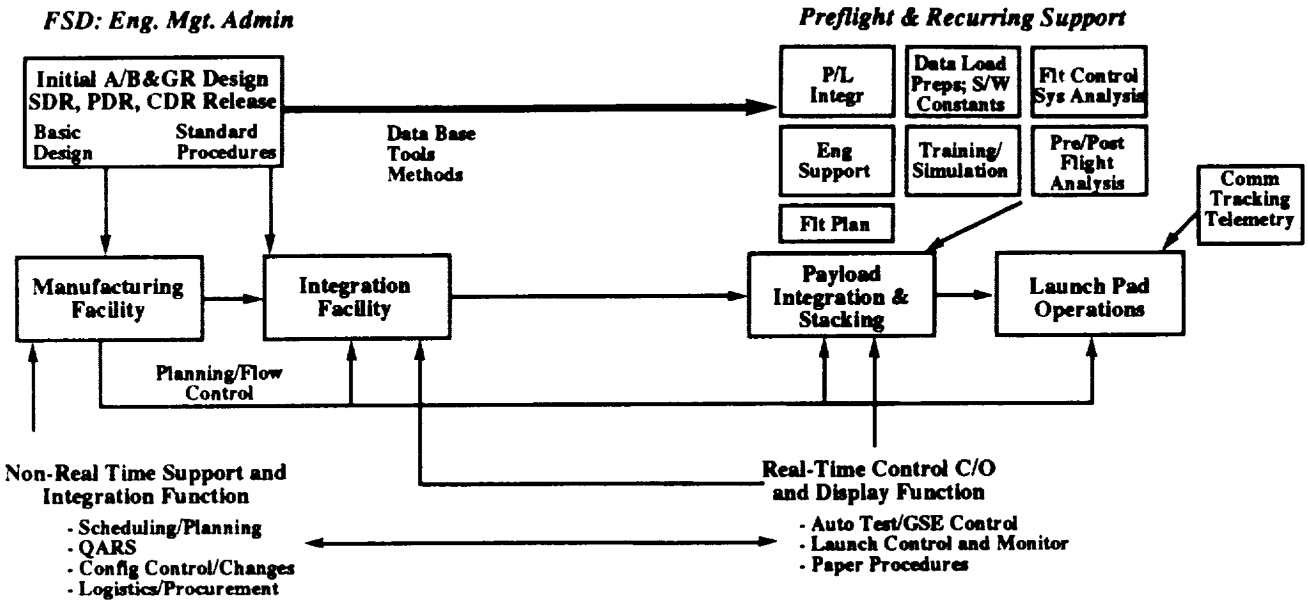


Figure 25. The Operations Function Flow Identifies Automation Opportunities.

operations. To achieve the high launch rate and low cost goals of advanced vehicles it will be necessary to identify, locate, and correct vehicle and ground support equipment hardware problems quickly without sacrificing reliability. IHM serves as a detection, diagnostic, and analysis tool to accomplish the program goals.

IHM provides quick, efficient, and thorough automated checkout procedures for vehicle and ground operations. If a hardware problem is detected, IHM will diagnose the problem to its source and serve as an analysis tool by which a user can automatically search a historical database for reference information. This capability will allow operators to focus their time and attention on the problem and resolution without having to sort through large quantities of nominal data.

All subsystems are affected by IHM as shown in Figure 26. The IHM concepts and ideas generated in the technology development can be to all vehicle subsystems for maximum efficiency and improved reliability.

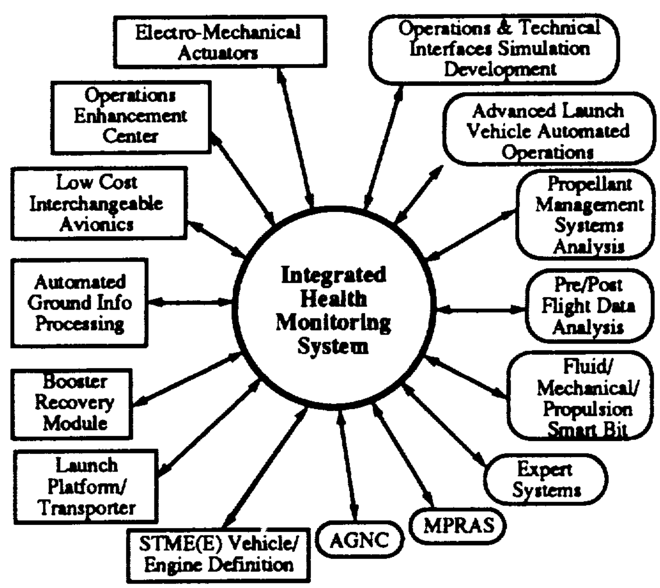


Figure 26. Representative Flow of Launch Vehicle Areas and IHM Concepts.

As an example, since rocket engine designs require such a long lead time before the initial vehicle itself, other subsystems that interface with the engine must be investigated (e.g., fluids flow) as well as the engine itself before design decisions concerning health monitoring can be made. By integrating "overall" IHM systems concepts and ideas with engine manufacturers' requirements early in the program, this will reduce problems that have occurred in the past with non-integrated health monitoring systems in the vehicle and ground operations areas. It is important that during the technology development all personnel know how the subsystems are interfaced to each other because of their interdependence (e.g., avionics control and feed system connections for the engine). This IHM philosophy ensures that all health monitoring design concepts remain consistent and tolerant of any vehicle or ground operations design changes that may occur.

"Integrated Health Monitoring is defined as an automated means of verifying the operational status of all critical hardware associated with vehicle assembly, launch, and support phases of operations. IHM is able to verify initial subsystems, detect abnormal performance and impending failures, and identify suspected components." Thus, a health monitoring system is required not only on the vehicle, but within the production and ground operations areas as well. Figure 27 shows a diagram of the overall IHM system and its relationships.

A cost benefit analysis has shown that IHM provides a life-cycle cost benefit of $435 million compared to current methods within the production and ground operations areas, for an initial investment of $22 million for this program. Figure 28 shows the time-dependent benefits curve for IHM compared to current methods of health monitoring.

Network Architecture and Operating System

The objective is to develop technology related to network architecture and the operating systems that supports pre-launch, launch and post-launch activities.

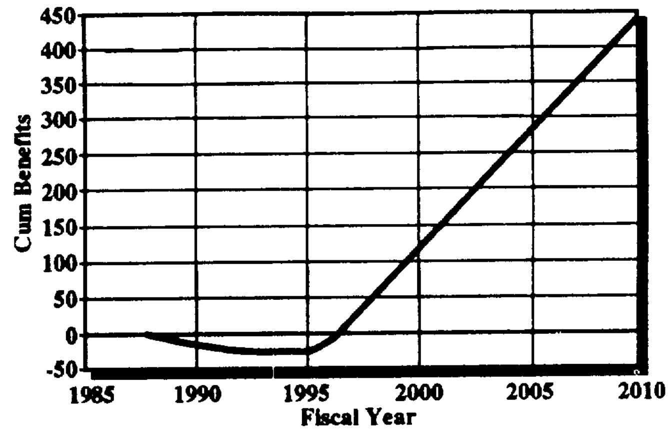


Figure 28. IHM Cost Benefits Potential.

By increasing the use of automation in the checkout and test of the vehicle and ground systems and post test data analysis, the cost of these operations can be reduced. It is crucial that the backbone network architecture and launch control system and its network architecture be defined in the early phases of technology development. Early definition of the backbone and launch control networks are critical to insure proper selection and to maintain low cost and schedule risk. Figure 29 shows a preliminary concept for the backbone network, that ties together all site elements.

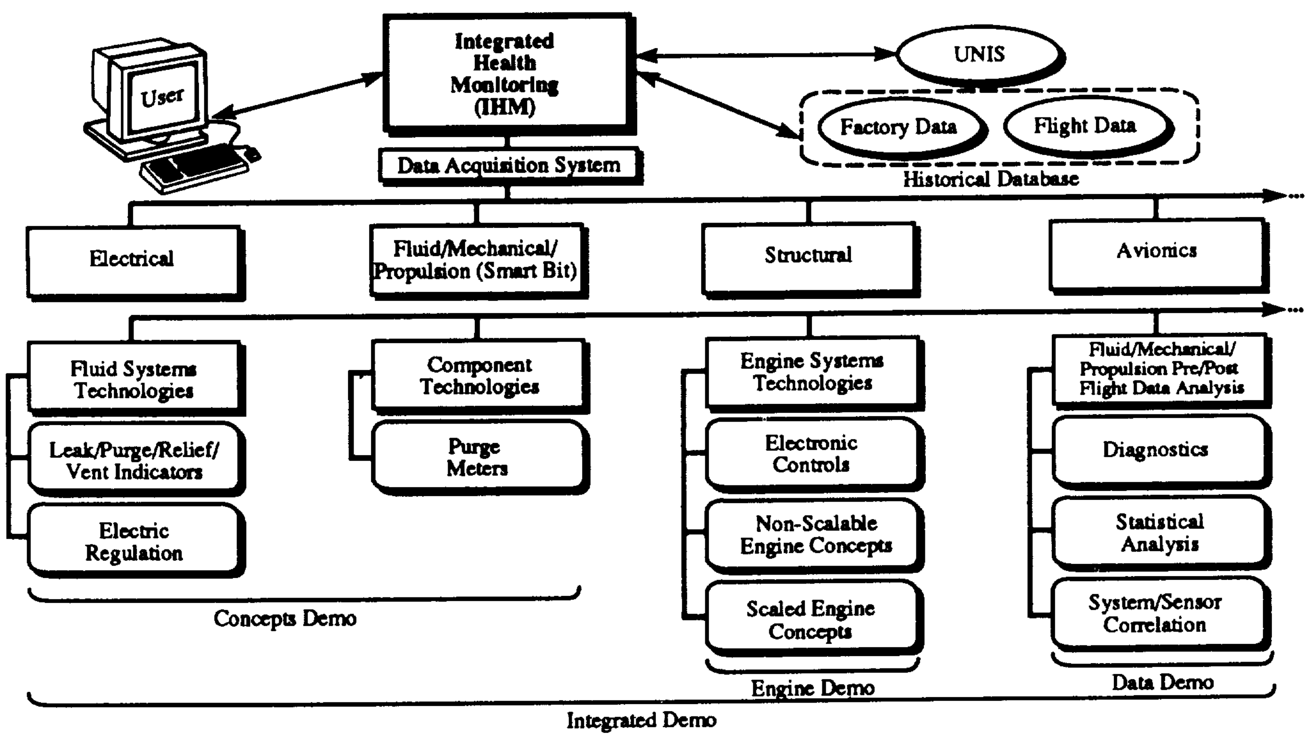


Figure 27. IHM Technology Development

Figure 30 shows a priliminary concept of the launch control network. The Network Architecture is the critical subsystem within the Ground Segment necessary to successfully integrate the elements for automated ground processing and launch operations.

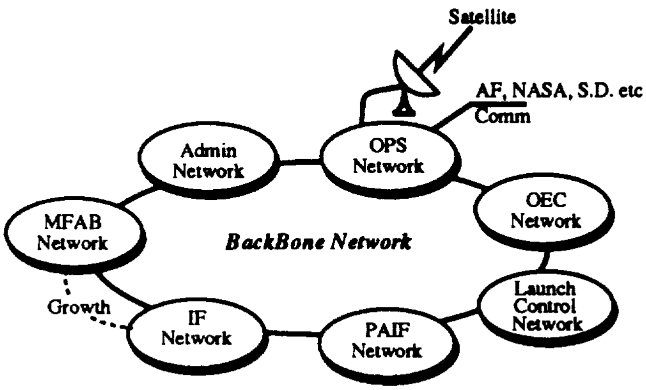
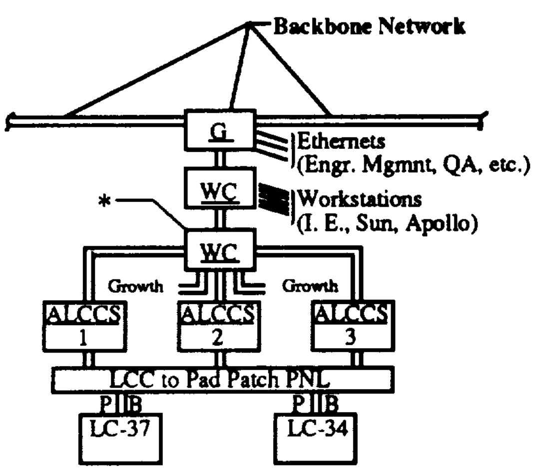


Figure 29. A Preliminary Concept for the Backbone Network.



Preliminary Concept of a Launch Control Network

WC	Wire Center/Concentrator (Fiber or Wire)
G	Gateway (Interoperable Connection Between Networks)
ALCCS	Advanced Launch Control Computer System
P	Primary Secure Comm Link
B	Backup Secure Comm Link
*	Provides Disconnect From Network and Connectivity Between ALCSSs During Critical Real-Time Operations

Figure 30. A Preliminary Concept for the Launch Control Network.

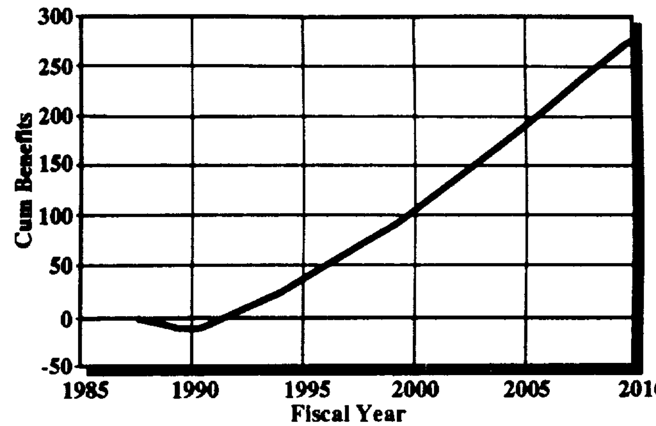


Figure 31. The Network Architecture and Operating System Operations Benefits Potential.

Experience has also demonstrated the need for a unified approach to automation in order to obtain the maximum cost savings.

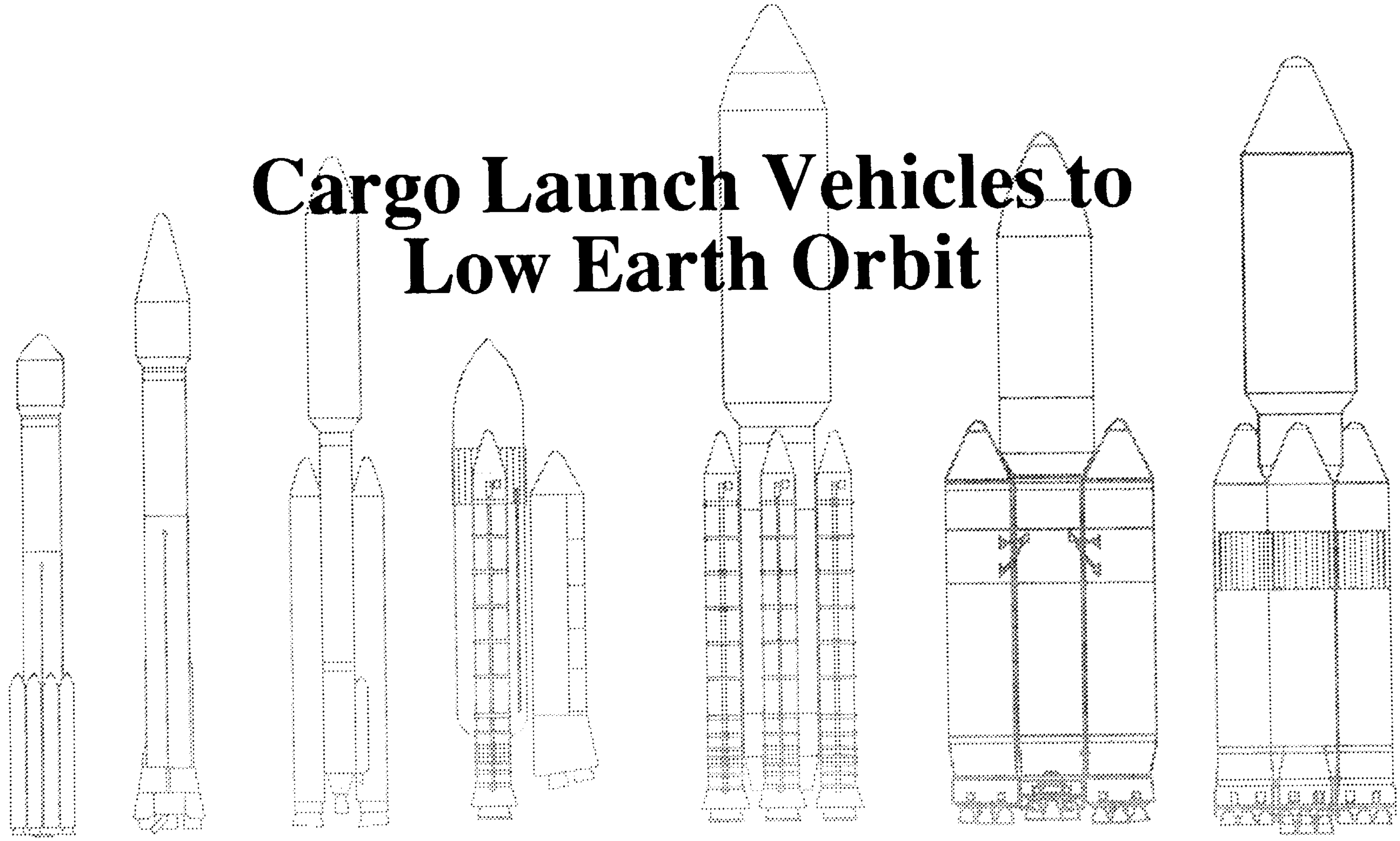
The cost benefit analysis shown in Figure 31 indicates a potential for significant cost savings.

Technology Transfer to Current ELV's and Commercial Launch Vehicles

Most existing ELV programs are committed to develop and implement cost saving technologies, thus they can develop and enhance the benefits of advanced launch vehicle technology development. These enhancements are enabled through, 1) in-house funded technology programs aimed at cost and turnaround savings that can be used as the building blocks for advanced launch vehicle technology development, 2) completed analysis and planned product improvements, which show that many of these technologies can be used on existing launch vehicle systems with minor impact to flight hardware, and 3) targeting some technology demonstrations for existing ESMC operations to prove these technologies and cost savings in comparison with current operations. In addition, new ELV systems have planned to incorporate some of these technologies.

Commercial launch vehicle programs do not develop new technologies because of the cost involved. They do plan to incorporate new technologies as they become available where it has been shown there is a substantial benefit in both hardware cost and particularly in operations costs.

Cargo Launch Vehicles to Low Earth Orbit



Robert E. Austin
Director, Space Transportation & Exploration Office
Program Development
George C. Marshall Space Flight Center

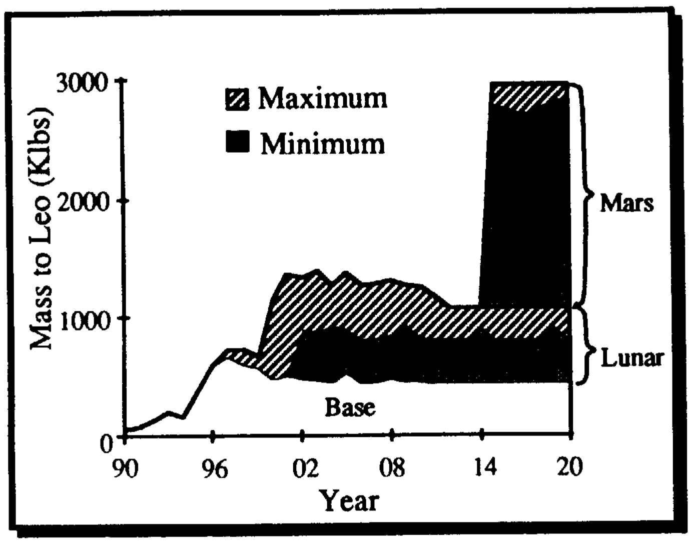
Cargo Launch Vehicle to Low Earth Orbit

Briefing Topics

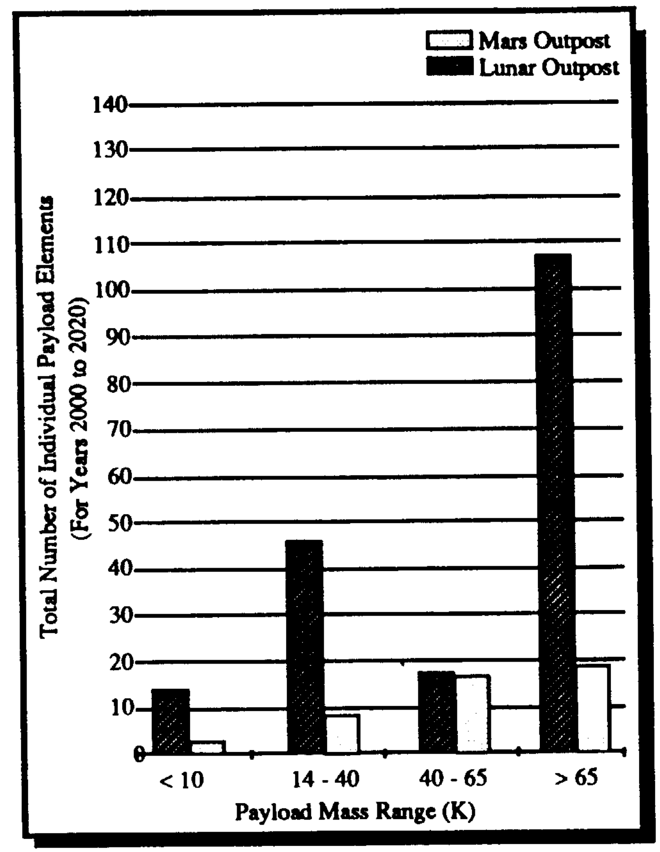
- Requirements for Cargo Launch Vehicles
- Cargo Launch Vehicle Concepts
- Avionics Technology Needs
  - Justification
  - Priorities
  - Interactions with Other Vehicle Areas
- Specific Avionics Technology Areas
  - Multi Path Redundant Avionics Suite (MPRAS)
  - Integrated Health Monitoring
  - Interchangeable Avionics
  - Expert Systems
- Technology Transfer
  - Expendable Launch Vehicles (ELV)
  - Commercial Launch Vehicles
- Summary

Composite Civilian Mission Model

Advanced Avionics Technologies



Mass to LEO



Number of Payloads to LEO

Utilization of Cargo Launch Vehicles

Earth-To-Orbit Launch Vehicle	Civil Mission Requirements						
	Base			Expanded			
	SSF Assy/Logistics	Spacelab	Science/Planetary/ Observatories	SSF Accommodations	Precursors	Lunar	Mars
Existing:							
• Atlas					x		
• Delta					x		
• Titan			x		x		
• STS	x	x	x	x		x	x
New:							
• HLLV					x	x	
• Growth HLLV							x

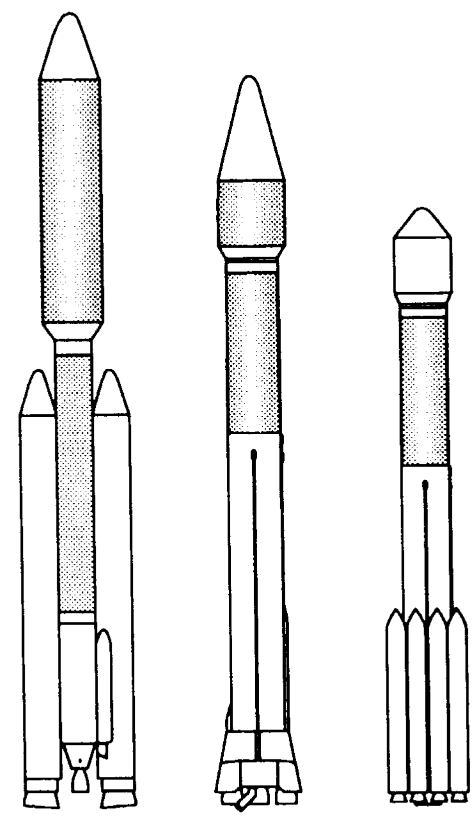
ETO Requirements

Destination	Mission (Flights)	Vehicle
Polar Orbit	Life Sat (10*)	Delta II
Lunar	Lunar Observer (2)	Atlas II
L_2 (Far Side)	Comm Sat (1)	Atlas II
Mars	Global Network (2)	Titan IV
Mars	Sample Return/ Local Rover (2)	Titan IV
Mars	High Res. Imaging/ Comm Orbiter (2)	Titan IV
Mars	Rovers (1)	Titan IV
Mars	Rovers (1)	Titan IV
Mars	Rovers (1)	Titan IV
Mars	Communication Sat. (1)	Titan IV

Note: *Two flights per year for five years.

Robotic Precursor Missions

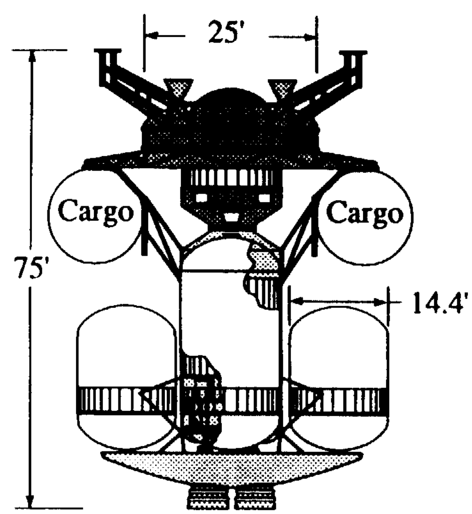
Expendable Launch Vehicles (ELV)



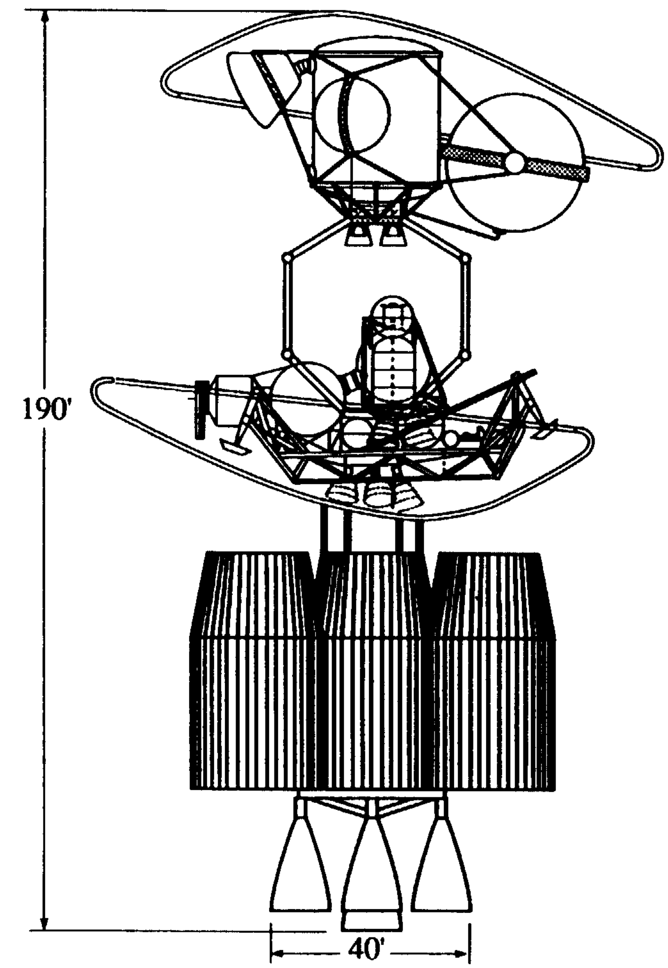
Launch Vehicle	Titan IV	Atlas II	Delta II
Payload to LEO	39-50K	15-20K	9-11K
Availability Date:	Jan 89	1991	Jan 89

New Cargo Element Requirements: Lunar and Mars Transportation Vehicles

Lunar Transfer and Excursion Vehicles

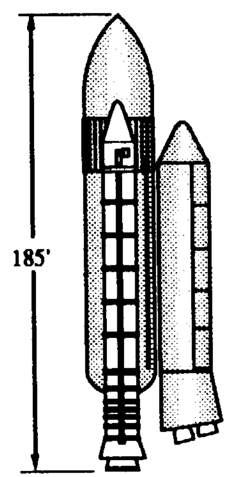


Mars Transfer and Excursion Vehicles

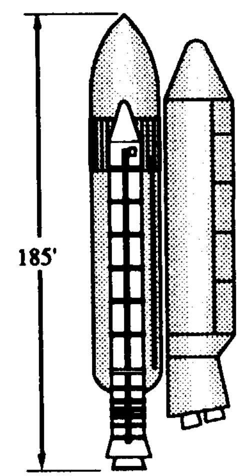


Shuttle Derived Vehicles for Lunar and Mars Missions Requirements

Lunar

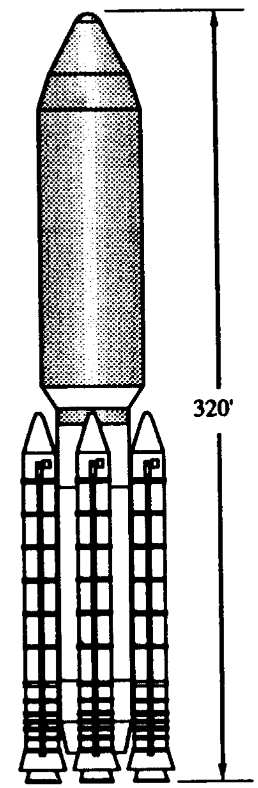


Net Payload	157K
Boosters	2 ASRB's
Core Stage	Standard ET
Core Propulsion	3 SSME's
Payload Envelope	15' Dia.
	82' Length



Net Payload	135K
Boosters	2 ASRB's
Core Stage	Standard ET
Core Propulsion	3 SSME's
Payload Envelope	25' Dia.
	90' Length

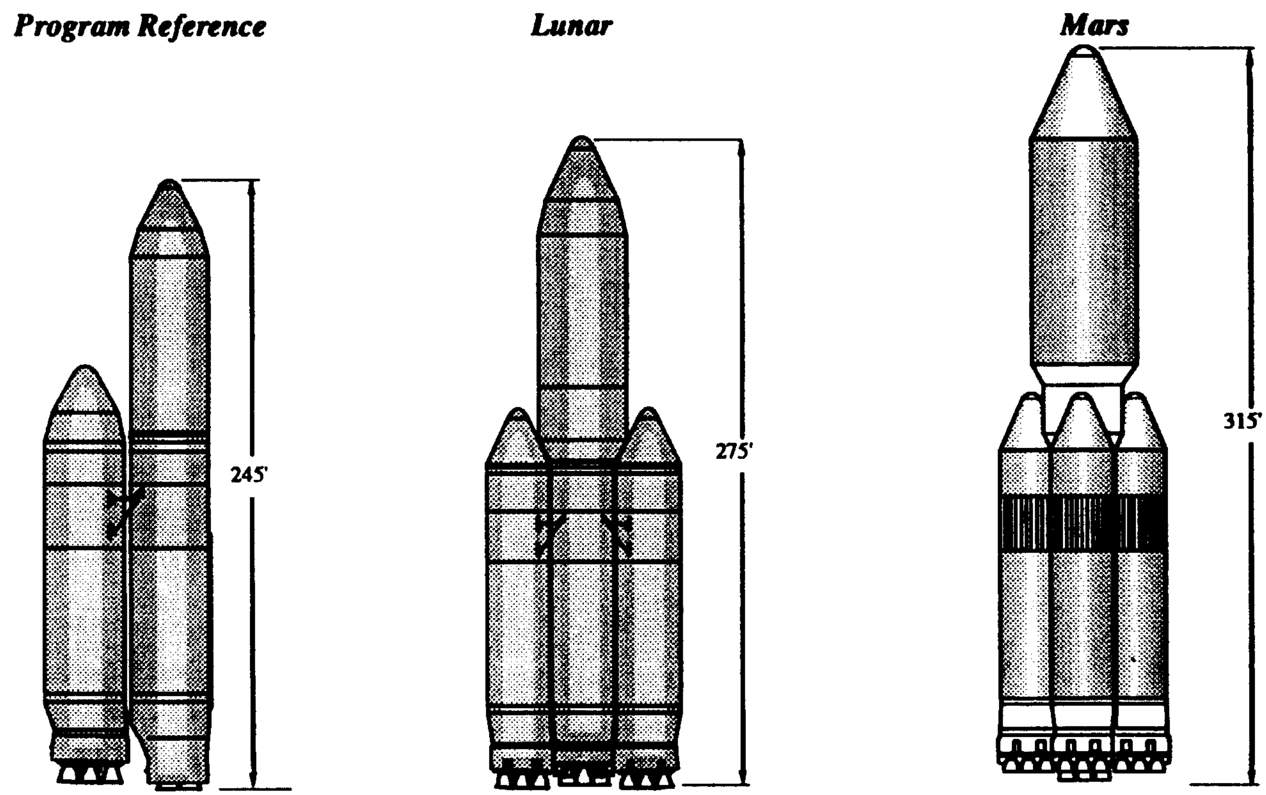
Mars



Net Payload	300K
Boosters	4 ASRB's
Core Stage	New 30' Dia.
Core Propulsion	Recoverable P/A
	w/5 SSME's
Payload Envelope	40' Dia.
	100' Length

Advanced Launch System (ALS) for Lunar and Mars Missions Requirements

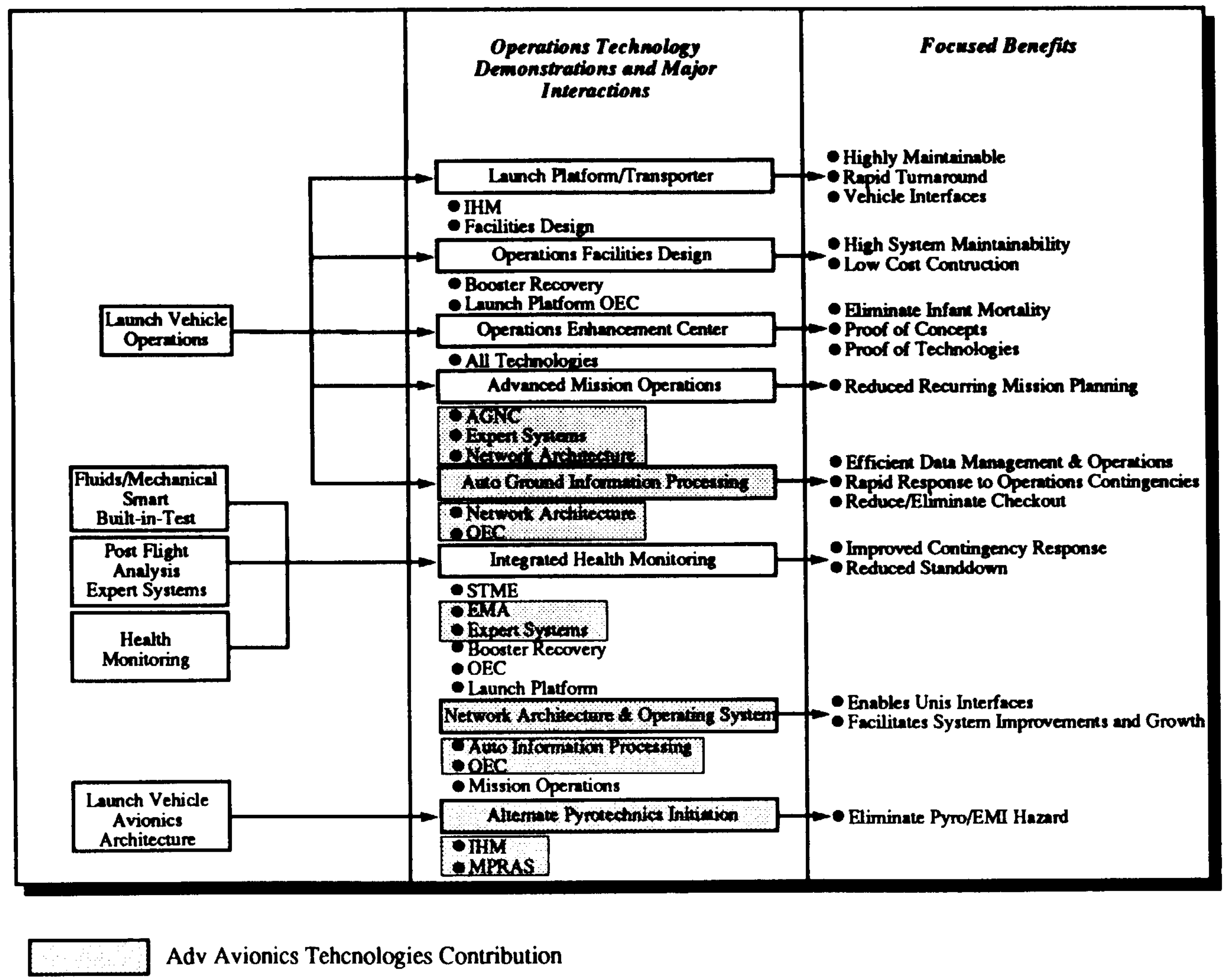
Advanced Avionics Technologies



	Program Reference	Lunar	Mars
Net Payload	115K	215K	300K
Boosters	1 LOX/LH_2 w/6 STME's	2 LOX/LH_2 w/6 STME's ea.	3 LOX/LH_2 w/6 STME's ea.
Core Stage	LOX/LH_2	LOX/LH_2	LOX/LH_2
Core Propulsion	3 STME's	3 STME's	3 STME's
Payload Envelope	25' Dia. 100' Length	33' Dia. 100' Length	40' Dia. 100' Length

Operations Benefit Through Advanced Avionics Implementation

Advanced Avionics Technologies



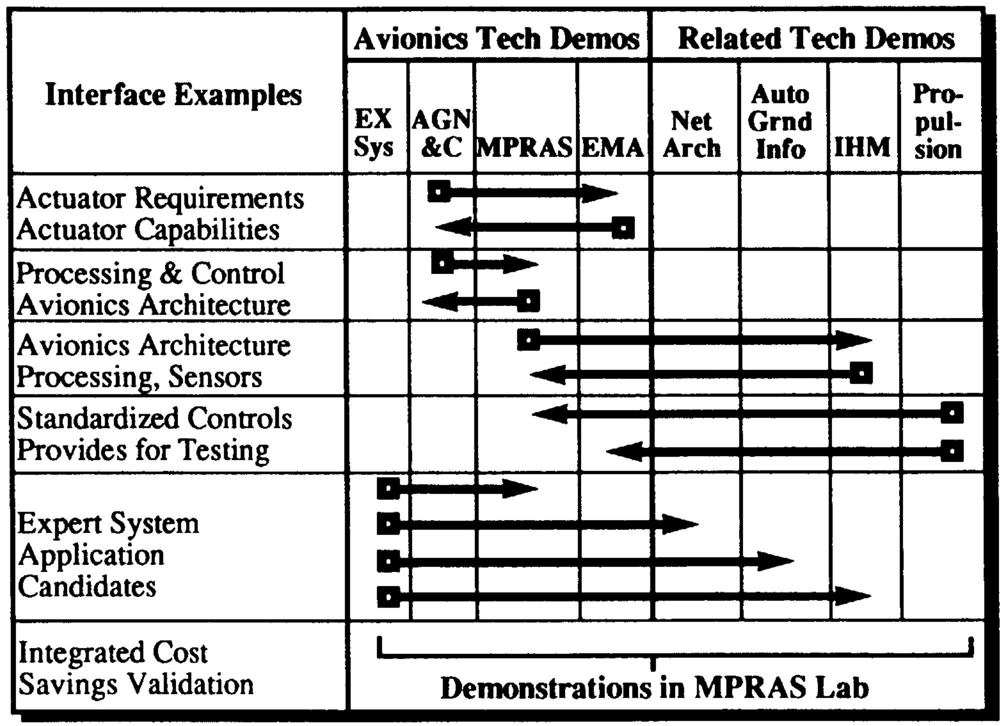
Technology Prioritization for Advanced Cargo Launch Vehicles

Advanced Avionics Technologies

Rank	Title	Contribution	Rationale
1	STME(E)-LO_2/LH_2 Gas Generator	Propulsion Cost	Major Cost Impact
2	STME(E)-LO_2/LH_2 Split Expander	Propulsion Cost	
3	STME(E) Vehicle/Engine Definition	Propulsion Cost	
4	Booster Recovery Module	Propulsion Cost (Booster Recovery & Eng Reuse)	
5	Expendable Tanks & Structures	Core & Booster Structures Cost	
6	MPRAS	Cost & Enables AGN&C and Vehicle Reliability	
7	Integrated Health Monitoring	Operations Cost, Engine & Vehicle Reliability	
8	Composite Payload Shroud	Shroud Structures Cost	
9	Interchangeable Avionics	Backup Avionics Cost	
10	Ops Facitilies Design-Ind Prep	Schedule-Preparedness for Assembly & Launch	Schedule Impact
11	Launch Platform/Transporter	Transporter Cost and Schedule	
12	Mantech-Automated Welding & NDE	Manufacturing Cost of Structures	Enables & Validates Other Technologies
13	Operations Enchancement Center	Validates Ops Cost & Procedures	
14	Expert Systems	Enables AGN&C, Health Mon, & Automated Ops	
15	Mantech-Composite Structures	Manufacturing Cost of Structures	
16	Advanced Mission Operations	Mission Planning Costs	Lesser Cost Impacts
17	AGN&C	Mission Planning Cost & Vehicle Robustness	
18	Network Architecture	Ops and Facilities (Computer) Cost & Schedule	
19	Solid Rocket Booster	Backup Propulsion Cost and SRB Reliability	
20	Electromech Act/Power Supply	Operations Checkout Cost	
21	Auto Ground Info Processing	Information Processing Costs	
22	Core Deorbit	Cost and Technology Risk Reduction	
23	Aero Data Bases	Supports Structure Cost Reduction	
24	Alternate Pyrotechnics Initiation	Operations Cost	

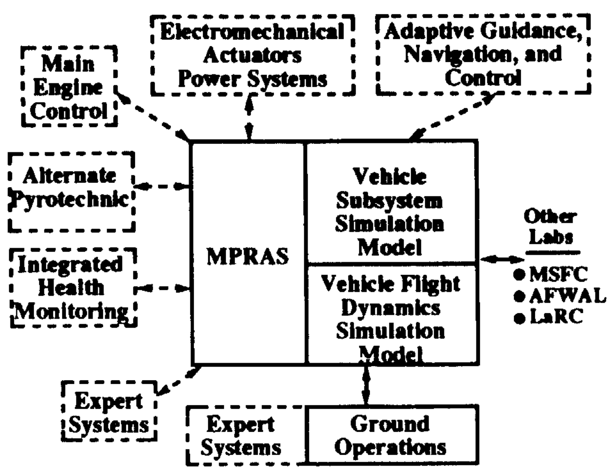
Avionics 33% of Top Priority Element

Avionics Technologies Interaction with Other Vehicle Technology Areas



Multi-Path Redundent Avionics Suite (MPRAS) Approach to Reduce Costs

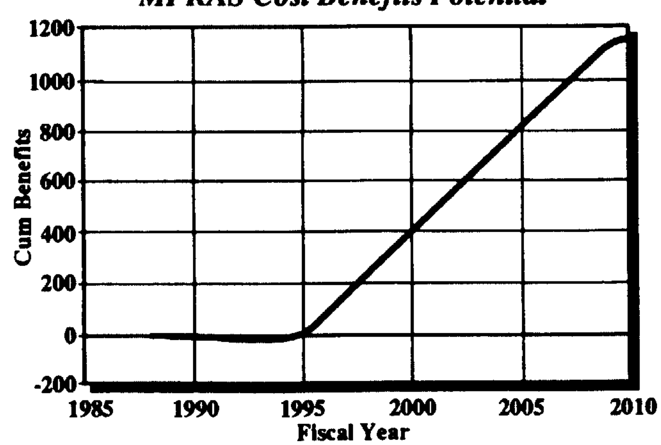
MPRAS: Integrated Avionics



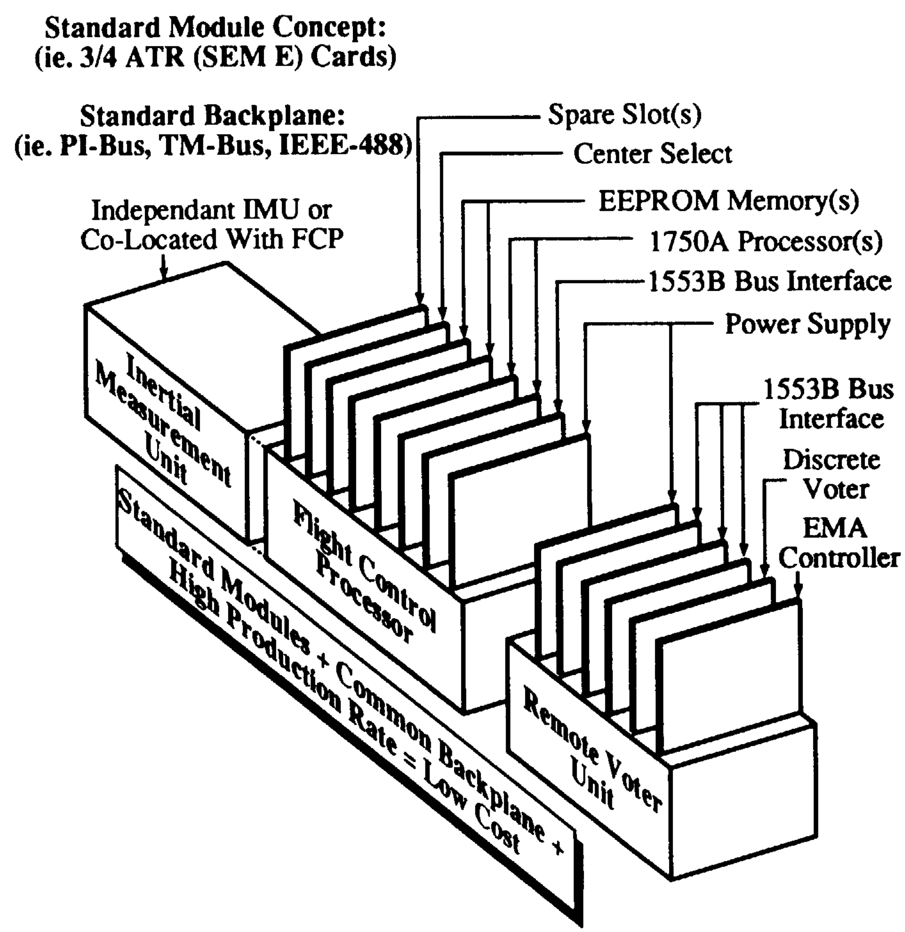
MPRAS Cost Savings Concepts

- Reduction of Hardware Cost
  - Common Modules
  - Standard Interfaces
  - Use of Data Buses
- Increased Reliability
  - Self-Test Modules
  - Redundancy
  - Reconfiguration
- Reduction of Operations Cost
  - Automatic Checkout
  - On-Board Data Processing
  - Mission Planning
  - Mission Analysis

MPRAS Cost Benefits Potential



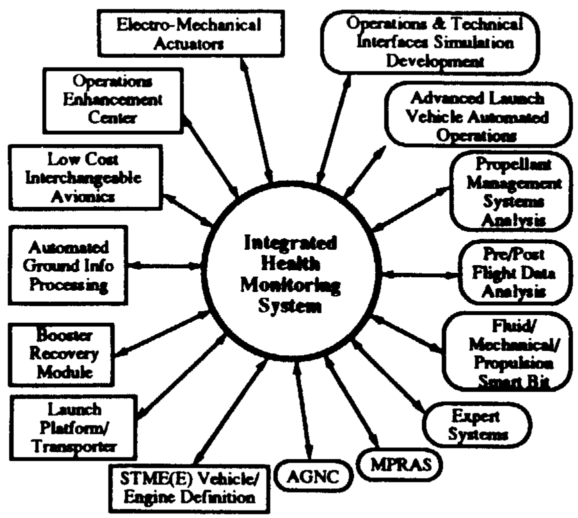
Interchangeable Avionics



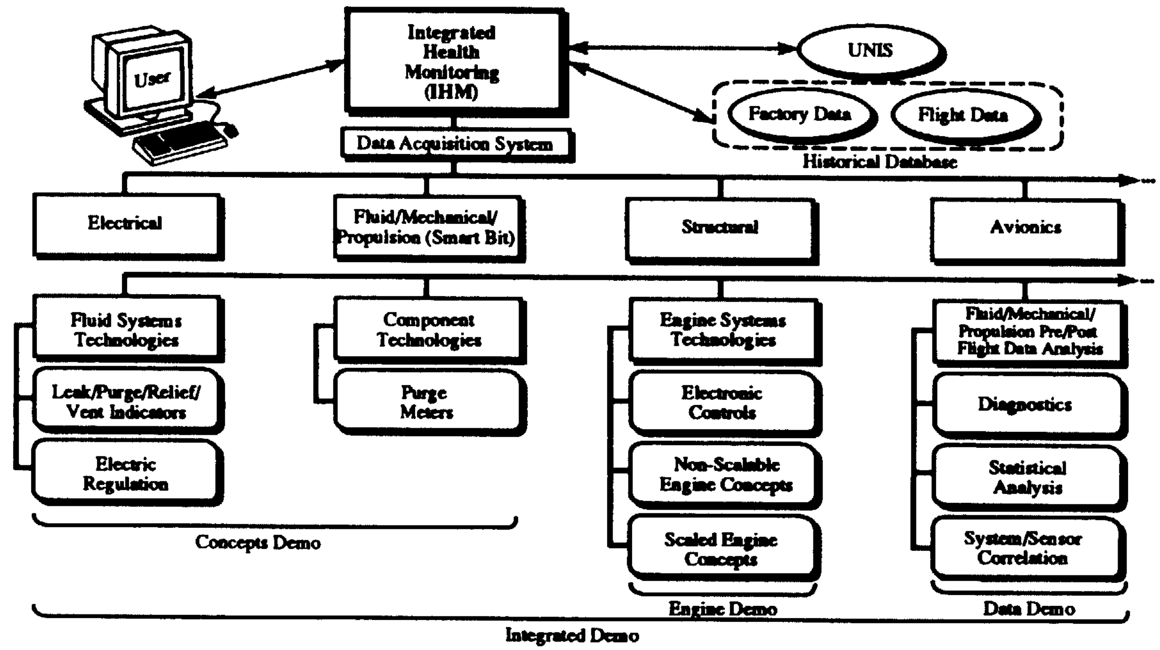
Integrated Health Monitoring (IHM)

Advanced Avionics Technologies

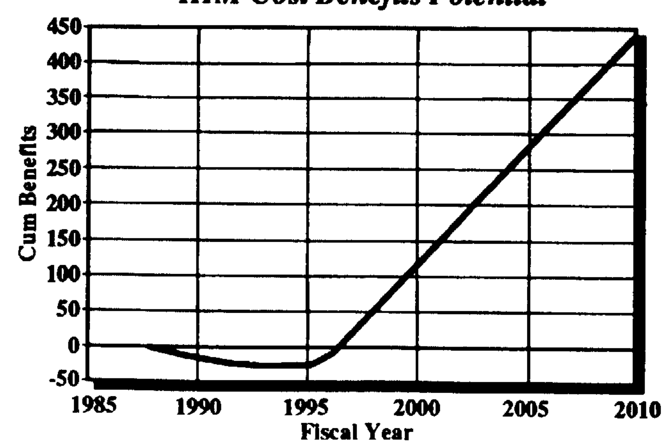
Representative Flow of Launch Vehicle Areas and IHM Concepts



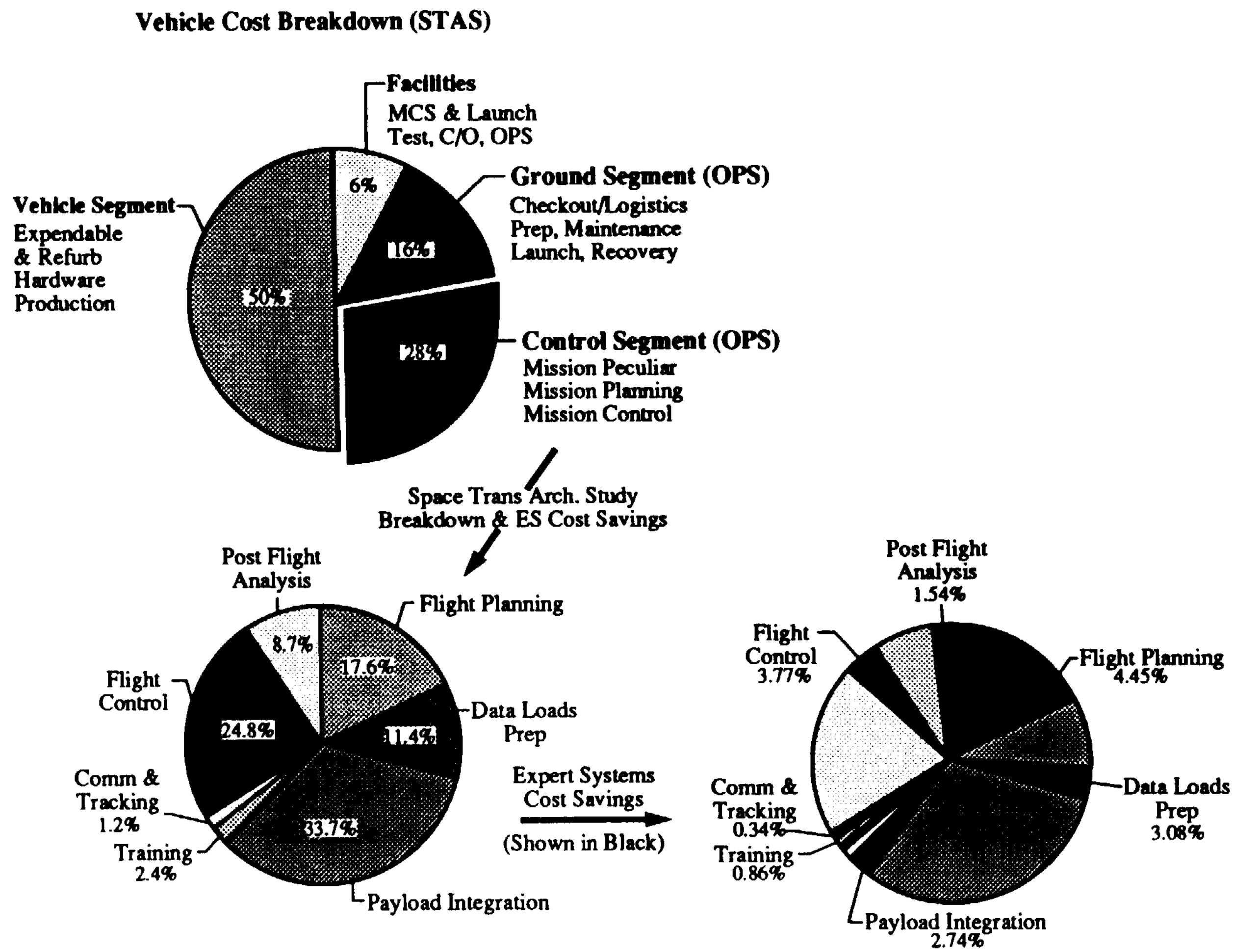
IHM Technology Development



IHM Cost Benefits Potential

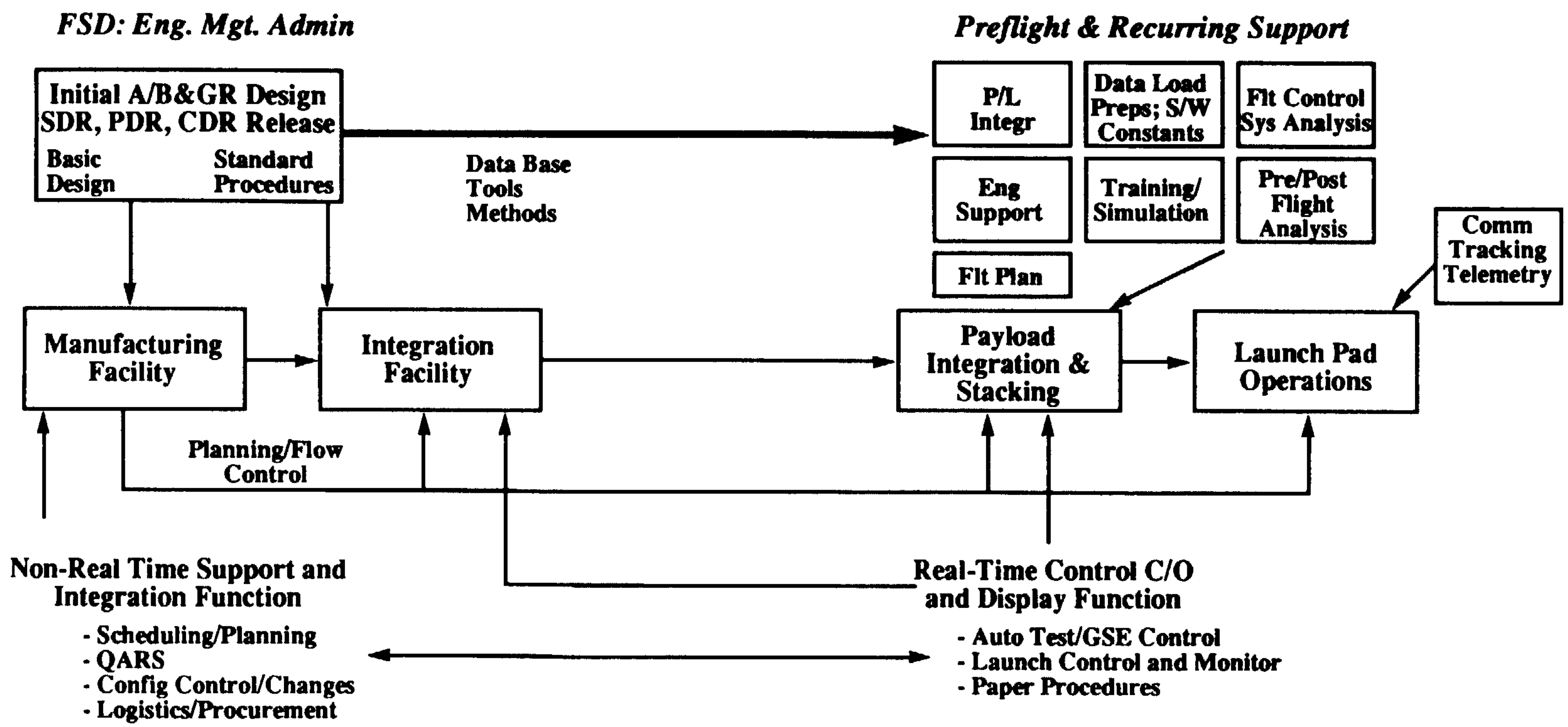


Expert Systems (Decision Support) Applications Contribution to Cost Benefits

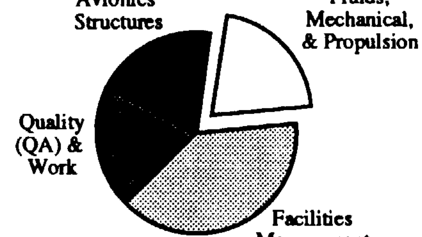


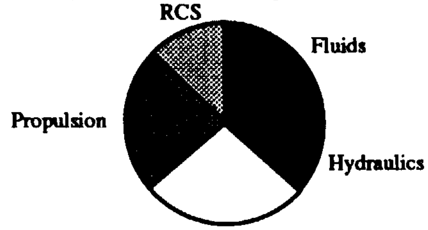
The Operations Function Flow Identifies Automation Opportunities

Advanced Avionics Technologies

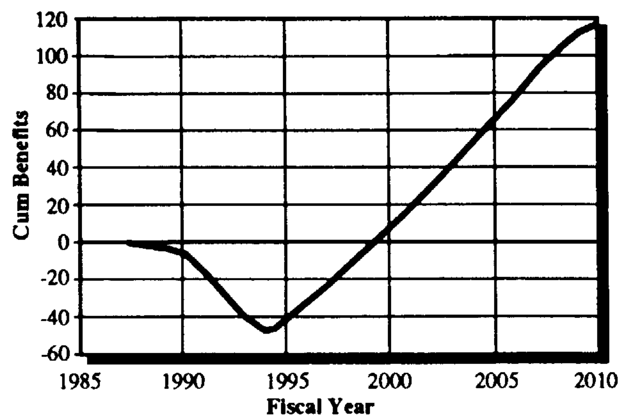


Potential Cost Savings From Electromechanical Systems





	HR	Savings Per Cent Used	Savings (HR)
Total ELV Launch Operations	91575		
Total F/M/P Test Time	19197		
Fluids	4928	10%	490
Hydraulics	2177	90%	1960
Pneumatics	5143	40%	2060
Propulsion	4616	20%	920
RCS	2333	<5%	0
			5430 HR
Equivalent Shuttle HRS			
Plumbing, Vent, and Drain	1069	20%	210
Hydraulics	1573	90%	1430
Propulsion	10099	40%	4040
ACS	2099	<5%	0
VAB Activities			5670
Pad Operations (35%)			3600
			9270 HR



EMA Cost Benefits Potential

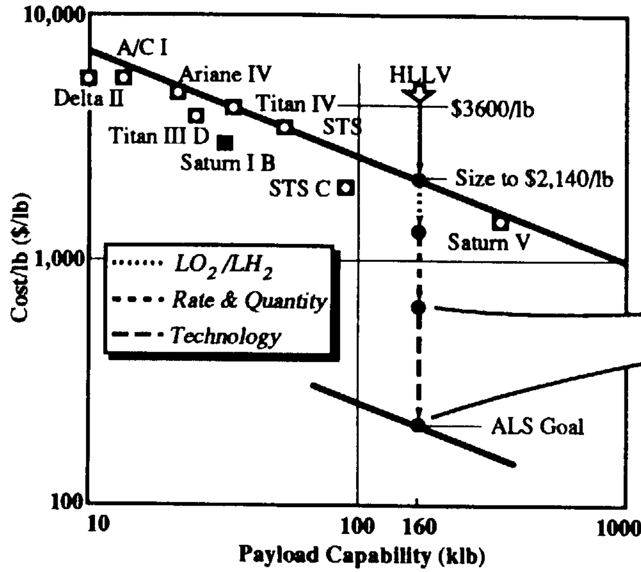
Avionics Technology Transfer

- **Expendable Launch Vehicles (ELV)**
  - Full System Demonstration In Valid Environments Permit Transfer Via:
    - Company Sponsored Efforts To Enhance System Competitiveness
    - Government Direction
- **Commercial Launch Vehicle**
  - <u>Do Not Develop New Technologies</u>
    - Incorporate Only After Full System Demonstration AND After Flight Vehicle Application
    - Must Benefit Hardware and/or Operations Cost

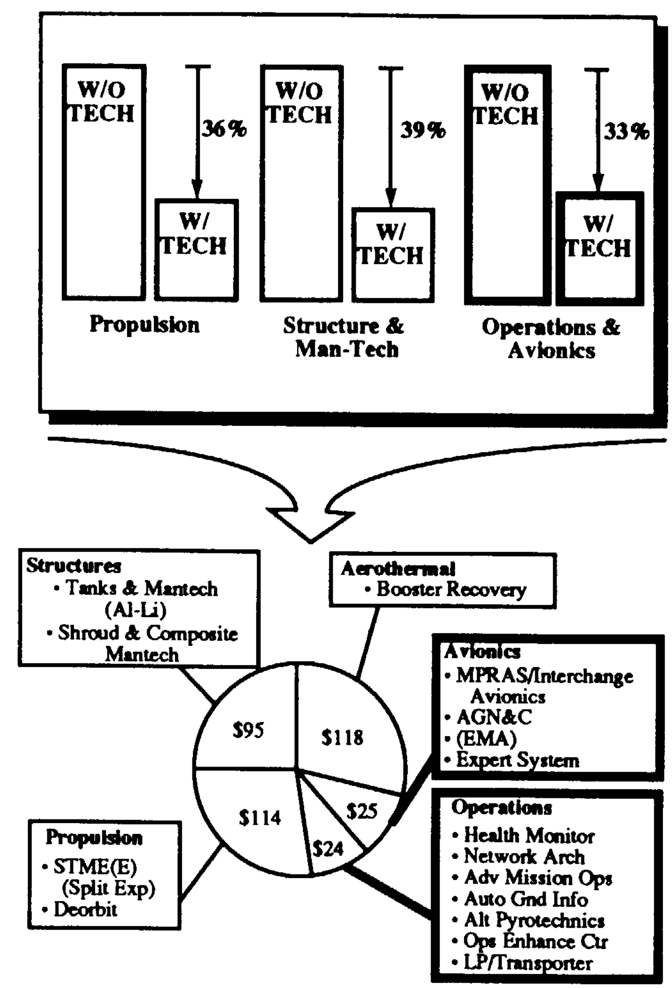
Avionics & Operations Technology Contributes Significantly to Lower Launch Costs

Advanced Avionics Technologies

Target Cost Savings for Technology Developments



Projected Cost Savings for each Technology Development Area



SPACE STATION FREEDOM AVIONICS