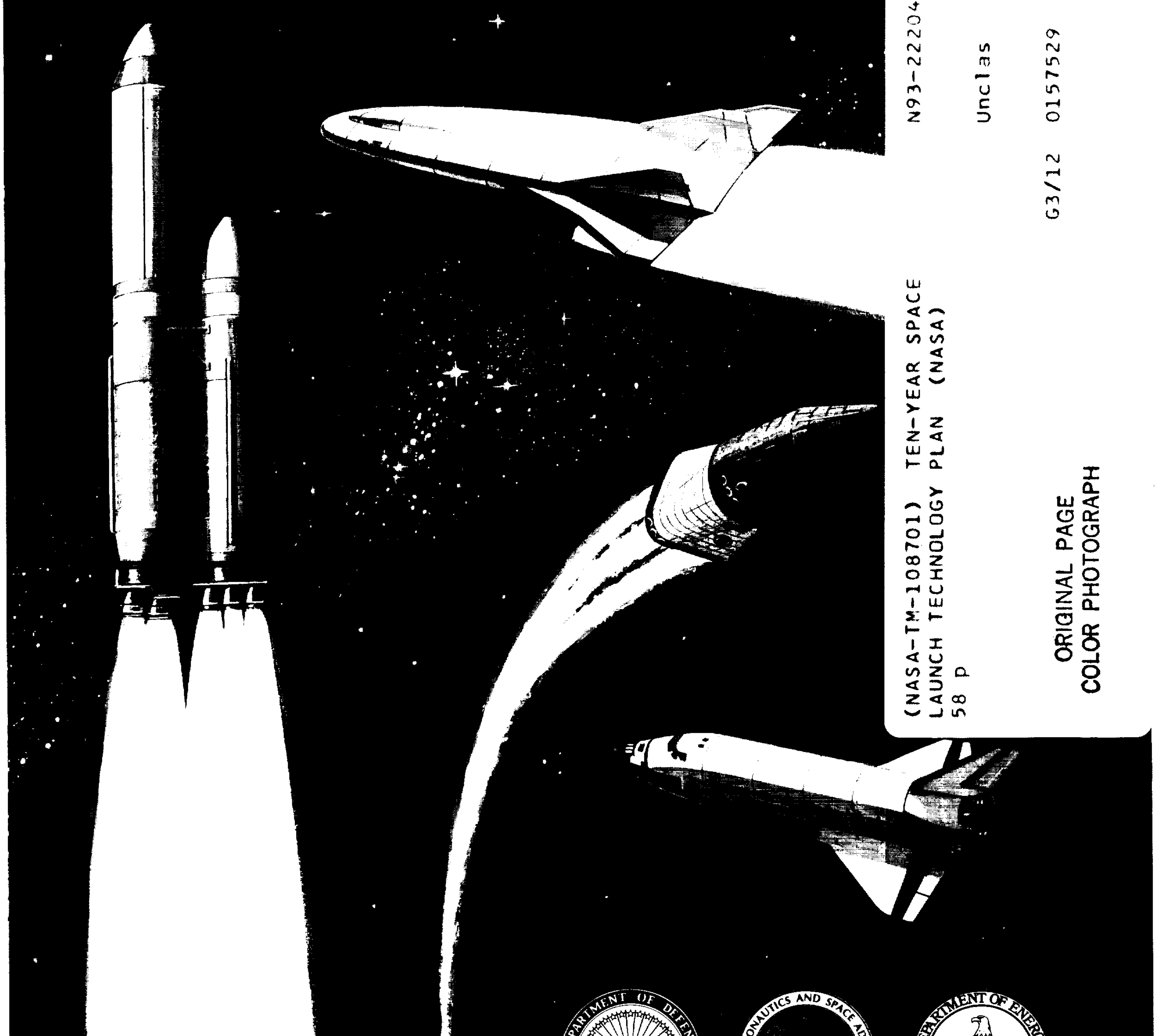
NASA-TM-108701

Year Space Launch Technology Plan



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DEPARTMENT OF DEFENSE · UNITED STATES OF AMERICA

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION · U.S.A.

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

A jointly prepared strategy for the National Space Council to shape the future of our national space launch technology programs

TEN-YEAR SPACE LAUNCH TECHNOLOGY PLAN

November 12, 1992

This plan is in response to the President's National Space Policy Directive 4. It provides a framework for coordination of the national investments in space launch technology, including identification of priority technology developments as well as an implementation strategy which is responsive to current fiscal contraints.

The development of this plan has served to emphasize the need for coordination in the direction of our respective technology development efforts. An existing interagency forum, the Space Technology Interdependence Group (STIG), will be utilized to strengthen our efforts in this regard.

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Figures

Acknowledgments

Representatives of the DoD, NASA, and DOE prepared this plan. The following organizations provided inputs.

Federal Agencies

Department of Defense

Department of Energy

National Aeronautics and Space Administration

Industry

Aerojet General

The Aerospace Corporation

The American Rocket Company

ANSER

Boeing Company

General Dynamics Corporation

General Research Corporation

Hercules Incorporated

Lockheed Missiles and Space Company

Martin Marietta Aerospace Company

McDonnell-Douglas Corporation

Orbital Sciences Corporation

Rockwell International Corporation

Science Applications International Corporation

Thiokol Corporation

TRW, Incorporated

United Technologies

Vision Statement

The nation's future in space rests on the strength of its launch technology program. Only by coherent investments in launch technology and systems can the nation ensure its lead and competitiveness in the space launch industry. This 10-year launch technology plan provides a baseline national architecture for space transportation to guide and direct the advancement of the nation's launch technologies, and to enable the development of the most promising launch and space transfer systems and infrastructures for military, civilian, and commercial missions. These technologies and systems will ensure the operability, reliability, responsiveness, and affordability of space transportation, leading to routine access to space--the U.S. highway to space for all mission needs. Technologies can be used to upgrade the current launch fleet until the new modernized launch systems are available for full operations. In addition to providing new capabilities, these technologies will expand the space commerce sector and provide benefits into other sectors of the economy. By uniting the space launch technology resources and capabilities of the Department of Defense, the Department of Energy, the National Aeronautics and Space Administration, and industry into a cohesive national launch technology program, this vision can be achieved.

Executive Summary

Introduction

This document is the response to the National Space Policy Directive - 4 (NSPD-4), signed by the President on July 10, 1991. NSPD-4 calls upon the Department of Defense (DoD), the Department of Energy (DOE), and the National Aeronautics and Space Administration (NASA) to coordinate national space launch technology efforts, and to jointly prepare a 10-year space launch technology plan. The nation's future in space rests on the strength of its national launch technology program. This plan documents our current launch technology efforts, plans for future initiatives in this arena, and the overarching philosophy that links these interagency activities into an integrated national technology program.

> ***The nation's future in space rests on the strength of its national launch technology program.***

If the United States is to be competitive in space in the decades ahead, it must develop launch technologies that will lead to more modern space transportation systems with significantly lower costs, improved infrastructure, enhanced operability, greater system reliability, and environmental compatibility. A sustained effort is essential to this technology development. Government investment in this research and development is critical. The government agencies involved recognize the importance of joining forces for the benefit of the nation's military, civilian, and commercial space transportation needs.

Requirements

A key element of national space policy stresses the need to develop and maintain assured access to space for military requirements, civilian needs, and U.S. commercial interests. To meet national security requirements, the DoD requires low cost, responsive, and flexible access to space, with a capability to augment available space assets during a crisis. Manned operations in space to support U.S. national security also have the potential to satisfy military requirements.

Reliable delivery of people and cargo to and from space is a continuing requirement for NASA's science, technology, and exploration missions. A significant expansion of launch capability will be required to support piloted lunar and Mars Space Exploration Initiative (SEI)missions. In addition, other government agencies use NASA for launches of their missions.

The DOE laboratories develop small, specialized payloads as part of the Department's arms control/non-proliferation mission and in support of cooperative programs with the DoD and NASA.

Historically, systems developed to satisfy DoD and NASA launch requirements provide the basis for commercial launch services. In an increasingly competitive world market, this fallout approach is not acceptable if the United States is to have a viable commercial launch industry. It is planned to consider commercial space launch needs as part of this activity.

National Space Launch Architecture

The vast majority of the existing Expendable Launch Vehicles (ELVs) are derivatives of ballistic missiles designed 30 to 40 years ago, upgraded frequently to meet growing satellite lift requirements. Product improvements must continue for ELVs, the Shuttle, and Upper Stages to improve reliability, safety, operability, on-time launches, and enhance performance capability. Existing systems can benefit only to a limited extent from the latest technologies. Prudent investments must be made in the current launch fleet and infrastructure, until replaced by new systems for an evolving operationally oriented space transportation system.

New ELVs are expected to come on line within the next ten years. These include the National Launch System (NLS)* and NLS-derived systems, as well as other specialized launch vehicles, such as Pegasus, that are not specifically derived from NLS technology. A heavy lift launch capability is provided for SEI. Future space transportation demands dictate that Medium-Class Launch Vehicles (MLV) capable of launching approximately 20,000 lbs to low earth orbit (LEO) receive priority. These demands emphasize the attributes of operability, reliability, and affordability.

Without making the necessary investments in technology, there will not be improved and new vehicles in the twenty-first century.

Development of Reusable Launch Vehicles (or Reusable Aerospace Vehicles, RAVs) to complement and then replace the Space Shuttle should begin by the year 2005. RAVs have the potential capability to support military global reach/global access needs with on-demand launch. Future plans include combining agency-specific RAV requirements into a single national requirement. Significantly lower operating costs, combined with increased safety and reliability, are critical attributes for manned RAVs.

New classes of space missions for the twenty-first century require new orbital transfer vehicles. The schedule and specific requirements for these systems depend on such programs as SEI.

Technology Programs

Without making the necessary investments in technology, there will not be improved or new vehicles in the twenty-first century. The highest priority should be placed on maturing critical technologies for advanced expendable launch vehicles and reusable launch vehicles, as currently being pursued in the National AeroSpace Plane (NASP) research program and the NLS. These developments represent the majority of the U.S. space launch technology development efforts. At initiation, these programs absorbed most of the launch technology activities being conducted within the generic research and technology programs. The technology development efforts then became focused on the specific program's needs. Such programs are stimulating and productive in the development of technologies applicable both to their specific systems and to a broader class of launch systems.

<u>Technology Discipline Areas</u>

Systems Analysis and Design

Propulsion

Structures , Materials, & Manufacturing

Avionics

Aerothermodynamics and Recovery

Operations and Processing

At the technology discipline level, propulsion represents the lion's share of the technology investments. It is responsible for the major acquisition and operations cost of every space transportation system. DoD, NASA, and the commercial launch industry identified propulsion as a serious area of deficiency within the technology base.

Traditionally, performance driven systems are the primary focus of propulsion technology. The evolution of the liquid propellant Space Shuttle Main Engine (SSME) best exemplifies this. This technically ambitious development, though achieving its goals of very high performance, fell short of its durability, operability, and cost objectives. Means must be found to meet future fundamental propulsion requirements of adequate performance, reliability, and low

* This plan uses the FY92 space launch technologies and programs as a basis from which to go forward. During the development of this document, the National Launch System (NLS) was the approach being pursued for the next generation of expendable launch vehicles. Congressional action, in October 1992, during the final coordination phase of this document, directed termination of NLS. Throughout this plan, there is reference to the NLS program, its goals and requirements, and the technologies being developed under it for this next generation of expendable launch vehicles. The termination of NLS does not effect the technologies needed for a future family of expendable launch vehicles. The reader should interpret all references to NLS in the context of the next generation of expendable launch vehicles.

cost. Key technology initiatives are necessary to establish advanced engine development efforts that encompass, from the onset, cost, operability, and reliability features, as well as performance.

Development of advanced propulsion concepts that could provide significant improvements in capability, along with the other desired attributes, has received minimal attention in the past. For booster systems, these concepts include high-thrust hybrid rocket motors and simple, low-pressure liquid engine designs. For upper stages and space transfer, the demonstration of advanced cryogenic space engines, and of nuclear thermal and electric propulsion will require substantial investments, including major new test facilities. Reusable aerospace vehicles, along with the airbreathing systems for NASP, require high performance rocket propulsion possibly incorporating modular engine designs and combined-cycle airbreathing/rocket technology.

Other technology disciplines (i.e., structures, materials, and manufacturing; operations and processing; avionics; aerothermodynamics and recovery; and systems analysis and design) offer significant potential for improvements in performance, operability, and reliability at lower costs. Targeted space launch technology activities should support these areas:

- development of lightweight, high strength, high temperature materials
- low cost manufacturing and inspection techniques
- highly fault-tolerant avionics incorporating a high degree of adaptive on-board guidance, navigation, and control
- development of materials and shielding techniques to protect personnel and electronics from space radiation
- incorporation of system health monitoring and management and automation of ground processing and flight operations
- improved operations simulation capability to streamline mission planning and allow for rapid reconfiguration of missions.

The infrastructure associated with U.S. space launch capabilities is receiving increased attention. Technologies for modernizing and developing new launch ranges and facilities are as important as vehicle technologies in providing the kind of space access capabilities the United States requires. A new operational philosophy, incorporating an innovative launch processing system (modular facilities and universal clean-pad design concepts) augmented by automation, health monitoring, and artificial intelligence offers potentials for significantly improving the operability and reliability, while reducing the cost of space launch.

Implementation

In today's austere budget environment, it is very difficult to justify plans that call for significant funding increases. This is particularly true for technology investments. Funding specifically allocated for technology developments must co-exist with the more immediate need to begin large systems development programs to improve the current launch fleet and to introduce new launch systems.

Implementation of this plan requires uniting of space technology resources with capabilities of government agencies and aerospace industry toward meeting the nation's needs for space launch technology. Through the various joint interagency programs, government/industry IR&D programs, and joint committees, there exists a high degree of information exchange at the technology working level. These exchanges are very successful in avoiding duplication of effort or overlap in the space launch technology programs. These joint planning activities are instrumental in building stronger relationships for cooperation.

The implementation strategy is to:

- Maintain a robust level of technology base to pursue the national strategy goals set forth in NSPD-4. This minimum investment does not provide for development of the X-30 or maturing nuclear propulsion options.
- Continue the current allocation of funding embedded in NASP and NLS for generic technology programs as NASP and NLS transition to their next development phase.
- Target a greater percentage of the budget to non-propulsion technology areas.
- Monitor investment funding distribution among technology disciplines.

- Compare potential technology payoffs against system attributes.
- Correct allocations where necessary.

All three agencies recognize the need for increased investment in non-propulsion technologies including structures, materials, and manufacturing, operations and processing, avionics, aerothermodynamics and recovery, and systems analysis and design. This plan sets forth the following ordered technology priorities:

- Complete the critical technology investments embodied in the NLS and NASP programs.
- Develop broad technologies that will enable truly affordable reusable launch systems.
- Develop technologies that will significantly improve upper and transfer stage performance. A significant investment will be required to mature nuclear propulsion options.
- Continue to make modest investment in technology suitable for insertion to improve the existing launch fleet.
- Increase the number of new concept test beds and flight test demonstrations when needed.
- Increase the funding of non-propulsion technologies,as future program options are implemented, especially in areas not sufficiently covered by the current focused programs.

The Road Ahead

The DoD, DOE, and NASA will continue to pursue vigorous space transportation technology programs. However, because of the ever-changing state of technology within and outside the U.S. (e.g., the hardware and technology currently available through the former Soviet Union), continued national level attention and oversight is required. This will ensure that the nation's space launch architecture and roadmaps for space transportation systems are current and properly focused. This plan will be routinely revisited as part of each agency's budget preparation process. Future revisions will be accomplished through normal interagency processes to ensure a coordinated effort among DoD, DOE, and NASA.

Section 1

Introduction

1. Introduction

National Space Policy Directive 4 (NSPD-4), National Space Launch Strategy, signed by the President on July 10, 1991, comprises four elements:

- Ensuring that existing space launch capabilities, including support facilities, are sufficient to meet U.S. Government (manned and unmanned) space launch needs
- Developing a new unmanned, but man-ratable, space launch system to greatly improve national launch capability with reductions in operating costs and improvements in launch system reliability, responsiveness, and mission performance
- Sustaining a vigorous space launch technology program to provide cost-effective improvements to current launch systems and to support development of advanced launch capabilities, complementary to the new launch system
- Considering commercial space launch needs in themselves and factoring them into decisions on improvements in launch facilities and in launch vehicles

This plan responds to the call that the Department of Defense (DoD), the Department of Energy (DOE), and the National Aeronautics and Space Administration (NASA) cooperatively develop a 10-year space launch technology plan to implement the third element of the strategy. If the United States is to remain competitive in space in the decades ahead, it must develop launch systems that are more affordable, operable, and reliable than its present systems. It is from this perspective that DoD, DOE, and NASA have joined forces for the benefit of the nation's military, civilian, and commercial space transportation mission needs.

1.1. Purpose and Objectives

The purpose of this integrated DoD, DOE , and NASA activity is to develop a strategic plan of national scope that emphasizes technologies of common benefits to defense, civilian space, and commercial sectors--a roadmap along the "highway of space."

The objectives of the technology program are to significantly enhance launch operability, reliability, and responsiveness both for manned and unmanned space missions, while providing a substantial reduction in the cost of space access. From an overall perspective, current U.S. launch systems are unable to provide these essential elements in a cost efficient manner. As a result, the United States is becoming less competitive relative to other nations in the international space launch market. Under current fiscal constraints and growing international competition in space, the three agencies accept the need to cooperate in directing their respective technology development efforts so as to enhance national launch capabilities while still meeting agency-specific agendas and objectives.

1.2. Scope

This 10-year plan describes the status of launch technology activities and sets forth a strategy for shaping the future of launch technology programs in the United States from a national perspective in response to the goals established in NSPD-4. This plan is the first major attempt at establishing a process to achieve these goals. Specifically, the plan:

- Identifies broad national space launch requirements and needs
- Defines the attributes of a national space launch transportation system
- Relates key technologies to the desired attributes of space launch systems
- Identifies promising technologies for future launch systems, launch architectures, and infrastructure options and upgrades to current systems in response to national needs
- Identifies technology requirements in relation to desired space launch options and launch system attributes
- Identifies and summarizes ongoing national space launch technology programs
- Presents options for future programs of research and development to satisfy the nation's space launch technology needs
- Recommends technology priorities
- Identifies a mechanism for inter-agency coordination and planning of the technology programs

1.3. Organization of the Report

The report comprises three sections: this Introduction, a proposed national space launch architecture, and the 10-year technology plan. The activities, including space launch technology, are described in terms of focused technology programs and six primary technology disciplines.

- Systems Analysis and Design
- Propulsion
- Structures, Materials, and Manufacturing
- Avionics
- Aerothermodynamics and Recovery
- Operations and Processing

The launch architecture section discusses a National mission model comprising individual agency launch requirements and U.S. commercial launch needs, the desired attributes of future launch systems (e.g., safety, reliability, availability), and the relationship between individual technology disciplines, launch requirements, and system attributes. The third section contains program plans for each of the six technology disciplines, and concludes with a discussion of investment benefits and funding strategy.

1.4. FY93 Congressional Action

This plan uses the FY92 space launch technologies and programs as a basis from which to go forward. During the development of this document, the national Launch System (NLS) was the approach being pursued for the next generation of expendable launch vehicles. Congressional action, in October 1992, during the final coordination phase of this document, directed termination of NLS. Throughout this plan, there is reference to the NLS program, its goals and requirements, and the technologies being developed under it for this next generation of expendable launch vehicles. The termination of NLS does not effect the technologies needed for a future family of expendable launch vehicles. The reader should interpret all references to NLS in the context of the next generation of expendable launch vehicles.

Section 2

A Proposed National Space Launch Architecture

2.1. National Mission Model

National space policy stresses, as a key element, the need to develop and maintain assured access to space. This broad policy framework is interpreted according to the requirements of the DoD, NASA, DOE, and U.S. commercial space launch industry. Historically, systems developed to satisfy DoD and NASA launch requirements have also been used to provide commercial launch services. If the United States is to maintain a viable commercial launch industry in an increasingly competitive world market, commercial space launch needs must be considered along with military and civilian requirements.

The national mission model forecasts launch requirements through the year 2010 (see Figure 2-1). This information has been extracted from the data bases maintained by the Air Force Space Command (AFSPACECOM) and NASA. The mission model includes DoD, NASA, and commercial payload lift requirements for a baseline and a growth option which reflects SEI and Space Station Freedom (SSF) evolution. The mission model does not include either the deployment of the space elements of a ballistic missile defense system which could have substantial launch requirements or possible military aerospace vehicle missions.

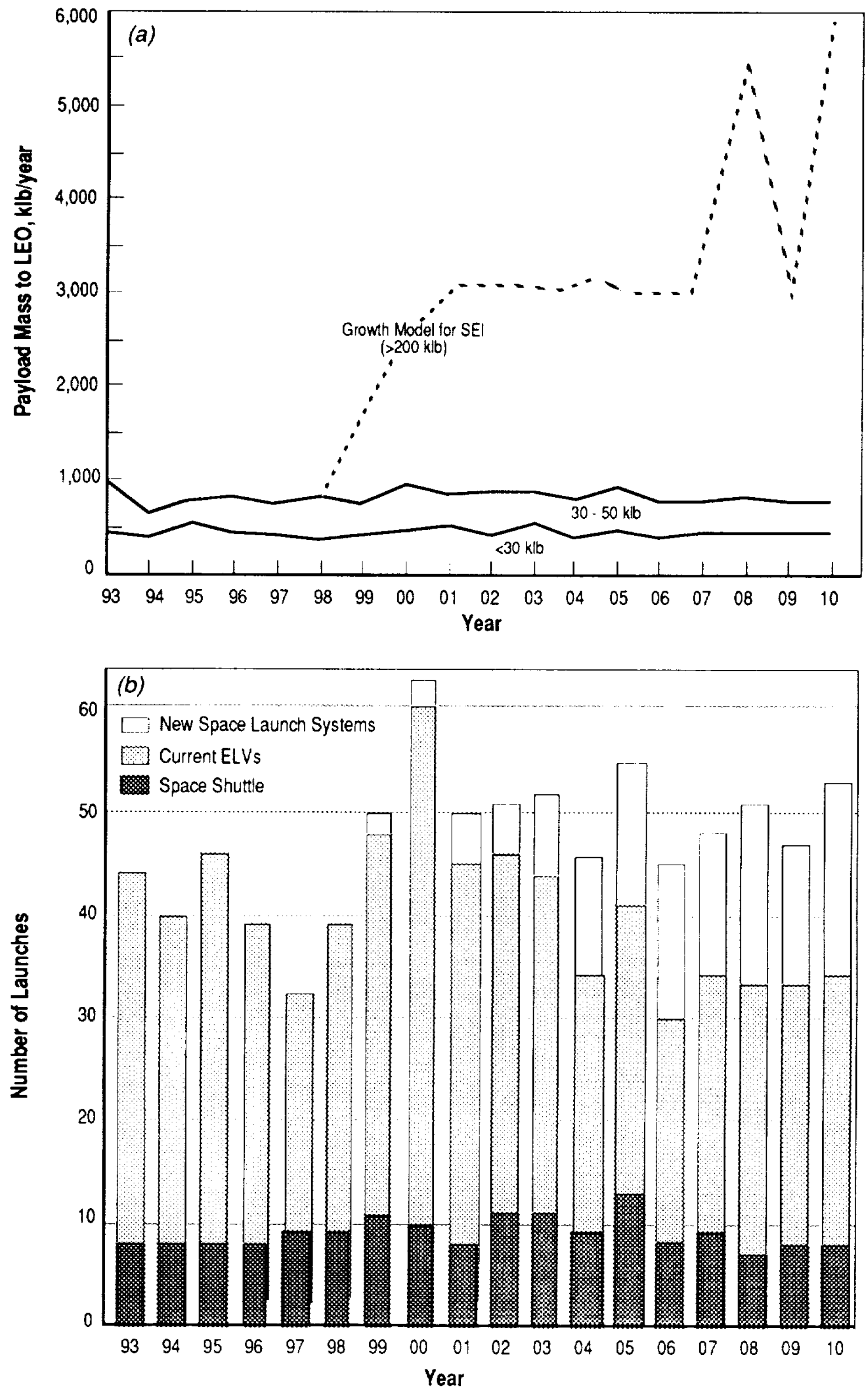
The mass to low earth orbit (LEO) requirements, presented in Figure 2-1.a, are subdivided by size, i.e., *medium* - less than 30 klb, *heavy* - 30 - 50 klb, and *very heavy-lift for SEI* - greater than 200 klb. The mission model shows a need to launch of approximately an average around 750,000 lbs of payload per year to LEO until about the year 1998. At this time, the growth mission model projects an emerging requirement for a very heavy-lift launch vehicle capable of payloads up to several hundred metric tons to support SEI. The projected number of launches is presented in Figure 2-1.b by vehicle type, i.e., the Space Shuttle, current ELVs, and new space launch systems which are expected to start operations in the year 1999 or later. Historically, launch expectations have been overstated by as much as 50 percent. The Shuttle and ELVs will continue to be the prime carriers into the twenty-first century.

2.1.1. DoD Requirements

The DoD requires assured, responsive, and flexible access to space as it increasingly relies on space assets to support military ground, sea, and air forces. Control and exploitation of space to provide global knowledge and situational awareness to ensure on-orbit mission capability is an important national security requirement. In a time when forces are being scaled back, space becomes the ultimate high ground to multiply the effectiveness of ground, air, and sea forces, as convincingly demonstrated in recent global events. The DoD accomplishes this by providing navigation, weather monitoring, communication, surveillance, warning, attack assessment, and space control. In Operation Desert Storm, there was time to reposition satellites already in orbit to increase their effectiveness throughout the conflict. But one must be able to launch replacement or enhanced-capability satellites quickly and reliably to satisfy the military requirement of flexibility, including the need for new capabilities, satellite repair, payload changeout, or increased satellite repositioning.

Figure 2-1

National Mission Model



Includes military, civil, and U. S. commercial launches.

Source: National Mission Model (AFSPACECOM), NASA Civil Needs Data Base, and projected U.S. Commercial ELV Launches, 1991

The DoD conducts launch operations to support space experiments for both the Space Test Program and the Strategic Defense Initiative Organization (SDIO), developing technologies for future military space applications including Ballistic Missile Defense.

Current DoD launch requirements represent an average demand of 18 missions per year. Of these, approximately 10 launches are required from the East Coast for navigation, communication, warning, and other missions, and approximately 8 launches from the West Coast for weather, surveillance, and research and development. A capability is needed to augment available space assets during crisis situations. A secure and survivable launch capability must be maintained during times of war.

Manned operations in space have the potential to satisfy U.S. national security requirements. These requirements include timely surveillance support and CONUS-based, rapid response, global-reach platform capability. The unique attributes of military-man-in-space are expected to enable a wide range of mission possibilities requiring routine access to space.

From a technology perspective, DoD's future needs are addressed in the *Defense Science and Technology Strategy*. Most notable in this regard is a thrust on global surveillance and communications, that clearly addresses the need for improved space launch capabilities. Similarly, the key technology areas of Materials and Processes, Energy Storage, and Propulsion and Energy Conversion address important technologies required to improve space launch capabilities.

2.1.2. NASA Requirements

Reliable delivery to and from space of people and cargo are continuing requirements for NASA's science, technology, and exploration missions and missions for other government agencies assigned to NASA for launch. NASA's requirements include Earth-to-orbit launches, on-orbit operations, high-energy geosynchronous and interplanetary transfer, and safe return of crews and cargo. Assembly and use of the Space Station Freedom will require significant launch support during buildup and will regularly require Earth-to-orbit launch systems to rotate crews and deliver and return supplies. Planetary robotic missions will continue to require launches within constrained launch windows as well as the use of high performing transfer stages. Manned space exploration is planned for the twenty-first century, which will include missions to the moon and Mars. A major expansion of launch capability will be required to satisfy space exploration goals during the coming decades.

Where available, NASA will continue to purchase launch services from the commercial sector. Continual improvements in these systems and supporting facilities are required to improve reliability, reduce operational costs, and provide needed performance enhancements. An alternate form of transportation may be required to complement the Shuttle during its planned lifetime to provide assured manned access to space. Eventually the Shuttle will be replaced by a second-generation vehicle. Substantial improvements in system reliability, operability, on-time performance, and reduced development and operation costs will be required of any new vehicles developed. Very high reliability will be required for human-rating of launch and space transfer vehicles. Life support, on-orbit, and return capabilities will drive the system requirements for manned elements toward reusability.

Currently, three potential categories of NASA missions will require heavy-lift launch:

- Space Station Freedom
- Alternate manned access to LEO
- Space Exploration Initiative

Planning for these missions is in the early stages. Thus, only estimates can be made of capability, time frame, and number of vehicles required. A launch capability in the 50,000-pound class will be required at a launch rate of one to two per year for Space Station growth and later for assured manned access to LEO. A launch capability in the 550,000 pound class (250 metric tons) with a launch rate of four to nine per year could be required for cargo and piloted lunar and Mars SEI missions. These heavy-lift requirements are identified for planning purposes only since the NASA programs they support are not baselined. A new generation of space transfer and lander vehicle systems must be developed to support SEI with a high level of reliability, propulsion efficiency, and systems autonomy.

A typical upper stage scenario includes:

- upgrades to current upper stages, including new chemical engines
- autonomous maneuvering stages for use in conjunction with ELVs to resupply the Space Station
- solar and nuclear electric/thermal transfer vehicles in the 50–100 kilowatt class for automated spacecraft missions requiring high levels of propulsion efficiency
- nuclear-based propulsion systems in the multimegawatt class for manned interplanetary flight (i.e., to Mars)

2.1.3. DOE Requirements

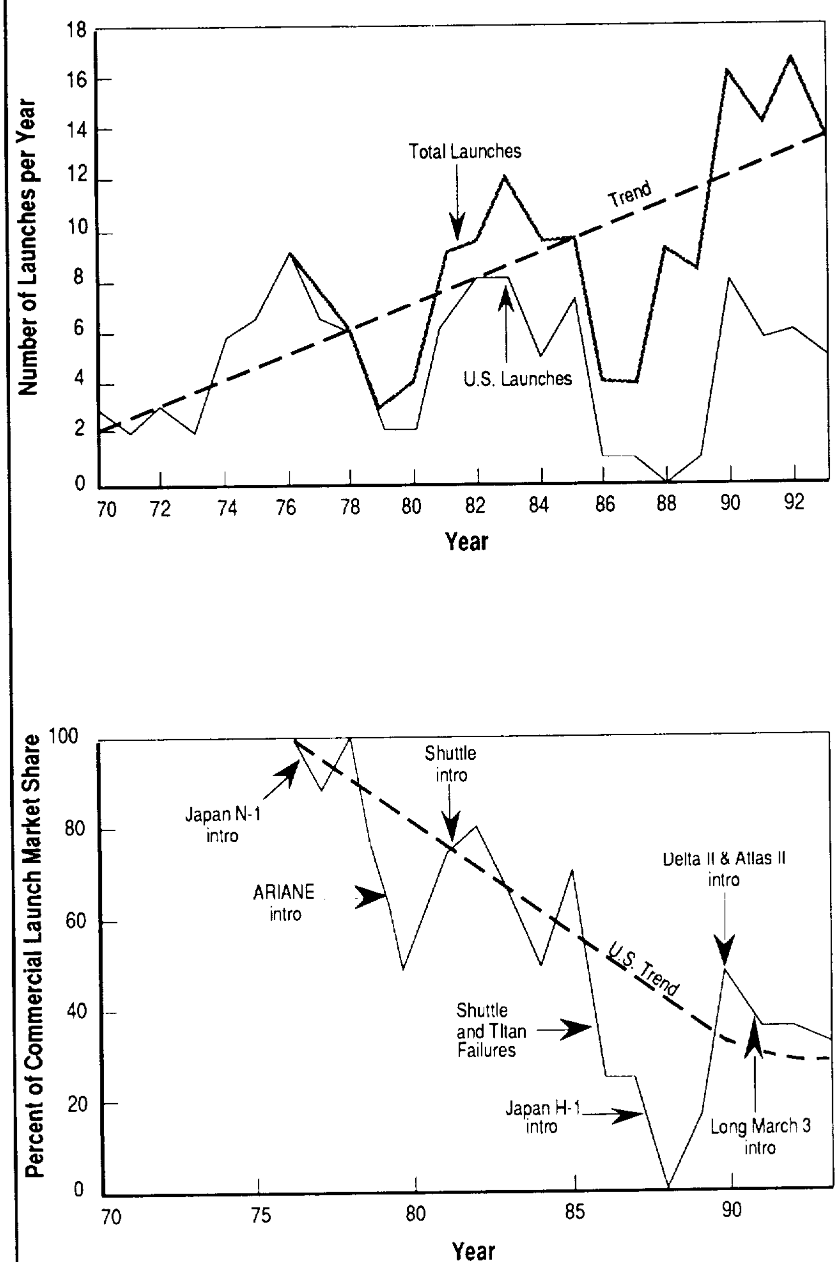
The DOE has been involved in developing space launch technology since 1953, when it was the Atomic Energy Commission, having launched over 1,500 rockets and supplied instrumentation for numerous satellites. The DOE laboratories will continue to develop small, specialized payloads as part of their arms control/non-proliferation mission and in support of cooperative programs with DoD and NASA. Nevertheless, its principal role in the National Space Launch Strategy is as a contributor to the technology base. In order to lower costs while improving the performance of launch vehicles that compete in the commercial market, advancements must be made to the state-of-the-art in developing robust, manufacturable structures from new materials, in instrumenting launch vehicles, in developing lightweight radiation shielding materials and techniques, in processing the resultant data to automate and simplify operations, and in developing vehicle health monitoring and system readiness capabilities. Such capabilities exist at the DOE laboratories, having been developed for other applications. Furthermore, the DOE provides a strong technology base in its traditional role in nuclear power, which can be applied to develop high specific impulse nuclear thermal rockets and nuclear electric propulsion systems.

2.1.4. U.S. Commercial Needs and Interests

Currently, the U.S. commercial launch industry is competing in the world market with privatized launch vehicles derived from ballistic missiles developed by the government in the 1950s and 1960s. This launch capability dates from an era of maximizing performance capability at the expense of operability. As a result of the U.S. Government's policy decision in the early 1980s to phase out ELVs and rely exclusively on the Shuttle, the U.S. fleet of ELV launch vehicles and facility upgrades were allowed to lapse. The Shuttle failure in 1986, combined with increased foreign space launch competition - notably from the European Ariane, has resulted in the U.S. losing a significant share of the world launch market as shown in Figure 2-2. U.S. ELV upgrades were introduced in the late 1980s as part of the reestablishment of a mixed fleet strategy and were successful in regaining some of the lost market share. However, to significantly reverse this downward trend, the U.S. industry must remain

Figure 2-2

U.S. Share of the Commercial Launch Market



The U.S. share of the launch market began to decline in 1976 with the introduction of new foreign launch vehicles.

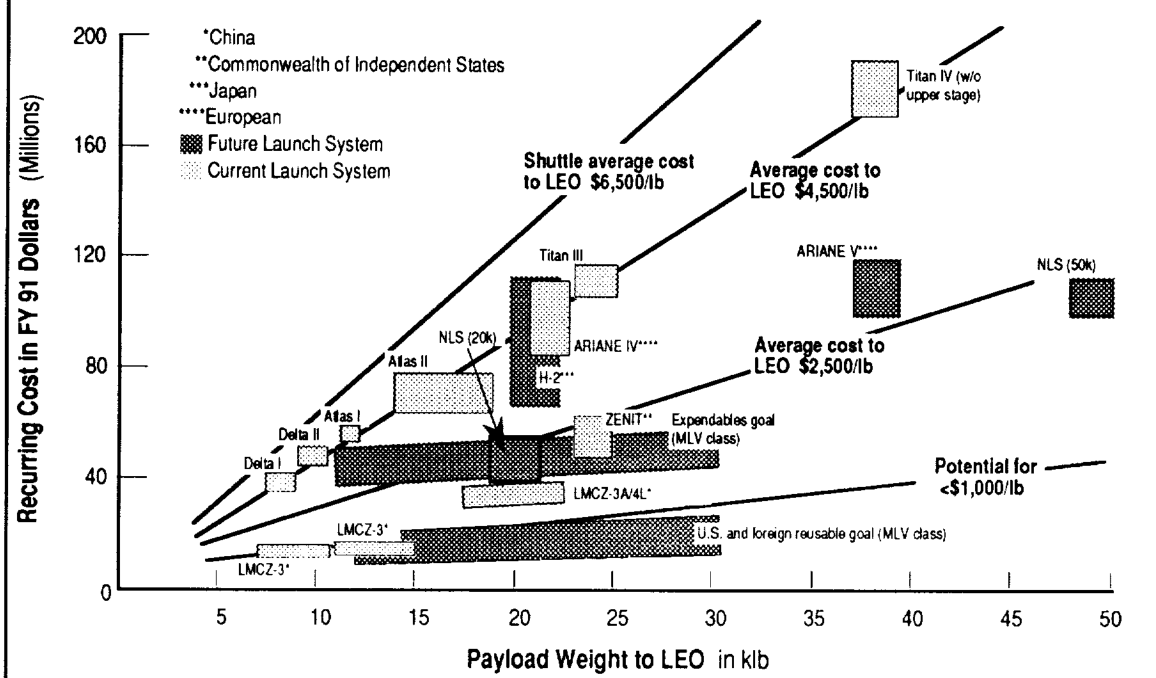
competitive in the international marketplace; thus requires launch costs to be reduced substantially. The Ariane and the Japanese H-2 represent new "clean sheet" approaches developed with government funds and designed from the outset to be low-cost. The Ariane family alone now captures 50 percent of the international launch market. The larger Ariane V is scheduled to become operational in the late 1990s and is intended to have significantly lower cost per pound than the Ariane IV. The H-2 operational costs and market share are yet undetermined. The CIS and China have an abundance of low-cost labor needed to fabricate labor-intensive performance-derived boosters. As a result, these countries are also posing new competition in the world market.

Launch vehicle cost comparisons are presented in Figure 2-3 for the entire range of performance classes. To be competitive with these new foreign commercial launch vehicles, the United States will need to reduce current launch system costs by at least 25 percent toward the end of this decade. A continuing program of improvements and component technology for current launch systems could extend the competitiveness of the existing fleet to somewhat beyond 2000; otherwise, the U.S. industry may not survive in the commercial market.

To remain competitive in the long term, however, the U.S. commercial industry

Figure 2-3

Launch Vehicle Cost Comparisons*



* Assumes a 100 nm, 28.5°, circular orbit

will require new low-cost (45 percent, or more, reduction in launch costs) launch vehicles within the next 10-15 years with a 9,000- to 15,000-pound payload capability to a geosynchronous transfer orbit. In this post-2000 era, it is possible that fully reusable medium class launch vehicles, offering flight costs approaching $500 per pound, could be developed. The first nation to realize this capability will most likely dominate the world market. Such systems, once developed, offer new and greatly expanded markets in space.

Direct launch costs do not tell the entire story. The requirement to pay for the development of a $50-million-plus launch vehicle several years prior to launch is a barrier to many commercial ventures. In addition, interest payments, insurance costs, and loss of revenues present additional risks to commercial launch ventures. Enhanced operability, reliability, and on-time, routine launches are therefore as important to the commercial launch community as they are to the civil and military communities.

2.2. Launch System Options and Roadmap

The requirements of DoD, NASA, and DOE lead to a set of goals for future launch systems. These goals include improving reliability (toward 98% or better for unmanned vehicles and to 99.6% or better for manned vehicles) reducing launch costs (toward $1,000.00 per pound to Low Earth Orbit), achieving operational flexibility (removing most or all of the constraints to launching on schedule), and making launch vehicles and infrastructure environmentally compatible (e.g., clean burning propellant).

System options for both launch vehicles and orbital transfer vehicles to ultimately achieve these goals are listed in Figure 2-4. Separate categories are indicated for existing launch vehicles, new expendable launch vehicles, and new

Figure 2-4

Missions for Existing and New Vehicle Concepts

		Missions / System Options	DoD					DoD/DOE/NASA				NASA					Commercial			
			Navigation	Warning/Surveillance	Other (classified missions)	SDI (ballistic missile defense)	Manned Military (Global Reach Missions)	Communication	Weather	Expendable R&D and Small Responsive Satellites	Sortie, Research & Development Missions	Planetary Probes	Space Station Freedom	SEI-Lunar Base	SEI-Mars Base	Earth Observation and Scientific Research	Commercial Launch	Expanded Space Industry	Technology Spinoff	Generic Hypersonic Transportation
Launch Systems	Existing Vehicles	Small/medium ELVs (up to 18K)	◍	◍	◍	◍		◍	◍	◍		◍		○		◍	◍			
Launch Systems	Existing Vehicles	Large ELVs (TITAN III, IV; 30 to 50K)		◍	◍			◍		◍		◍	○		○	◍	○			
Launch Systems	Existing Vehicles	Shuttle (50K)	◒	◍	◍			◒	◒	◒	◒	◒	●	◒	◒	◒				
Launch Systems	New Expendables	NLS (20K, 50K, 130K)	●	●	●	●		●	●	●		●	○	◒	◒	●	●		○	
Launch Systems	New Expendables	Very heavy lift (200K +)										◒	○	●	●					
Launch Systems	New Expendables	Commercial MLVs and small launchers	●	●	●	●		●	●	●	●	●	◒	○	○	●	●		○	
Launch Systems	Reusables	Personnel Launch System					○				◒		◒	◒	◒	○			○	
Launch Systems	Reusables	All rocket concepts	◒	◒	◒	◒	●	◒	◒	◒	◒	◒	◒	◒	◒	◒	◒	◒	○	
Launch Systems	Reusables	Airbreathing (NASP/NDV)	◒	◒	◒	◒	●	◒	◒	◒	◒	◒	◒			◒	◒	◒	○	●
Launch Systems	Reusables	Combined Rocket/Air Breathing	◒	◒	◒	◒	●	◒	◒	◒	◒	◒	◒			◒	◒	◒	○	◒
Orbital Transfer	Existing	Existing upper stages	◍	◍	◍	◍	○	◍	○			◍					◍			
Orbital Transfer	Advanced Chemical	New upper stages	●	●	●	●	○	●	○			●		◒			●		○	○
Orbital Transfer	Advanced Chemical	Cargo transfer vehicle				◒					◒	○	◒	○	○				○	○
Orbital Transfer	Advanced Chemical	Space transfer vehicle										◒	○	●	○	○		○	○	○
Orbital Transfer	Advanced Chemical	Ascent/Descent	○	○	○	○	○	○	○			●	○	●	●	○	○		○	
Orbital Transfer	Solar/Nuclear	Nuclear Thermal	○	○	○	◒	○	○	○		○	◒		◒	●		○		○	○
Orbital Transfer	Solar/Nuclear	Nuclear Electric	○	○	○	◒	○	◒	○		○	●		◒	◒		○		○	
Orbital Transfer	Solar/Nuclear	Solar Electric/Thermal	○	○	○	◒	○	◒	○		○	◒	○	◒	◒	◒	◒	○	○	

● Required to meet goals ○ Enhances capability above goals

◒ Competing technology option ◍ Improves capability but cannot meet new system goals

Spaces without symbols are not applicable

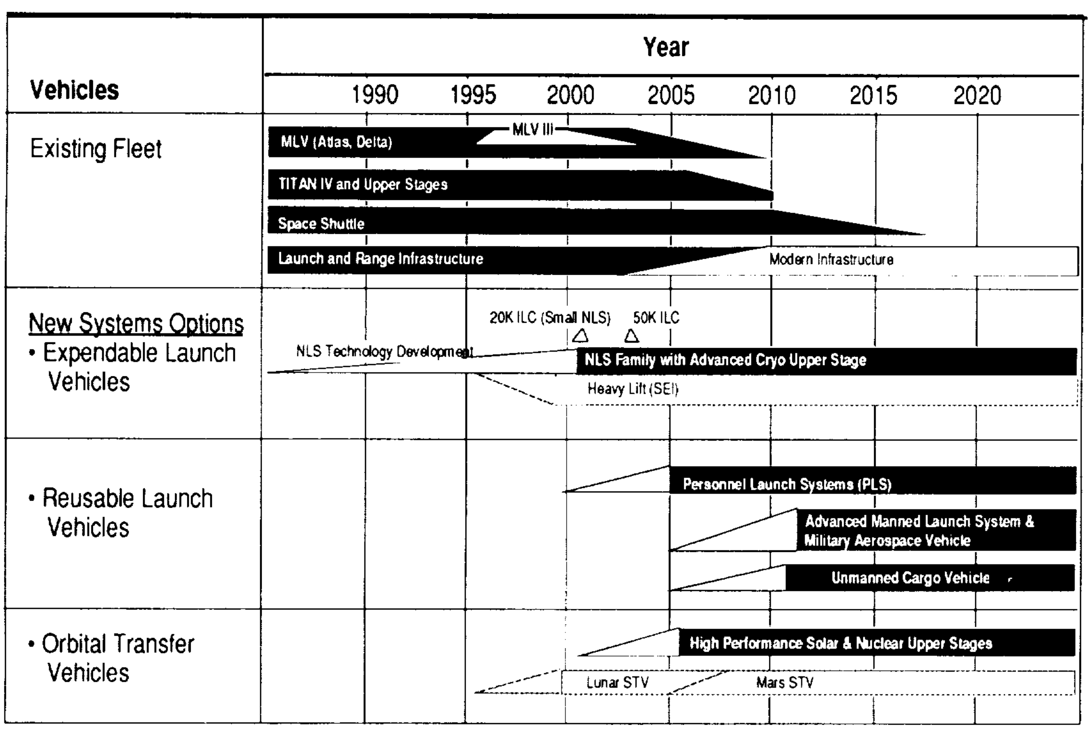
reusable launch vehicles (both manned and unmanned). Similarly, categories of orbital transfer vehicles are shown for existing upper stages, advanced chemical propulsion, and solar/nuclear. The figure provides a qualitative assessment of the capability of the various options to fulfill mission requirements at desired levels of affordability and operability. Improvements to the existing fleet, while providing enhanced or additional capability, cannot achieve goals for overall mission requirements currently on the books. New systems are needed to meet virtually all future mission requirements, a number of which represent competing technology options.

A roadmap showing the potential options to replace aging systems and to improve the nation's launch capabilities is displayed in Figure 2-5. It is assumed that the existing fleet will be upgraded to remain viable until replaced soon after the turn of the century. New ELVs include NLS and NLS-derived systems and small responsive vehicles. A heavy lift launch capability will be required for SEI. Reusable Launch Vehicles to complement and then to replace the shuttle will be needed early in the century. Orbital Transfer Vehicles will be required, depending on the schedule, for programs such as the SEI and ELV cargo delivery to SSF.

The roadmap depicts an evolving space launch architecture that responds to changes in requirements and in technological capabilities. Thus, it should adapt to near- and far-term requirements, to available technologies enabling new capabilities (technologies push), and to technologies that can be developed to satisfy a system need (requirements pull), while satisfying cost and schedule constraints. As will be discussed in Section 2.2.2., the new system options, as well as the upgrades to the current systems, drive the planned technology development efforts. It is not assumed that all of the system options shown in the architecture will be carried to completion. Instead, as system trade studies are completed and updated, and depending on the progress of enabling technologies, changing requirements, and prototype flights, there will evolve an informed basis for proceeding with full-scale engineering of selected systems.

Figure 2-5

National Space Launch Roadmap



Current fleet is mapped with potential new launch system options for both launch vehicles and orbital transfer vehicles.

2.2.1. Existing Space Launch Systems

The current U.S. fleet of launch vehicles and their infrastructures includes Delta II; Titan II, III, and IV; Atlas II; Space Shuttle; and a variety of small launch vehicles, such as Pegasus. Representative launch vehicles are shown in Figure 2-6. The vast majority of ELVs are derived from ballistic missiles designed 30 to 40 years ago, with upgrades to continually stretch performance to meet growing satellite launch needs.

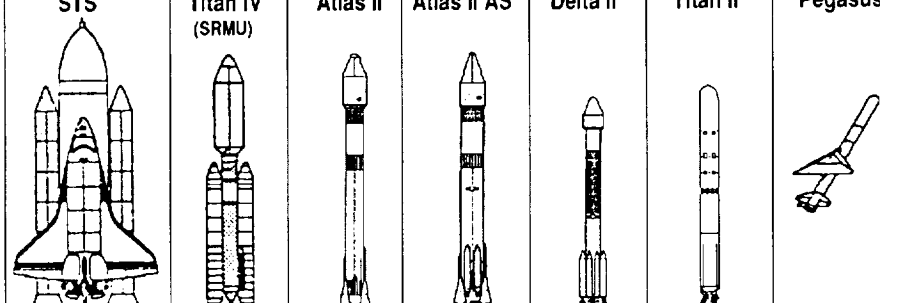
The largest ELV is the Titan IV with a capability of 39,000 lbs to LEO, soon to be increased to 49,500 lbs, by a larger solid rocket motor upgrade (SRMU) program. The Titan III is capable of launching 31,800 lbs to LEO. The Atlas II and the Delta II MLVs are capable of launching 14,500 lbs and 11,100 lbs to LEO, respectively. Smaller MLV payloads, up to 5,300 lbs, are launched on the Titan II. These current expendable vehicles have reliabilities ranging from 94 to 98 percent, and relatively lengthy launch processing (preparation) times of from 102 to 190 8-hour shifts.

The Space Shuttle, a partially reusable vehicle, has a launch capacity of 51,000 lbs to LEO and performs missions not possible with current expendables. These missions include space access, satellite assembly and repair, satellite retrieval, on-orbit stay and return missions, rendezvous, and docking. The Shuttle has a demonstrated reliability of 98 percent and requires 240 8-hour shifts to process for launch.

This launch vehicle fleet is complemented by storable and cryogenic fueled upper stages. The cryogenic Centaur G upper stage can place up to 10,000 lbs into geosynchronous orbit (GEO) when launched on top of a Titan IV (12,000 lbs with the SRMU). A smaller Centaur D is used in conjunction with the Atlas

Figure 2-6

Representative Current U.S. Space Launch Systems

Characteristics	Launch System						
	STS	Titan IV (SRMU)	Atlas II	Atlas II AS	Delta II	Titan II	Pegasus
							
Performance (klbs to 28.5°, 100 nm)	51	39 (49.5)	14.5	19	11.1	4.2 (100 nm, Polar)	0.8
Reliability	0.98	0.95	0.94	0.94	0.96	0.98	0.98
Launch Processing Time (8-hour shifts)	240	190	115	125	102	135	18

Performance for a Titan IV is shown without and with the solid rocket motor upgrade (SRMU).
Atlas II AS will be commercially available in the mid-1990s.

launch vehicle to boost up to 3,500 lbs to GEO. The solid rocket motor Inertial Upper Stage (IUS) is used with the Titan IV and Shuttle vehicles, allowing up to 5,000 lbs to geosynchronous orbit. The smaller Payload Assist Module (PAM) D family of solid motor upper stages can deliver up to 2,300 lbs to GEO on the Delta II.

Through technology insertion, improvements to the current fleet of ELVs, the Shuttle, and upper stages can enhance to some extent payload capability and improve reliability, safety, operability, and on-time launches. Only new technology-based improvements are addressed in this plan.

2.2.2. New Space Launch System Options

Infrastructure

A limited and aging launch infrastructure contributes to the lack of launch flexibility and responsiveness of current systems. Most facilities are tailored to specific vehicles which are largely assembled on the launch pad. Operations are extremely labor intensive and costly. The Plan advocates a new operational philosophy based on modular facility construction sized for multi-vehicle configurations, without fixed or mobile service towers, encapsulated payloads, and off-pad processing. This universal "clean pad" concept will reduce the cost per flight and improve operability. Flexibility might also be improved by incorporating advanced technologies such as vehicle health monitoring, artificial intelligence, and automation. Additionally, the range infrastructure should be integrated with launch vehicles to achieve standardized operational effectiveness.

New Expendable Launch Vehicles

The NLS family of vehicles is intended to replace existing, higher-cost ELVs and provide new capabilities. The objective of the NLS program is to create a robust launch system including improved production capabilities, launch operations, and a modular family of expendable launch vehicles. Launch operations are targeted to begin in the first decade of the twenty-first century. The goals of operability and affordability are the driving factors in the NLS design philosophy. Thus, the objective of the NLS is not to push technology to new performance extremes but rather to allow technology advances in the areas of operability and affordability to push new design philosophies. The critical technologies for the NLS include:

- a robust engine (the Space Transportation Main Engine)
- fault tolerant, multi-path avionics
- lightweight, high-strength Aluminum-Lithium structures
- advanced manufacturing techniques
- the use of Artificial Intelligence and a Vehicle Health Maintenance System to automate and streamline operations and processing.

The baseline NLS family includes the phased introduction of core vehicles capable of launching 20,000 lbs and 50,000 lbs to LEO. Strap-on boosters can provide additional payload capacity. A heavy-lift capability in the 550,000-pound class and beyond to support SEI requirements could be developed using large hydrocarbon engine systems or large solid rocket boosters. These systems could be complemented with a nuclear thermal rocket engine to enable interplanetary exploration. Supporting elements to NLS include a payload accommodation vehicle for autonomous delivery of cargo to the Space Station Freedom or a more capable upper stage for spacecraft delivery to high energy orbits. The 20,000-pound class NLS may be used to satisfy commercial needs. Accelerated development of this vehicle would provide an earlier market penetration for a more competitive MLV than available today.

Concepts are being studied to provide an improved capability of placing satellites weighing 5,000 lbs or less to LEO. Such vehicles will provide for a low cost alternative for small responsively launched payloads including small commercial satellites, military tactical satellites, and space experiments. The Defense Advanced Research Projects Agency (DARPA) is sponsoring development of the Taurus launch vehicle. It is a demonstration for an economical, responsive, and flexible launch capability for small payloads featuring road-mobile launch options.

Industry-led ELV options are focused on the commercial challenge to provide reliable, low-cost access to space for 4,000 to 10,000-pound payloads to GTO to allow for commercial satellite growth. Propulsion concepts include a low-pressure pump-fed and passively cooled engine, a hybrid (solid and liquid) motor, and an advanced expander cycle engine for upper stages. These vehicles would employ many of the subsystem and component technologies developed for NLS, such as avionics, electromechanical actuators, and hydrostatic pump bearings.

New Reusable Launch Vehicles

Advanced reusable launch system options are being explored both for manned and unmanned operation. Several pathways are currently under study to define future manned transportation requirements. NASA is conducting concept studies for a Personnel Launch System (PLS) to augment the Shuttle for transporting Space Station Freedom personnel. PLS may be derived from the assured crew return vehicle (a rescue capsule, currently under concept development, to support the SSF permanent manned capability), or it may be based on other vehicle concepts. A near term option that could complement the Shuttle and provide assured manned access to space would be to develop the PLS as a reusable manned upper stage launched by NLS or another expendable vehicle. Technology readiness is planned by 1997 with an operational capability in 2005.

Eventually the Shuttle will be replaced by a second generation reusable vehicle. NASA currently refers to the vehicle options studied to address NASA manned launch requirements as the Advanced Manned Launch System, or AMLS. This new system would be designed for frequent operations, launch on demand (even in adverse weather), rapid turnaround, environmental compatibility, and significantly lower life-cycle costs. Once operational, this vehicle would allow the elimination of the costly Space Shuttle infrastructure and would, therefore, provide significant life-cycle cost reductions.

The DoD also is considering a reusable aerospace vehicle with similar capabilities for evolving military man-in-space requirements. Development of a Military Aerospace Vehicle (MAV) to provide robust, lower cost operations and access to space may begin in the 2005 time frame. It is envisioned that in the near future the NASA AMLS, the DoD MAV, and the commercial requirements for a low cost-per-flight reusable vehicle can be broadened in scope so that they address national requirements. This may allow a single reusable vehicle design to satisfy all U.S. needs for this class of vehicle. Such a vehicle could be designed to be initially flown unmanned to address commercial needs and later outfitted to support manned capability. A variety of fully reusable Single- and Two-Stage-to-Orbit concepts, employing rocket and/or airbreathing propulsion, have been proposed to address such needs. Focused technology efforts underway, including the NASP, the SDIO Single Stage Rocket Technology (SSRT) program, and the NLS technology efforts, will make major contributions to these vehicle concepts.

Single-Stage-to-Orbit (SSTO) and Two-Stage-to-Orbit (TSTO) concepts are being studied. Concepts incorporating advanced technologies could begin development by 2005. The technologies being developed for the NASP will make significant contributions to both of these concepts.

Unmanned reusable launch vehicles could potentially provide a truly low-cost transportation system (approaching $500 per pound to LEO for cargoes up to 30,000 lbs). Concepts are being studied in the SDIO SSRT program for an early demonstration of some of the technologies for an all rocket-powered SSTO system named Delta Clipper.

The Navy is sponsoring the Sea Launch and Recovery (SEALAR) system. It is a demonstration for flexible operations of a deployable wing and air-snatch recovery booster system.

Upper Stages and Orbit Transfer Vehicles

Upgrades are required in existing upper stage capabilities for orbital transfer improvement and automated interplanetary flight. Autonomous maneuvering stages will be needed to resupply the Space Station Freedom. Solar and nuclear thermal and electric propulsion systems in the 50-100 kilowatt class can be used for automated spacecraft transfer missions requiring high levels of propulsion efficiency. Nuclear-based propulsion systems in the multimegawatt class can be used for manned interplanetary flight (e.g., to Mars).

Transfer vehicles are differentiated from upper stage systems by their long-term exposure to the space environment. For orbital transfer stages or Lunar missions measured in days, significant economic advantages may be gained by basing systems in LEO for reuse, thus avoiding the discarding of hardware elements and reducing launch costs for replacements. However, the systems must survive for long periods on orbit. Emphasis will be on high propulsion performance and on propulsion-enhancing approaches such as aerocapture, a technique which uses the atmosphere to decelerate, instead of a retro-burn. Nuclear propulsion options require thorough examination because they increase launch opportunities and reduce interplanetary transit times and associated crew exposure to space radiation. Nuclear propulsion systems also have the potential for reducing in-space vehicle masses and launch requirements. The mass and dimensions of assembled and fueled vehicles will normally exceed the nation's single-launch delivery capabilities and will require some levels of in-space vehicle docking and assembly, check-out, and processing.

2.3. Technology Needs

This section discusses technology needs in relation to desired space launch options and launch system attributes. The "technology drivers" identified determine the benefits of technology investments and the setting of investment priorities.

2.3.1. Technology Needs for Space Launch Systems Options

A summary of technologies required to support the space launch systems options is presented in Figure 2-7. Program oriented activities are listed for each of the six technology disciplines identified in the Plan (details are in Section 3). The same symbol notation introduced in Figure 2-4 is used here.

Propulsion technologies are shown to be much more system specific than the other technologies. A variety of thrust levels are required to satisfy the wide range of payload requirements. Expendable vehicles designed for affordability will favor low manufacturing cost engines over performance driven designs. Reusable engines emphasize performance, reliability, and long life, since production costs can be amortized over many missions. Airbreathing propulsion, nuclear thermal propulsion, and electric propulsion all require unique engine types. Upper stages emphasize high specific impulse (performance) over high thrust; while initial boost requires engines that emphasize high thrust over high performance.

Additionally, upper stages must include storable propellants to satisfy on-orbit propulsion needs over the mission life, as well as cryogenic propellants for high performance in delivering the satellite to orbit. As a result, a wide range of propulsion development efforts are underway, many of which are focused on a single system application. Of particular interest are those whose attributes offer the broadest general utility. As shown in

Figure 2-7

Technology Relationship to Space Launch Systems

	System Options	Launch Systems										Orbital Transfer							
		Existing Vehicles			New Expendables			Reusables				Existing	Advanced Chemical				Solar/Nuclear		
	Technologies	Small/medium ELVs (up to 18K)	Large ELVs (Titan III, IV, 30 to 50K)	Shuttle (50K)	NLS (20K, 50K, 130K)	Heavy lift NLS (200K+)	Commercial MLVs and Small Launchers (non-NLS Derived)	All Rocket Concepts	Airbreathing (NASP/NDV)	Combined Rocket/Airbreather	Personnel Launch System	Upper Stages	New Upper Stages	Cargo Transfer Vehicle	Space Transfer Vehicle	Ascent/Descent	Nuclear Thermal	Nuclear Electric	Solar Electric/Thermal
Systems Analysis/ Design	Concept Definition and Assessments	⊛	⊛	⊛	●	●	●	●	●	●	●	⊛	●	●	●	●	●	●	●
	Design/Cost Models	⊛	⊛	⊛	●	●	●	●	●	●	●	⊛	●	●	●	●	●	●	●
	Analytical Tool Development	⊛	⊛	⊛	●	●	●	●	●	●	●	⊛	●	●	●	●	●	●	●
	Technology Assessments	⊛	⊛	⊛	●	●	●	●	●	●	●	⊛	●	●	●	●	●	●	●
	Advanced Management Tools	⊛	⊛	⊛	●	●	●	●	●	●	●	⊛	●	●	○	●	●	●	●
Propulsion	Space Transport Main Engine (STME)				●	◓													
	Liquid Rocket Component Technology	⊛	⊛	⊛	⊛	⊛	◓	●	○	●			●	○	◓	●			
	Airbreathing & Combined Cycle Prop								●	●									
	Solid Rocket Propulsion	⊛	⊛	⊛	◓	◓	○	○				⊛							
	Adv Cryogenic Propulsion Technology									●		⊛	●		●	◓	○	○	
	Nuclear Propulsion												◓		◓		●	●	
	Adv Reusable Rocket Engine Concept							●	●	●			◓		◓				
	Complementary ELV Propulsion	⊛	⊛	⊛	◓	◓	◓						◓						
	Advanced Concepts									○					◓		◓	◓	
Structures, Materials & Manufacturing	Composites	⊛	⊛	⊛	◓	◓	◓	●	●	●	●	⊛	◓	◓	◓	◓	◓	◓	◓
	Aluminum Alloys	⊛	⊛	⊛	◓	◓	◓	●	⊛	●	●	⊛	◓	◓	◓	◓	◓	◓	◓
	High Temperature Alloys	⊛	⊛	⊛	◓	◓	◓	●	●	●							◓	◓	
	Ceramics/TPS	⊛	⊛	⊛	◓	◓	◓	●	●	●	○						◓	◓	◓
	Advanced Processes	⊛	⊛	⊛	●	●	●	●	●	●	○	⊛	◓	◓	◓	◓	●	●	●
Avionics	Adaptive GN&C	⊛	⊛	⊛	●	●	◓	●	●	●	●	◓	●	●	●	●	●	●	●
	Flight System Management	⊛	⊛	⊛	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●
	Electromechanical Actuators	⊛	⊛	⊛	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●
	Architectures & Software	⊛	⊛	⊛	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●
Aero-thermo / Recovery	Comp. Fluid Dynamic (CFD) Tools	⊛	⊛	⊛	●	●	○	●	●	●	●		○	●	●	●	●	●	
	Generic Hypersonic Technology							◓	●	●									
	Experimental Facilities	⊛	⊛	⊛	●	●	●	●	●	●	●	⊛	●	●	●	●	●	●	
	Recover and Refurbishment	⊛	⊛	⊛	◓	◓	◓				◓								
Operations & Processing	Automation & Artificial Intelligence	⊛	⊛	⊛	●	●	●	●	●	●	●	⊛	●	●	●	●	●	●	●
	Test Facilities and instrumentation	⊛	⊛	⊛	●	●	●	●	●	●	●	⊛	●	●	●	●	●	●	●
	Propellant Systems (ground & flight)	⊛	⊛	⊛	●	●	●	●	●	●	●	⊛	●	●	●	●	●	●	
	Weather Prediction/Mitigation	⊛	⊛	⊛	●	●	●	●	●	●	●								

● Required to meet goals

◓ Competing technology option

○ Enhances capability above goals

⊛ Improves capability but cannot meet new system goals

Spaces without symbols are not applicable

Figure 2-7, these include Advanced Reusable Engine Concepts due to its promising approach to provide an operable, high-performance design with a wide range of thrust capabilities; complementary ELV propulsion techniques such as hybrids due to its potential to replace conventional solids used pervasively on launch vehicles; and certain advanced concepts with potential revolutionary improvements.

The remainder of the technology disciplines--structures, materials, and manufacturing, avionics, operations and processing, aerothermodynamics and recovery, and systems analysis and design--typically are much more generic in nature. As discussed later in the report, much of the current support derives from a few focused development programs; e.g., NASP and the NLS ADP effort. It is important to recognize that these technologies are necessary to meet the desired goals of virtually any new launch system and are independent of any particular launch system.

2.3.2. Technology Needs for Launch System Attributes

A qualitative assessment of the relationship between the technologies and desired launch system attributes is presented in Figure 2-8. These attributes include:

Operability - relates to a combination of availability and responsiveness and is used throughout this report.

Affordability - relates to launch costs; one measure being the cost per pound of payload to the desired orbit.

Reliability - relates to the probability of successfully inserting payloads into their proper orbits.

Safety - relates to the risk of injury to personnel and damage to equipment. Safety implies no fatalities to the flight crew, ground personnel, or the public; safe return of the vehicle (if applicable); and no catastrophic destruction of launch facilities.

Performance - relates to the mass that can be carried to the desired orbit per launch or period of time.

Environmental compatibility - relates to vehicle manufacturing, testing, and launch without having an adverse impact on the environment.

Responsiveness - relates to the amount of time needed to launch a vehicle from an assembled condition and to the ability to allow late manifest changes.

Availability - relates to the probability that the vehicle will be launched within some specified time of the scheduled launch time.

The relative importance of an attribute depends on the application. The most important attributes for a manned launch vehicle are safety and reliability. Responsiveness is the attribute that enables military, unmanned launch applications to have the required flexibility. Unmanned launch systems for civilian/commercial applications must be affordable. However, they must also be reliable and available, or else they are not likely to be truly affordable.

The symbols used in the figure depict the relative value of the technology for each attribute. Some propulsion entries show an acceptable level of degradation for performance (denoted by Θ). This indicates a situation where an engine may be designed to trade performance in favor of reduced cost, enhanced operability and reliability--typically of interest to the commercial space launch industry (see Figure 2-7).

The proposed technologies are generally well balanced. This is a result of a shift in emphasis toward new systems that address a broader range of launch attributes, rather than focusing mainly on performance as in the past. The dominance of solid circles highlights the synergism of technology developments in providing multiple payoffs. Note that high fidelity design/cost models must be developed, if the trade studies conducted during the conceptual design phase are to be valid.

Because of an international concern for environmental affects, it is important that environmental compatibility be given strong consideration. Environmental compatibility is primarily a function of propulsion system selection and, therefore, is an important parameter in concept definition and assessment. Future launch system design should provide nontoxic propellants and clean effluents. Advanced manufacturing processes also contribute to environmental compatibility.

2.4. Summary

The principal goals for new launch systems are to:

- Improve launch reliability to 98 percent or better for unmanned cargo vehicles and to 99.6 percent or better for manned vehicles
- Reduce the launch costs toward a goal of less than $1,000 per pound to LEO
- Achieve operational flexibility by removing most (or all) of the constraints to launching on schedule
- Make launch vehicles and infra-structures environmentally compatible (e.g., clean burning propellants).

Figure 2-8

Technology Relationships to Launch Systems Attributes

	Technologies \ Attributes	Operability	Affordability	Reliability/Safety	Performance	Environmental Compatibility
Systems Analysis/ Design	Concept Definition and Assessments	●	●	●	●	●
	Design/Cost Models	●	●	●	●	
	Analytical Tool Development	●	●	●	●	◒
	Technology Assessments	●	●	●	●	●
	Advanced Management Tools	●	●	◒	◒	
Propulsion	Space Transportion Main Engine (STME)	●	●	●	○	◒
	Liquid Rocket Component Technology	●	◒	●	●	◒
	Airbreathing and Combined Cycle Propulsion	●	◒	●	●	◒
	Solid Rocket Propulsion	○	◒	●	○	○
	Advanced Cryogenic Propulsion Technology	●	◒	●	●	○
	Nuclear Propulsion	◒	●	●	●	⊖
	Advanced Reusable Rocket Engine Concepts	●	◒	●	●	◒
	Complementary ELV Propulsion	◒	●	●	○	◒
	Advanced Concepts	◒	◒	◒	●	
Structures, Materials & Manufacturing	Composites	◒	●	◒	●	○
	Aluminum Alloys	◒	●	◒	●	○
	High Temperature Alloys	◒	◒	◒	●	○
	Ceramics/TPS	◒	◒	●	●	
	Advanced Processes	●	●	●	○	○
Avionics	Adaptive GN&C	●	●	●	●	
	Flight Systems Management	●	●	●	○	
	Electromechanical Actuators	●	●	●	○	
	Architectures & Software	●	●	●	○	
Aerothermodynamics/ Recovery	Computational Fluid Dynamics (CFD) Tools	◒	●	●	●	◒
	Generic Hypersonic Technology	◒	◒	◒	●	○
	Experimental Facilities	●	◒	●	●	○
	Recovery and Refurbishment	●	●	●	○	○
Operations & Processing	Automation & Artificial Intelligence	●	●	●	●	
	Test Facilities & Instrumentation	●	●	●	○	
	Propellant Systems (ground and flight)	●	●	●	○	
	Weather Prediction/Mitigaton	●	◒	●	○	

● Primary Objectives ○ Some Benefits

◒ Secondary Objectives ⊖ Degradation Acceptable

Spaces without symbols are not applicable

These goals are essential to all future U.S. launch systems, whether military, civilian, or commercial. The key to achieving these principal goals is technology. ***Without making the necessary investments in the technology base, there will not be improved and new vehicles in the twenty-first century.***

Section 3

Ten-Year Technology Program

3.1. Approach

A comprehensive survey of all space launch technology-related activities was conducted at the outset of the planning effort. This agency- and industry- wide "data call" yielded information on 175 individual technology efforts, detailing objectives, benefits, and plans including deliverables, schedules, and investment requirements. A macro analysis of this data base led to grouping the technologies into six primary technology planning areas:

- Systems Analysis and Design
- Propulsion
- Structures, Materials, and Manufacturing
- Avionics
- Aerothermodynamics and Recovery
- Operations and Processing

The desirable launch system attributes (discussed in section 2.3.2) were also derived in part from analysis of these data. The decision to classify these technology efforts as either generic or focused was more arbitrary and as much for programmatic reasons as any.

As used in this report,

Focused programs are motivated by, and conducted in the context of, a specific application or launch system option; airbreathing propulsion for the single-stage-to-orbit NASP, or advanced structural materials and propellant tank manufacturing methods for the NLS family of vehicles are examples.

Generic programs, in contrast, are not tied to specific applications or concepts. In fact, there is a good deal of generic technology embedded within focused programs, but it is more difficult to account for them in budgetary terms when divorced from the application. Also, for planning purposes, generic technologies point up commonalties among otherwise diverse appearing applications, as well as the inherent risk in sustaining a broad technology base by means of a few large application programs.

In either event, however, the technologies with which we are most concerned offer the potential for revolutionary improvements in capability for more than one application or launch option, whether or not they presently are supported by a single option.

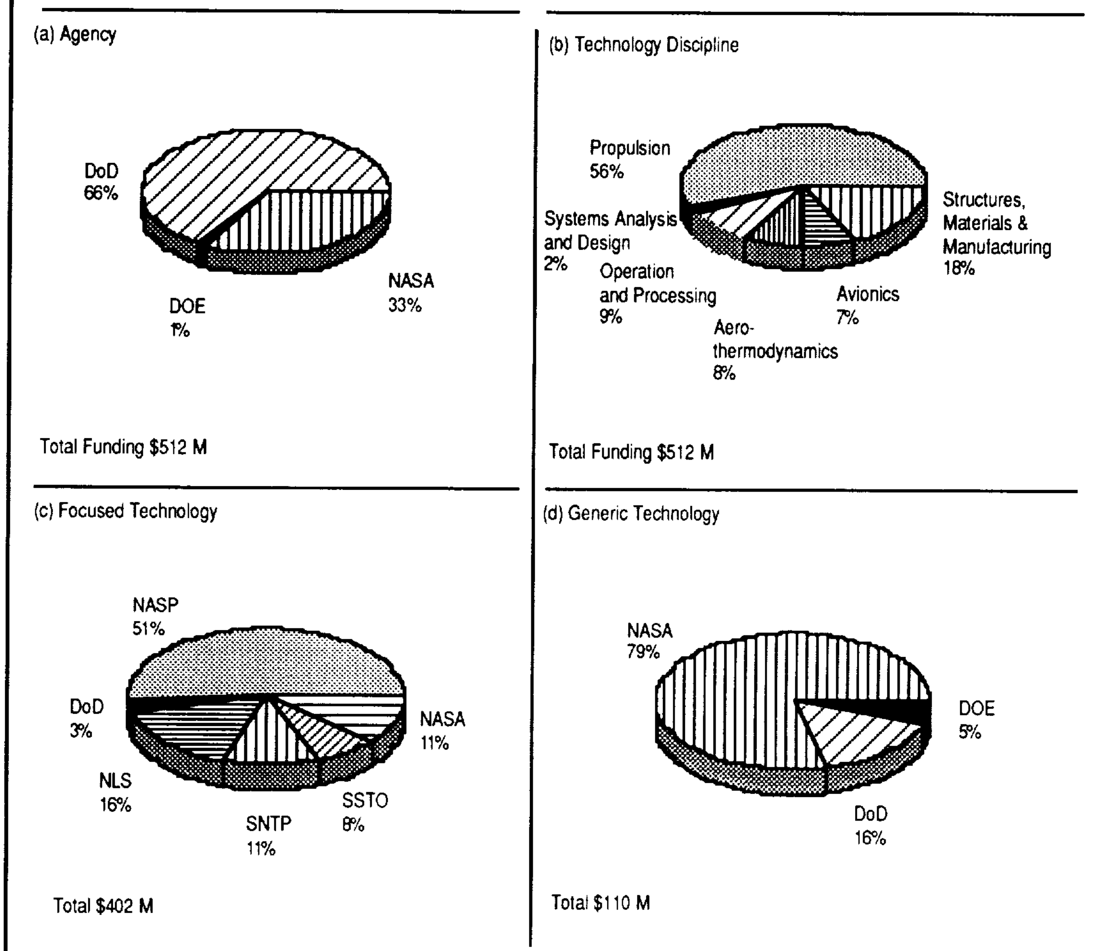
This technology plan provides a basis for assessing the appropriate level of future investment among the various technology disciplines, between focused and generic programs, and cooperative agency involvements.

3.2. Current Funding

The combined agency funding identified for space launch technology in FY92 totals $512 million, 66 percent DoD funds, 33 percent NASA funds, and the remaining 1 percent DOE funds. The funding distributions are shown in Figure 3-1 from several perspectives. Over three-fourths of the total ($402 million) derives from a few focused technology programs (Figure 3-1.c), over half of which is the NASP. Generic technologies constitute the balance of the investment ($110 million), most of which (79 percent) are NASA programs (Figure 3-1.d). Viewed from the perspective of the six principal technology disciplines, over half the total investment is in advanced propulsion technology. Most of this is associated with hypersonic engine development in

Figure 3-1

FY92 Approved Funding for Space Launch Technologies



keeping with the primary focus on NASP. NASP also funds a large share of the Structures, Materials, and Manufacturing technology.

3.3. Focused-Technology Programs

3.3.1. Existing Launch Capabilities

The need to ensure that existing space launch capabilities continue to meet national needs through the coming decade or so of transition to modern systems, such as NLS, is recognized in the National Space Launch Strategy. This will require an investment to maintain and appropriately improve our current fleet of ELVs, the shuttle, and supporting launch infrastructure. For the most part, these investments are highly focused on specific launch vehicles and facilities, and are not within the scope of the present technology plan. However, the application of new and emerging technologies to existing systems--a primary goal of the National Launch System--provides opportunities for early technology demonstrations of their practical benefits. Technology insertion in such areas as artificial intelligence, launch and mission operations, fault-tolerant guidance, navigation and control, advanced material characterization, and electro-mechanical actuators are being pursued. Additionally, the NASA's Solid Propulsion Integrity Program (SPIP) was initiated to develop an engineering capability to provide continuous improvement in the reliability of solid rocket motors. It will be extremely useful to evaluate the potential for near term improvements in launch costs, reliability, and operability.

3.3.2. NLS Advanced Development Program

The NLS is a Presidentially directed, joint program between DoD and NASA to develop a modular family of expendable launch vehicles and supporting launch infrastructure, offering routine, reliable, and low cost access to space. The NLS Advanced Development Program (ADP) is a focused effort to advance technology in all subsystems to achieve the primary goals of operability, reliability, and lower costs. As such, it is as much a matter of changing the philosophy of launch system design as it is introducing new technology. Funded technology developments include:

- **Systems Analysis and Design**
  Concept definition studies leading to the current NLS family of launch vehicles designs with modernized launch facilities and operations. These studies concentrate on launch system characteristics that provide lower cost to orbit capabilities with significant improvements in reliability, flexible operations, and environmental compatibility. The program's technical reference document describes the system engineering requirements as guidance and direction to the technology development projects.

- **Propulsion**
  A low-cost, highly reliable and operable liquid oxygen and liquid hydrogen (LO_2/LH_2) engine, the Space Transportation Main Engine (STME) and all of its components.

- **Structures, Materials, and Manufacturing**
  Characterizing aluminum-lithium (Al-Li) alloys, developing structures for low-cost cryogenic tanks, and in-process inspection of welds.

- **Avionics and Software**
  Multipath redundant avionics, adaptive guidance, navigation and control, expert systems, and electromechanical actuators.

- **Aerothermodynamics and Recovery**
  Demonstrating engine and avionics recovery techniques; and improving analysis techniques.

- **Operations and Processing**
  Improving launch operations by paperless management, autonomous control, system health management; improving operations concepts to reduce time on pad; and simplifing flight operations and mission planning.

3.3.3. National AeroSpace Plane

The NASP is a Presidentially directed, joint DoD/NASA research program to demonstrate hypersonic technologies with the goal of Single-Stage-to-Orbit flight. The current phase of the program is to demonstrate and validate technology capabilities. NASP is a revolutionary concept; achieving its goals will advance technologies applicable to a range of endo- and exo-atmospheric transportation concepts. Program goals within each technology area are:

- **Systems Analysis and Design**
  Studies led to the design of an X-30 technology demonstration flight vehicle and applications of this advance concept. Feedback from these system studies are used to focus and guide the NASP technology program.

- **Propulsion**
  An efficient airbreathing propulsion system capable of hypersonic

speeds and ultimate single-stage-to-orbit flight. New technologies are being developed for the production, storage, servicing, pumping, and transfer of cryogenic slush hydrogen.

- **Structures, Materials, and Manufacturing**
  Increase specific strength of structural materials 2 to 4 times with metal matrix composites, carbon-carbon hot structures and control surface, graphite epoxy cryogenic tanks, active and passive reusable thermal protection systems.

- **Avionics and Software**
  Advanced avionics software and automated technologies for full flight management navigation and control.

- **Aerothermodynamics and Recovery**
  Computational fluid dynamics simulation of the entire flow field to allow efficient ground test at advanced facilities and extrapolation to flight conditions. Active and passive thermal protection systems, capable of multiple flight service.

- **Operations and Processing**
  Advanced flight operations concepts allowing a routine vehicle turnaround time of a few days, including onboard health management. Containerized payload concept to allow routine, assured access to space.

Additionally, the NASP program is advancing the state-of-the-art in flight test and propulsion systems facilities. Technology transfer to government and industry is a major NASP objective. For example, DoD's Single Stage (to orbit) Rocket Technology project selected graphite-epoxy cryogenic fuel tank technology.

3.3.4. Space Nuclear Thermal Propulsion Program

The Space Nuclear Thermal Propulsion (SNTP) program is being conducted by the Air Force, with DOE and NASA support. It is intended to explore new nuclear technologies for high-performance upper stage rocket propulsion of interest to the DoD. The program is focusing on particle-bed reactor technology expected to more than double the efficiency of the best chemical rocket engines. The initial goal is a proof of principle demonstration of a 75,000-pound-thrust space engine with a specific impulse of 1,000 seconds at a 30-to-1 thrust-to-weight ratio. Technologies under development include:

- High-Temperature Materials
- Particle-Bed Reactor and Components
- Fuel Elements and Moderators
- Expansion Nozzles
- Design Algorithms and Control Laws for Heat Exchangers
- Composite Turbopumps
- Long Term Cryogenic Hydrogen Storage and Engine-Scaling Relationships
- Nuclear Ground Test, Handling, Manufacturing and Operating Facilities.

3.3.5. Technology Flight Demonstrations

There are technologies explored by flight demonstration, such as the Air Force's Electric Insertion Transfer Experiment (ELITE) and SDIO's SSRT. ELITE is a full-up system demonstration of an operational electric orbit transfer vehicle including propulsion, power, and guidance and control. SSRT is a suborbital, atmospheric test of rocket-powered vertical takeoff, maneuvering control, and vertical landing characteristics of a subscale reusable vehicle concept. The SSRT program is also designed to demonstrate efficient operations including vehicle retrieval and relaunch in less than one week. These and other technology demonstration programs combine many disciplines into a complete system and validate these technologies as a whole by flight test.

3.4. Technology Plans by Discipline

Plans to improve the technology base for launch systems are presented in this section for each of the six disciplinary areas. After a brief overview of the general requirements for the discipline, the technology-improvement efforts are described as current activities (those currently funded) and future program options (those offering significant benefits and which may be funded in the future, pending more detailed assessments of costs, risks, and payoffs).

3.4.1. Systems Analysis and Design

Overview

There is growing recognition that systems analysis and design, the collection of tools and analytical processes underpinning the art of engineering, is a key technology discipline in its own right. This view was advanced strongly by industry representatives at the "data call." Traditionally, the development of these tools is associated with individual technologies (e.g., propulsion, or structures). While much of this disciplinary focus will remain, there also needs to be a more comprehensive methodology for vehicle design and system-level assessment of competing launch concepts and technologies. This will provide the quantitative basis for establishing the relationships discussed earlier between technology requirements, launch concepts, and system attributes.

The bulk of recent conceptual vehicle design and trade studies performed by U.S. agencies was focused on the NLS space launch architecture, NASP, and NASP-derived vehicles. A smaller effort is under way in NASA to examine advanced manned vehicles to eventually replace the Space Shuttle. In addition to NASP-derived vehicles, Air Force studies have concentrated on single stage rockets and two-stage-to-orbit concepts with air-breathing first stages and chemical rocket second stages. Recently, NASA has begun to focus on manned spacecraft launched on an expendable launch vehicle as an interim approach to complement the Shuttle and alternative heavy-lift rockets for the SEI. Within the area of Single Stage to Orbit rocket concepts, SDIO is funding conceptual design studies of the SSRT. These efforts have identified the need for intensive system design definition and infrastructure assessments against national requirements to aid in rational development decisions.

Current Program

Development of analysis techniques for concept assessments has been accelerated substantially by the NASP program. Computational fluid dynamics (CFD) tools have been brought out of the laboratory to support the design analysis by simulating flight conditions and propulsion combustion phenomena not yet achievable through ground testing or flight experience. Unique thermal/structural modeling tools were developed to analyze coupled thermal/mechanical interactions with advanced materials. Also, pilot-in-the-loop and automated simulations are being used for flight system design verification and also for configuration aerodynamic shape refinements. Multidisciplinary codes, originally used to assess NASP designs, are being applied to advanced launch systems, orbital transfer, and interplanetary systems.

The NLS program has developed tools to model the manufacturing processes and operational flows, providing a means to measure and optimize operability and cost. Generic operations and processing models are being developed to evaluate the range of new launch and space transfer options. Further enhancements and developments are required to provide the necessary tools to support the conceptual design process for space transportation systems. These tool development efforts include:

- Flight trajectory optimization including aerothermo/elastic factors
- Computational fluid dynamics of internal and external flows
- Space systems environmental analysis
- Structural and thermal loads analysis for integral structures and cryo-tankage
- Concurrent manufacturing and design
- Operations and process-based cost models
- Launch system environmental effects

Future Program Options

Intensive efforts should begin to address candidate reusable launch systems to replace the Shuttle sometime after the turn of the century. Emphasis should be on TSTO and SSTO concepts with a variety of propulsion system designs, such as advanced rockets and airbreathing propulsion developed through the NASP program. An effort is also needed to define the space transfer architecture associated with future space exploration, including advanced chemical, nuclear, electric, and hybrid propulsion systems. DoD should continue to focus on military aerospace vehicle designs to meet its requirements. However, future systems analysis and design efforts should be coordinated between DoD and NASA mission planners. These organizations should perform the mission analyses and launch architecture studies required to meet national launch requirements.

Advanced Management Tools: Significantly improved operations simulation capability is required to accurately model realistic launch processing situations. Simulation capabilities should include the ability to model entire multivehicle mission models, detailed processing activities, facility and personnel resources, and the effects of work interruptions due to hazardous activities. This capability is critical for assessing the impacts of vehicle characteristics on operations and developing optimal designs for operations scenarios, facilities, and system modifications. Regarding, the operations infrastructure, the nation will need to develop (1) an integrated concept to streamline mission planning and support operations, and (2) a concept to simplify and automate paper processes now inherent in launch base operations. These capabilities should be on line for NLS.

Funding

The U.S. Government is spending approximately $11 million for systems analysis and design technology activities in FY92, or approximately 2 percent of the total launch technology investment. Most of this is funded by NASP research and NLS ADP programs. Additional emphasis is needed. Over the next ten years, the percentage share for Systems Analysis and Design should double to 4 percent.

3.4.2. Propulsion

Overview

Propulsion is the cornerstone of every space transportation system and is responsible for the major acquisition and operations cost of these systems. Yet, propulsion has been identified by the DoD, NASA, and the commercial launch industry as the most serious area of deficiency in the nation's space program. The U.S. propulsion technology base has been significantly eroded. In fact, the only new liquid engine system developed by the United States in the past 20 years prior to the NLS and NASP programs was the SSME. By contrast, in the same period, the former Soviet Union developed and tested more than 140 different rocket and airbreathing engines, including some previously conceptualized in the United States. Much of this erosion can be traced back to the success of earlier national space and missile programs. This success has bred the general attitude of being satisfied with a mature (if static) technology, one in which significant technology investment is no longer needed.

Traditionally, the primary focus of propulsion Research & Development (R&D) has been on performance driven systems. This is best exemplified by the evolution of the SSME liquid propellant rocket engine, a technically ambitious development that while achieving its very high performance goals, fell short of its durability, operability, and cost goals. Current engine development trends, shown in Figure 3-2, reflect a move away from maximizing performance exclusively, toward being able to meet more robust program requirements. This will require technology efforts that acknowledge cost, operability, and reliability objectives from the outset.

Figure 3-2

Propulsion Requirements
in relation to Current and Future Engine Options

	Expendables	Reusables	Space Transfer
Requirements	• High Reliability • Safety • Robust • High Design Margins • Low Manufacturing Costs • Environmental Compatibility	• High Performance - High Isp (sea level to vacuum) - High T/W (>100) • High Reliability • Fully Reusable (long service life) • Moderate, Predictable Design Margins • Moderate Manufacturing Costs • Low Operating Costs • Environmental Compatibility	• Performance - High Isp - Moderate Thrust • High Reliability • Simple Operations • Space Maintainable • Deep Throttling • Long-term Multiple Restarts • Dormancy Capable
State-of-the-Art	ELV Liquids (Expendable) • LO_2/HC, LO_2/LH_2 • Moderate Performance • High Manufacturing Costs • High Operations Costs SRMs (Recoverable) • Low Performance • High Manufacturing Costs • High Refurbishment Costs	SSME (Reusable) • LO_2/LH_2 • High Performance • High Manufacturing Costs • High Operations Costs • Frequent Changeouts	RL-10 • Flight Status • LO_2/LH_2 • Moderately High Performance • Restartable • Moderate Manufacturing Costs • Moderate Operations Costs XLR 132 • Experimental Status • Storable Propellants • Moderate Manufacturing Costs • Moderate Operations Costs Solids • Low Performance • Moderate Manufacturing Costs • Moderate Operations Costs • Limited Operational Flexibility
Options	• Evolution of Current Engine Systems • New, Robust LO_2/LH_2 Engine (STME) • Clean Solids • Hybrids (Solids/Liquid) • Simple, Passively Cooled Low-Pressure LO_2/HC, LO_2/LH_2 Engine • Advanced LO_2/LH_2 Upper Stage	• SSME Derivative • Advanced Rocket Engine - Expander Derivative - Full Flow Stage Combination -Variable Mixture Ratio LO_2/LH_2 - Dual Fuel • Combined-Cycle Airbreathing/ Rocket • Airbreathing	• LO_2/LH_2 Based - Expander Derivative - Modular Engine Approaches (IME) • Nuclear/Solar Based - Electric - Thermal • Advanced Concepts - Low Thrust, High Impulse - High Thrust, High Impulse

Propulsion technology tends to be more application oriented than other technology disciplines. Types and characteristics of propulsion systems depend on the class of launch vehicle--expendable, reusable, and orbit transfer. Generally, ELV propulsion systems are driven toward designs with minimal components and manufacturing processes to reduce acquisition costs while achieving a higher degree of reliability and system robustness. In contrast, life-cycle costs for reusable propulsion systems are dominated by operations (i.e., recurring) and failure related costs. To achieve lower operations and failure costs, propulsion concepts are driven toward aircraft-like designs (e.g., NASP), which implies design performance and safety margins that ensure high reliability, operational flexibility, and robustness. Here, engine performance is of paramount importance along with required structural improvements. Since the engine is reused, manufacturing costs are of less importance than durability, operability, and long life.

Reusable launch systems designs encompass both rocket and airbreathing options. Airbreathing systems require multiple propulsion systems or subsystems, each tailored to a flight regime. Examples include midspeed ramjet and high-speed scramjet operating modes. The airbreathing propulsion engine must be augmented by rockets for final orbit injection, as well as orbital deboost.

Orbit transfer propulsion concepts, including upper stages, propulsion for planetary missions, and on-orbit maneuvering for satellites, also are driven toward low manufacturing cost and more operable designs. Cryogenic liquid upper stage engines are more than 30 years old. Both high-performance cryogenic engines for orbit insertion and storable propellant engines for maneuvering during the multiyear life of the satellite or extended duration planetary mission are required. Planetary missions place additional stringent requirements for long life, and for reliable and maintenance-free operation. As upper stages benefit most from high performance (high I_{sp}), efforts are constantly underway to achieve revolutionary increases in performance. These include thermal and electric (nuclear and solar) propulsion concepts.

Other supporting technologies to aid in these developments are also required. These include:

- Engine Testing Technologies
- Engine Test Beds to validate feasibility and performance
- Nondestructive Evaluation Techniques
- New Computational Tools to assess engine performance, solid motor integrity, and to predict the material and structural thermomechanical response to the operating environment.

Current Programs

Current propulsion technology efforts are divided into the following major elements:

- Space Transportation Main Engine, part of the ADP program for NLS
- Liquid Rocket Component Technology Development Efforts
- Airbreathing Technology Developments, including the NASP X-30 systems and generic hypersonic development efforts
- Solid Rocket Motor Propulsion Efforts.
- Advanced Cryogenic Propulsion Technology, including cryogenic fluid management systems development
- Nuclear Propulsion, including both electric and thermal variants
- Advanced Concepts efforts in the area of low-thrust, very high specific impulse orbit transfer propulsion (receives less than 0.5 percent of the resources)

Space Transportation Main Engine: For the next generation of expendable vehicles, the NLS/ADP is focused on the development of a 600,000-pound-force thrust class LO_2/LH_2 gas-generator cycle engine, the STME. The program is developing design approaches, components, and lower-cost manufacturing techniques for a highly reliable liquid rocket engine. The STME is being designed to provide the main propulsion system for the booster and core stages of a family of new ELVs. To provide a wide range of payload options for the NLS core, strap-on boosters are envisioned that could range from current and planned solid rocket boosters to new liquid rocket boosters using the STME, hydrocarbon engines, or hybrid units.

Liquid Rocket Component Technology: NASA's Earth-to-Orbit Propulsion Technology Program is focused on providing high performance and highly operable engine component technologies required in reusable launch vehicles. Specifically these include NASA's Advanced Manned Launch System, and new heavy-lift vehicles, plus the NLS, as well as hardware and operating improvements to the current fleet. This program provides:

- enhanced analytical methods, enabling extremely accurate definitions and predictions of internal engine environments, combustion, and stability processes, steady and unsteady thermal and mechanical loads, component structural design margins and expected service-life, and component and overall system performance
- improved materials, coatings, and fabrication techniques for much lower cost, higher quality, and more reproducible hardware production, particularly for main combustion chambers, nozzles, turbine blades and wheels, pump impellers, bearings, and housings
- integrated controls and health management system hardware and software to provide greatly improved reliability and operability, to minimize preflight servicing and checkout times, to allow maintenance by need rather than by time, and to enable safe fault-tolerant operations.

Technology validation will be carried out in subsystem test beds and in the Space Shuttle Main Engine Technology Test Bed at the Marshall Space Flight Center.

The Air Force Advanced Cryogenic Engine Program has been initiated to develop generic reusable liquid engine technology for a range of space launch vehicles and upper stage propulsion. This program focuses on component technologies, including turbopumps, thrust chambers, gas generators, and preburners and their associated health management instrumentation sensors and control effectors required to extend engine life to greater than 100 flights without major overhaul or detailed post flight inspection. Future planning efforts should be directed to coordinate these individual-agency focused efforts and provide an adequate level of funding for this generic liquid propulsion technology development.

The storable liquid propulsion subtopic area has no significant ongoing effort. This subtopic is discussed in the future program options section.

Airbreathing Propulsion Technology Development: The Air Force and NASA are jointly pursuing a focused technology development program in support of the NASP X-30 hypersonic research vehicle predevelopment program. The current focus is in the advanced airbreathing propulsion system arena, namely in a ramjet/scramjet-capable engine. As NASP began to focus on specific X-30 vehicle objectives, NASA and the Air Force recognized a need to institutionalize a long-term investment in hypersonics that addresses a broader, more fundamental set of technology needs that would enable and enhance future hypersonic missions.

The present Hypersonics Research Program in NASA and the Hypersonics Technology Initiative Plan in the Air Force are long-range multidisciplinary endeavors that stress the need for a fundamental understanding of the controlling physical processes, as well as for promotion of technological innovations and new ideas. The programs emphasize applied research and technology development, and focus on slender, airbreathing hypersonic vehicles that use highly-integrated airframe/propulsion concepts. The scope is quite broad and includes both accelerator and cruise vehicle applications, both hydrogen and hydrocarbon fuel systems, etc. The propulsion program should provide enabling fundamental new technology-based analytical and design methodologies for defining subsonic and supersonic combustion ramjet systems and other innovative propulsion concepts. Air Force and NASA studies in endothermic fuels open possibilities of hypersonic applications of hydrocarbon fuels, utilizing ramjet and dual mode scramjet cycles. These propulsion efforts will interact with vehicle system studies to identify and define enabling propulsion systems for future hypersonic vehicles.

Solid Rocket Propulsion: A Solid Propulsion Integrity Program is under way to provide a broader solid motor technology base for achieving higher performance, higher reliability, improved operability and availability, and longer shelf and service life. Specifically, this program aims at mitigating the several solid rocket motor failures experienced in the 1980s through improved characterization. Specific efforts include bond line characterization, service life prediction, analysis codes, NDE methods, advanced nozzle materials, and a visco-elastic material properties data base. The basic objective of these efforts is to provide the technology for increased engineering comprehensiveness and process standardization among manufacturers. These efforts are designed to benefit both earth-to-orbit and upper stage applications.

Advanced Cryogenic Propulsion Technology: This technology discipline area is comprised of three major subtopics.

- Advanced Cryogenic Liquid Propulsion Technology
- Cryogenic Fluid Management Systems
- Storable Liquid Propulsion

Current work in the advanced cryogenic liquid propulsion area is providing the technology necessary to proceed in the late 1990s with the development of new moderate thrust LO_2/LH_2 expander cycle engine for upper stages, space-based transfer vehicles, and planetary and lunar landers and ascent vehicles. This technology extends the capability of the RL-10, developed in the 1950s, in terms of thrust per engine, high-pressure operation (high performance in a small envelope), low-cost, ready-operability; and precision-controlled deep throttling, high reliability, safety, and space basing.

Alternatively, innovative nozzle designs are being pursued that maximize the nozzle exit-area and relax the need for high operating pressures and their concomitant costs. The technologies being addressed include high heat-transfer combustor designs, high-speed turbomachinery with fluid film bearings, high-expansion ratio nozzle performance, space-basing capability, full reusability, and integrated controls and health management capabilities for hands-off preflight operations and inflight fault tolerant operations. A major element of this program is the design, fabrication, assembly, and test of an Advanced Expander Test Bed (AETB) that should provide the much-needed means for evaluating and verifying advanced component technologies in an expander cycle engine systems environment, as well as addressing system level issues, such as actual versus predicted cycle balance and integrated controls and health management operations. This effort benefits from current component technology development effort for larger cryogenic rocket engines.

Technologies are being developed for simple, lightweight, low-cost, zero-leakage feed system components and long-term storage (minimum boil-off), venting, acquisition, and transfer of cryogenic fluids under zero gravity conditions for fueling and utilizing space-based transfer stages and in-space cryogenic depot facilities. In-orbit flight experiments are needed to validate zero-gravity technologies. This technology should enable the design and operation of space-based transfer vehicles.

Nuclear Propulsion: Nuclear propulsion has the potential for more than doubling the specific impulse of today's propulsion missions. Both nuclear thermal propulsion (NTP) and nuclear electric propulsion (NEP) are candidates for planetary transfer stages and DoD advanced missions where reduced vehicle mass, reduced trip times, or an enlarged launch window are desired characteristics. NASA and DOE are working together closely to develop technologies and components, and demonstrate system readiness. Nuclear thermal propulsion developments will expand upon the Nuclear Engine for Rocket Vehicle Applications (NERVA) technology for solid-core nuclear rockets by improving fuels technology to enable higher operating temperatures. Other fuel technology options will also be explored, including NERVA derivatives, particle-bed, and ceramic-metalic (CERMET) concepts.

For the nuclear electric systems, specific impulses of 3,000–5,000 seconds, specific mass of 25 kilograms per kilowatt, and 100 kilowatt power levels (representative of the SP-100 class reactor system now under development) will be required for the advanced outer planet and multiple small body rendezvous missions.

The current nuclear propulsion programs are limited to conducting preliminary assessments and key technology development for a few of the most promising, near-term nuclear propulsion systems, with the nuclear electric propulsion part of the program relying mostly on technologies from the SP-100 program. The Air Force is focusing on the SNTP program previously discussed. However, their effort is limited to lifetimes and burn durations less than those required for piloted Mars applications. DOE will have a lead role in the development and testing of nuclear technologies and systems for these nuclear propulsion programs.

Advanced Concepts: This technology area comprises two major subtopics.

- Solar Low-Thrust, Very High Specific Impulse Space Transfer Propulsion
- High Energy Propulsion Concepts.

The solar space transfer propulsion research efforts by the Air Force include solar thermal propulsion arcjets and magnetoplasmadynamic thruster developments. These efforts offer high specific impulse for space applications. Critical technologies include efficient solar concentrators and thrusters, erosion and corrosion resistant materials, and associated computational fluid dynamics analysis capability. NASA is conducting research on electrodeless electric propulsion thrusters, electron-cyclotron resonance plasma engines, supersonically heated microwave electrothermal rockets, and beamed energy systems. These technologies are being advanced continually and have the potential capability to triple payload weights. Arcjet electric propulsion, typically, is expected to double the payload capability to high circular orbits. The electric thrusters development efforts support both nuclear and solar electric system options. The majority of these technologies have been in development at low levels of effort for more than 25 years.

An ongoing, limited funded fundamental research effort in high energy propulsion concepts is aimed at identifying and exploiting high-energy chemical systems for use as propellants. This Air Force High-Energy Density Matter (HEDM) program seeks to increase the payload capability by several times over existing best propulsion systems. Combining both theoretical and experimental efforts, the HEDM program is examining several energy storage concepts, encompassing the following specific approaches: high positive enthalpy compounds derived from unusual bonding situations, high-energy oxidizers, metallic hydrogen, and energetic highly reactive metastable molecules. Storage, or packaging, concepts, such as the use of cryogenic solids of hydrogen or oxygen, are also being explored. Complementing this work, NASA is pursuing the ion-compressed antimatter-catalyzed nuclear propulsion approach conceived of by Pennsylvania State University researchers, atomic hydrogen storage techniques, and carbon-60 (bucminsterfullerine) based ion propulsion.

Future Program Options

Liquid Rocket Component Technology: Storable liquid propulsion continues to be a significant element for the U.S. space program because of its ability to provide long-duration on-orbit satellite maneuvering and station keeping capability and orbit transfer capability of small and medium payloads. For long-term planetary missions, storable systems may also be required for the return phase. Key technologies include small, high-speed, hot-gas driven turbopumps, high-combustion performance, combustion stability, advanced nozzle construction (durable, lightweight, and low cost), thrust chamber cooling, and high reliability. Pressure-fed systems require technologies for high efficiency pressurization systems, materials for high operating pressure thrust chambers with lifetime endurance, and light-weight composite overwrap propellant tanks.

Combined-Cycle (Airbreathing Plus Rocket) Propulsion: Extensive systems studies have indicated that synergistic integration of airbreathing capabilities with those of rocket capabilities is a promising alternative approach to achieving aircraft-like space transportation systems. Combined-cycle engine concepts are applicable to both transatmospheric boost-stage applications and to hypersonic cruise aircraft. Subscale ground-test engines, utilizing flight weight hardware, have been successfully demonstrated over the last decade. Building on this extensive background, further technology development and validation efforts could complement the X-30 and generic hypersonics activities already under way. Comprehensive systems-level studies are required to more fully evaluate the promise of combined-cycle propulsion and to define current technology needs.

Solid Rocket Motors: Solid motors provide a convenient method of thrust augmentation for higher performing liquid propulsion launch systems, in addition to numerous military applications in their own right, e.g., large ballistic missiles. However, the need for clean propellants (chlorine from current solids depletes the atmospheric ozone layer and contaminates the local launch environment) requires development of low- or no-chlorine compounds for solid motor propellants. Technology efforts are also needed to reduce the manufacturing cost of nozzles, cases, and insulation materials.

Nuclear Propulsion: Space nuclear propulsion is probably the only practical way to accomplish piloted missions to Mars currently planned for shortly after the turn of the century. The NASA nuclear propulsion program is primarily focused on near-term nuclear thermal propulsion technologies in which a full scale engine can be ground demonstrated by 2000 and flight qualified by 2005. The key engine performance parameters of interest are 25,000 to 75,000 pound thrust per engine with specific impulse from 900 to 1,000 seconds with up to 30 to 1 thrust-to-weight ratio.

Major new test facilities must be started in the near term if any NTP ground tests are to be completed in the next decade. NEP technologies capable of several megawatt output are competing technology options for cargo and piloted Mars missions. The near-term focus for NEP is a 100 kw class transfer vehicle for outer planetary missions. Improvements in thermal management and in power conversion and conditioning could also be initiated. Liquid and gas core system technologies, which are potentially much more promising than solid core technology, could also be pursued.

Advanced Reusable Rocket Engine Concepts: A highly operable and fully reusable rocket engine is required for any reusable (all rocket-powered) vehicle concept. This engine would be targeted for approximately 200,000 pounds of thrust, minimization of catastrophic failure modes, and greater than 50 missions between overhauls. A promising design approach option is the IME. Though synthesized from conventional component building blocks, the IME differs from existing stand-alone rocket engines used singly or in clusters. Major subsystems, such as thrust chambers and fuel and oxidizer turbopumps, would be "horizontally networked" (e.g., through a common propellant manifold), so that a faulty unit could be isolated and, if necessary, turned off without adversely impacting overall propulsion system operation.

This approach allows component and even major subsystem (e.g., a complete turbopump) development prior to the establishment of a complete propulsion system specification. To achieve a chosen thrust level, test-proven thrust chambers, turbopumps, and controllers linked by common sensing and effecting means and propellant-supply manifolds would be selected. This would shorten full-scale development time, while sharply reducing both risk and cost. Component technologies developed under the current generic liquid engine development efforts are adaptable to this engine development approach.

The IME also is appropriate for unconventional engine designs such as a booststage plug nozzle, with its high-performance altitude compensating feature, and for differentially throttled (non-gimbaled) high-area-ratio nozzle-equipped space systems. As an example, a linear arrangement of small rectangular thrust cells is viewed as an attractive approach for the liquid rocket system for the NASP X-30 vehicle. A scaled down version of this specific IME design and use of selected components is also being studied for advanced cryogenic upper stages.

Complementary ELV Propulsion: The commercial space launch community has expressed a need for advanced propulsion systems and technology applicable to both existing fleet upgrades and a potential new-start expendable vehicle family. Among these are innovative, low-cost development and production approaches. Examples under current investigation include hybrid (solid/liquid) rocket systems, low-pressure pump-fed liquid rocket designs, and a more capable upper stage engine.

Hybrid solid motors could be used to propel a future commercial MLV concept in lieu of solid motors. Although these systems offer increased safety, operability, reliability, and throttling capability over existing solids, they have not been seriously considered because of a lack of performance characterization at large scale. If the viability of hybrid systems is proved, these systems could also support a variety of DoD and NASA requirements currently satisfied with solid rocket boosters. Unlike current solids, these hybrid motors are being designed to be environmentally compatible.

As an alternative approach, a low-pressure pump-fed, ablatively cooled thrust chamber engine could serve as the main engine for a commercially focused MLV. This engine approach is being modestly funded by industry and supported in subscale testing by NASA test facilities and personnel. A low-pressure, pintle injector engine design requiring significantly fewer weld joints and piece parts than a comparable thrust SSME engine is targeted for prototype development. Critical technology items include the gas generator, stage mounted turbopumps, liquid hydrogen- and oxygen-compatible foil bearings (a non-rolling-contact hydrodynamic type), and ablatively protected combustor and nozzle. By the end of FY92, more than $1.7 million of contractor Independent Research and Development funds will have been invested in this engine development. This class of engine could also provide low-cost and reliable propulsion for future liquid rocket strap-ons to support NLS growth options, or provide reliable propulsion for orbit transfer and planetary launch.

Advanced Concepts: Depending on the sucess of efforts underway in high energy density matter, ion compressed antimatter, nuclear propulsion, and fusion-based propulsion concepts to move beyond the concept study level. These investments in propulsion related technologies coupled with success in terrestrial fusion energy research programs may pave the way for extremely high efficiency space propulsion systems.

Ground and Flight-Test Propulsion Test Beds: Systems-level propulsion test beds have demonstrated their unique value in developing new space launch propulsion systems and in effecting the technology validation step. For example, NASA's Earth-to-orbit propulsion technology program profits substantially from the experimental evaluation of advanced-technology hardware and software in the currently available Space Shuttle Main Engine Technology Test Bed at the Marshall Space Flight Center. The companion NASA-focused technology program addressing future in-space propulsion is currently focused upon the development of the Advanced Expander Test Bed (AETB). Once developed, two sets of operating hardware would support both parametric systems-level testing and, in parallel, advanced-component experimental validation hardware testing in the real-engine environment. At current funding levels, the AETB hardware delivery date is 1998.

The ground and flight test bed projects complement each of the technology efforts and engine developments discussed earlier. These test beds are included in each of their respective technology efforts and are, therefore, not budgeted as separate elements or shown as a separate line in the technology matrices (Figures 2-7 and 2-8). They are discussed here as a forum to emphasize the need for test beds to be included in all technology development efforts to reduce launch and orbital system development cost, schedule, and technical risk.

A new set of subscale and/or full-scale segment test beds are anticipated to be needed for such new systems as the IME or other advanced concepts for future vehicle engines. In addition to ground testing, flight test beds are of high potential value for combined-cycle propulsion systems, especially those that operate in supersonic combustion ramjet (scramjet) modes. Such systems cannot be ground-tested because of the limitations of simulation capabilities beyond Mach 7 or 8.

For any nuclear propulsion approach, major ground test facilities are recognized to be critical long lead-time elements. Most important are nuclear fuel-element testers and full flight system reactor and engine test complexes for qualification tests. Nuclear test facilities must include full exhaust effluent cool down and cleanup to ensure environmental compliance. Significant upgrades to existing vacuum facilities are also critical to development efforts. An enlarged reactor test facility above the 100 kW space power (SP-100) class may be required if clustering is insufficient for the power levels required to validate nuclear technology for the Mars missions.

Funding

The United States is currently spending about $285 million for propulsion R&D in FY92, or 56 percent of the total space launch technology investment (Figure 3-1). Funding for the SP-100 is not included in these totals. All but about $16 million of this is funded by the NLS and NASP programs. As NASP and NLS enter their next development phase, propulsion technology efforts will be devoted to the options discussed above. Significant additional funding is required to accelerate development of enabling nuclear propulsion technologies if required for deep space exploration.

3.4.3. Structures, Materials, and Manufacturing

Overview

The primary improvements in structures, materials, and manufacturing technology relate to the development of lightweight, high-strength materials and compatible coatings that can be efficiently and economically manufactured into structures capable of withstanding the launch environment. The benefits of developing such materials and their applications to producible, durable structures include:

- reduced manufacturing lead time
- reduced vehicle costs
- increased launch capability
- improved reliability and increased margins for launch systems.

Launch vehicle performance can be improved by developing materials with better strength-to-weight, increased stiffness-to-weight, and long-duration dimensional and thermal stability. The requirements for expendable launch vehicles differ somewhat from those of reusable or partially reusable vehicles. SSTO concepts require lightweight materials since their performance depends on drastic weight reductions when compared to similar components optimized for two-stage systems. Targets for weight reduction are 25–60 percent of the baseline Shuttle designs. To achieve a 25-percent overall reduction in dry weight requires near-term, evolutionary technology advancements. To achieve a 40- to 60-percent reduction in dry weight requires revolutionary advances in technology. There is a spectrum of materials used in the construction of launch systems, all of which require advances in technology. The classes include:

- advanced metals, such as aluminum lithium
- organic composites, such as carbon/carbon composites
- metal matrix composites, such as titanium aluminide alloys
- ceramic matrix composites, such as those with silicon nitride and silicon carbide.

Operational considerations, such as fewer vehicle elements to check out and to integrate, should have a significant impact on lowering launch costs. Future aerospace systems should incorporate embedded sensors and computer networks to provide monitoring of structural integrity and in-flight loadings. These composite structures with integrated health-monitoring systems are known as smart skins/structures.

Current Programs

Aluminum Alloys: Programs are being conducted to develop materials and advanced processes that could be used to manufacture lightweight tanks and structures to store, for a relatively long time, cryogenic propellants. NASA in coordination with NLS ADP is working to define material properties and processing methods (i.e., production and fabrication) for aluminum-lithium (Al-Li) alloys in order to be able to produce a large cryogenic tank. At this point, subscale tests and system-specific component development could begin for either current launch vehicle applications or for future system developments. This work is closely integrated with the NLS advanced development program activities, which plan to build and test a subscale Al-Li NLS tank in 1993. NLS is investigating labor, time, and cost-saving processes for fabricating cryogenic tanks from Al-Li alloys. This research and development includes large extrusions to replace time-consuming machining operations currently used to make tanks. NLS is also investigating spin forming of large tank domes in one piece, roll forming of ring stiffness, and development of automatic welding and inspection techniques to save time and labor.

High Temperature Alloys: Advanced high-temperature, high-strength lightweight materials are an enabling technology for either horizontal or vertical take-off for single-stage launch vehicles. The revolutionary advances in materials, such as those pursued by the NASP Program, include metal matrix composites, ceramic matrix composites, and advanced carbon/carbon composites. The NASP Program has invested in excess of $150 million over the past three years into the development of materials, such as advanced titanium, titanium-metal-matrix composites, carbon/carbon ceramics and coatings, high-conductivity composites, and high creep-strength materials. Accomplishments include definition of material requirements, component and fuselage demonstrations, and high-temperature coating reusability in excess of 300 cycles. These efforts should continue through advanced demonstrations and environmental testing. NASA, in coordination with NASP, is exploring the use of advanced metallics, composites, and woven ceramics for thermal protection systems.

To operate efficiently and economically over an extended lifetime, the health of the launch system and its payload must be monitored and protected. Phillips Laboratory is developing a vibration isolation adapter for small, lightweight satellites. This system should reduce the vibration induced by the current, hard-mounted launch-system adapters and, thus, reduce the risk of failure, reduce the weight and cost, and increase payload interchangeability. The technology development activity would be completed in FY96 for a launch demonstration in approximately 2002.

For in space construction of large structures, NASA is working to develop ground-based, robotic assembly of complex platforms and structural components. Future efforts should focus on in-orbit fabrication and joining techniques.

Composites: An effort is underway within the NASP Program to develop a graphite epoxy cryogenic fuel tank that has the potential for a 40–60 percent weight reduction. Technology for this activity will freeze in 1994 to support the assembly and testing of tank articles that year. Upon completion of a successful test program, manufacturing methods and designs would be validated.

The Air Force Phillips Laboratory should complete the technology development of a filament-wound, composite, isogrid payload shroud in FY93. If successful, the composite payload shroud program is projected to save more than $360 million for the Titan IV program (beginning in the late 1990s), while reducing the manufacturing time to 3 months (versus the 15–30 months needed today).

Future Program Options

The Air Force proposes to conduct advanced demonstrations of the composite payload shroud (start in FY94) and the vibration-isolation adaptor (start in FY95). The composite isogrid technology has proven so successful with the shroud that significant benefits could be realized through the application of this technology to fuel tanks and interstages. A follow-on effort for full-scale fabrication and advanced demonstration of this technology is needed. Estimates indicate an approximate 40-percent reduction in component weight and a 50-percent reduction in the manufacturing lead time. Both efforts could start by FY96.

Ceramics: While significant advances have been made in high-strength lightweight structural materials, they are extremely costly and applications are further limited by the lack of an established data base and design methodology. To overcome these constraints, a comprehensive program is required that focuses on an integrated program of material development, processing, design, and component fabrication and testing. The DOE has proposed a 10-year continuous fiber ceramic composites initiative. These improved materials could be available at the turn of the century and could be incorporated into designs within a decade.

Advanced Processes: NASA has proposed three major efforts in addition to their on going efforts. The first, structures, materials, and manufacturing for Earth-to-orbit applications will be investigated. The Earth-to-orbit Program will look at developing materials and automated processing and testing to reduce the cost and the weight of cryogenic tanks and vehicle structures by 20–40 percent. The long-term program would develop a national infrastructure of analytical design tools, competent engineers, and test facilities to assure rapid, efficient development of high-quality, producible structures. The planned Low-Cost Transport Technology Program would address the application of aluminum-lithium alloys and an advanced process for cryogenic propellant tanks for fabrication of vehicle upper stages. This program is designed to support the commercial launch industry. The Space Transportation Vehicle Structures and Cryotankage Program would develop low-mass, space-durable materials for use on upper stages and transfer vehicles. The objective of this program would be the development of materials with a 25 percent, or better, improvement in specific properties.

The need for new lightweight, high-strength, durable materials is well recognized. Materials and coatings that could be used in the NASP propulsion system could also be used with Nuclear Thermal Rockets. The DOE would evaluate metal, polymer, and carbon-matrix components, advanced metallic alloys of aluminum, lithium, magnesium, and beryllium, and low-density intermetallics. The follow-up to this investigation would be the application of the most promising materials to space-launch hardware. The DOE also would contribute to the development of a health-monitoring system for launch structures, focusing on imbedding diagnostic sensors within the material, i.e., smart skins, and advanced thermal control techniques. The proposed improvements to the thermal management techniques would include carbon and ceramic insulators, phase-change storage materials, heat pipes, high specific-power generators, and composite flywheels. Drawing on their defense-related experience, the DOE Labs would develop shield designs to protect the launch systems, their payloads, and their crews from hypervelocity particles and from space debris. Finally, development of lightweight materials shielding techniques to protect personnel and electronics from radiation must be pursued.

Funding

The U.S. Government currently is spending approximately $91 million for structures, materials, and manufacturing technology R&D in FY92, or 18 percent of the total space launch technology investment (Figure 3-1). Nearly 90 percent of this total is funded by the NASP program. The balance is supported almost entirely by NASA as generic Research and Technology (R&T). The future program options should achieve a minimum of 20 percent of the total technology investments over the next ten years.

3.4.4. Avionics

Overview

The U.S. avionics technology program addresses system and component improvements that yield a high payoff in cost, performance, and reliability, with greater assurance of mission safety. Avionics includes electronics, electronic devices, inertial instruments, and software for controlling, affecting, or sensing various aspects of vehicle environments and operations. This technology program responds to specific user requirements within DoD, DOE, and NASA, as well as more general requirements derived from the vision of future system needs. The primary objectives are to develop adaptive systems that permit real-time adjustments, thus increasing launch availability and fault tolerance and eliminating much of current prelaunch operations. Other objectives include component developments that reduce subsystem power, weight, and size while increasing performance, and fault tolerant avionics to enable significant vehicle flight autonomy.

Technology improvements and standardization in avionics offers significant savings to both launch and space systems. Labor costs, which are by far the most expensive, should be reduced both in numbers of personnel and in numbers of hours spent to manage the resources. Standardization should save funding for every space program in both the hardware and software expenses. Test, validation, and verification should be easier and less costly. Test facility costs, expertise required to operate both the systems and the test facilities, and design and development time and costs should be reduced. The vendor base for space systems should be increased. Launch and on-orbit risk should be reduced through the fault tolerant programs in hardware. A great window of opportunity exists to reduce significantly the cost of space systems through advancing technology in this area.

Current Program

Current programs can be divided into technology research and development and advanced system development efforts. The former are, in general, longer term and seek technology enhancements; whereas the latter focus on developing currently known technology for specific space launch programs. The NLS program is an example of the second type. It is funding advanced development work in the following areas:

- Adaptive guidance, navigation and control for reducing mission preparation time and improving launch availability
- System health management for vehicle and ground checkout and inflight management system
- Electromechanical actuators replacing high-maintenance, trouble-prone hydraulic systems
- Multipath redundant avionics suite distributed architecture with fault tolerant structures
- Laser firing unit and flight termination system

These advanced development programs are focused on the NLS objectives of lowering life-cycle costs and improving operability of launch vehicles. However, there is general applicability to other programs (SSRT, NASP) and upgrades to current ELVs.

The generic technology development effort addresses the launch vehicle management system, space computers and electronics, advanced controls, vehicle health monitoring, and advanced guidance. Technology research and development is characterized by the NASP program, with far more technical risk and demands. The vehicle management system for the X-30 implements the guidance, navigation, and control (GN&C) functions for the vehicle throughout several flight regimes while controlling the airbreathing engine performance. Highly fault tolerant, radiation-hardened processors and memory components are being developed within the advanced spaceborne computer module effort. The generic very high speed integrated circuit (VHSIC) spaceborne computer should establish a radiation-hardened VHSIC production baseline, driving down cost through new space qualification and standardization. Radiation-hardened electronics efforts address advanced computer systems and diagnostic instrumentation for communication, command and control, and for health monitoring.

The basic research in advanced controls is focused on development of engineering software tools for avionics system design and includes application of expert systems and artificial intelligence for integration with space hardware. Efforts are directed toward knowledge engineering for autonomous spacecraft control, specification of a standard spacecraft operating system, and development of an expert system environment for spaceborne processors. Intelligent workstations are being developed to provide a more powerful tool to the satellite controllers. Examples are range scheduling for automation of labor intensive tasks and standardized approaches for displays and other aspects of the human-computer interface. Decreased training time should increase the effective time on station for control personnel.

Phillips Laboratory and other government agencies are involved with programs such as intelligent computer-aided training, which is used to decrease time for training personnel in the performance of complex procedural tasks. The vehicle health monitoring and system readiness effort is developing techniques to monitor and analyze the performance of launch vehicles. A ground-based laser wind profiler system is being developed for use in the real-time adaptive guidance system.

Development efforts in NASA are aimed at providing reliable and highly fault tolerant avionics systems to meet the GN&C and autonomous rendezvous and docking needs for the space station. The objective of the autonomous GN&C program is to identify, develop, and demonstrate GN&C architectures, sensors, and algorithms. The multipath redundant avionics suite and adaptive GN&C expert system provide adaptive guidance and robust avionics with high reliability and operability. Electric actuators and power management and distribution systems tasks are developing and demonstrating advanced systems that are highly reliable, replacing current hydraulic components and powered systems. The autonomous rendezvous and docking technology effort also is investigating self-contained systems for rendezvous and docking to function when ground support systems and/or crew are not available.

Future Program Options

The avionics technology program needs a more national perspective. Standardization of hardware and software in avionics components can yield a great cost benefit. It is critical to design into the system easy upgrading capability as new technology becomes available. For example, advancements in computer technology make it difficult to freeze a system design without almost immediate obsolescence. Standardized interfaces should allow new processors to be introduced in the future and still maintain communications, design integrity, and schedule.

Avionics benefits in cost, performance, and reliability will come both from hardware and software. Increased autonomy and standardization is the goal that should enable the future missions to succeed in reducing manpower required and allowing more advanced mission objectives.

A national avionics software technology program for launch systems should allow insertion of the following avionics technologies into programs, such as NLS, NASP, SSF, SEI, during the first decade of the next century.

Adaptive Guidance, Navigation, and Control: GN&C technologies should be developed to achieve on-demand launch and recovery, precision rendezvous and docking, and in-space operations without ground support. This effort includes developments required to achieve adaptive, all-weather, optimal, autonomous, fault-tolerant, on-board guidance, navigation, and control. Flight hardware demonstrations could include low-cost redundant inertial measurement units incorporating GPS and electrical actuators for engine thrust vector control and aerosurfaces.

Flight Systems Management: Flight systems management technology advances are sought in three major areas:

- Automated System Health Monitoring and Control

- On-Board Mission Planning and Retargeting
- Flight Operations Management.

System health management uses knowledge based systems to perform self-test and diagnostic tasks, display risk evaluations, and initiate appropriate redundancy management. The onboard mission planning and retargeting allows fast reaction to changed mission requirements, payloads, and parameters.

Architecture and Software: Data systems architecture concepts and technologies should be developed to improve data systems reliability, standardization, computational speed, and storage and retrieval. Methodologies for distributed (parallel) processing architectures and operating systems, fault tolerant data systems, and standardized module applications should be established. Critical developments include high-performance mass memory, radiation-hardened components, and real-time distributed operating systems.

Software technology developments will be directed toward reducing the costs of software production and maintenance. Methodologies for automatic fault tolerant code generation, software size and cost prediction, computer aided software management control, and reusable software module capability will be established. Acceptable techniques for reducing the costs of required verification and validation cycles by self-validation will be emphasized.

Artificial intelligence technologies should be developed for automation of selected launch, mission control, and on-orbit operations. Significant technology transfer from industry, academia, and other government agencies should be advanced, leveraged, and exploited. Critical disciplines include knowledge based system development and application to include reasoning with uncertainty, pattern recognition, fault identification, and isolation, and system validation, evaluation, and testing.

Systems Integration and Modeling: Candidate avionics technology and subsystem architecture concepts should be explored to identify building blocks for custom configuration of autonomous, fault tolerant avionics systems. Methodologies should be developed for evaluating the approaches to ensure synergistic benefits, optimization, and system compatibility. Antics models should be derived for evaluating systems performance and cost. A systems test bed is proposed for facility system level trades of conceptual design candidates.

Communication: Jam resistant secure communications technology should be developed for all mission phases with emphasis on the on-orbit and reentry blackout phases. Current communication technology procedures will be focused on the critical concepts and disciplines that include autonomous and secure communication, adaptive multifunction antenna systems, multiple beam formulations, and phased array semiconductor laser communication. Antenna system improvements should reduce reliance on ground station support; laser communication developments should be applicable to on-orbit operations especially for data collection and reporting self-monitoring system status.

Human and System Interface: The human factors technology base should be extended to support development of an optimized person and machine interface through applications of automation and electronic display and control technologies. Emphasis should be placed on increasing performance with less labor, with new control and display technologies and with information management and decision support.

Funding

The United States currently is spending approximately $36 million for avionics technology activities in FY92, or 7 percent of the total space launch technology investment (Figure 3-1). More than 90 percent of these funds are derived from focused technology efforts; again, most of this is embedded within the NASP program. The generic avionics R&T is supported by NASA. Over the next ten year, the avionics percentage of total technology investments should increase to 8 percent.

3.4.5. Aerothermodynamics and Recovery

Overview

Aerothermodynamics designates those activities directed toward the determination of the forces, moments, and heat-transfer acting on a vehicle in high speed flight. Thus, aerothermodynamic technology impacts the flight path, stability and control, and the range of the vehicle. It also impacts the thermal protection system and, therefore, the weight of the vehicle, which directly affects the cost of placing a payload in orbit. Both issues directly affect the safety of the crew and the success of the mission. The safe recovery of a vehicle involves either powered- or drag-aided technology. Developments in the associated recovery technology base yield improvements in safety and reductions in cost.

To plan the development of the aerothermodynamics technology base for launch systems, three types of vehicles are considered: (1) rocket-powered launch to orbit, (2) orbit-transfer vehicles, and (3) airbreathing propulsion systems. The flight envelopes for each of these three systems are so different that many features of the flow field are unique to that type of system. For all three types of vehicles, the aerothermodynamicist uses ground-based testing, theoretical analysis, computational techniques, and flight testing to develop a data base and design tools for determining the optimum design. New test facilities are needed, if research and development and certification of hypersonic vehicles that employ airbreathing engines are undertaken.

Current Program

For rocket-powered vehicles, aerothermodynamic issues are addressed by efforts imbedded within the specific vehicle program. As possible future options to reduce costs, the designers of the NLS continue to investigate novel recovery techniques for specific high-value components. Characterization of the chemical combustion heating process with chemical rockets clustered at the base of the vehicle is another concern of the NLS program.

Computational Fluid Dynamics Tools: To reduce design costs, the NLS has developed computational fluid dynamics computer codes. These codes allow mathematical simulation of fluid dynamic forces and heating of the vehicle structure. This enables the designer to look at design options without performing wind tunnel tests.

Although initial NLS plans do not include recovery of high-value components, the technologies and methods should be mature enough for potential application in the late 1990s and will potentially be incorporated as the NLS family expands operations in post-2000. The SDIO SSRT program plans to demonstrate the ability to recover a reusable vehicle via a powered vertical landing. The NASP program is making unprecedented use of CFD as a design tool with researches developing computer codes of increasing levels of complexity. Capability has been demonstrated for completely computing a single propulsive flow path from nose to tail at high supersonic and hypersonic speeds.

Hypersonic Technology: The aerothermodynamic technology program that supports the NASP includes several thousand hours of wind-tunnel tests from Mach 0 to Mach 20, with emphasis on high dynamic pressures and high-enthalpy heating. Although ground tests provide valuable data, they provide only partial simulations of the flight parameters. Thus, the prediction of the vehicle's performance in the flight environment is done with computer codes containing numerous approximations that were developed using experimental data. Critical to the code development are exercises in which the appropriate data are obtained to validate the physical models employed in the codes and to calibrate their overall performance.

Through the NASP program office and the NASA Hypersonics Research Program, focused efforts are underway to improve our understanding of hypersonic boundary layers (especially turbulent) and high-speed transition, mixing and combustion at supersonic speeds, real-gas effects at high-temperature, rarefied flows of high-altitude flight, and surface catalytic effects. Some flight experiments will focus on providing data to calibrate the design codes, thereby enhancing confidence in these codes and improving their capabilities.

Efforts to characterize hypersonic flight regimes for the NASP program are progressing and are scheduled to produce results in the mid-1990s. Subsequent flight experiments should move to extend the characterization of hypersonic flight environments and improve and validate codes. In addition, ground-based modeling should continue through 2000.

Recovery: Personnel from NASA and DoD have completed a study to define the general requirements for precisely controlled parachute systems to provide soft landings for large objects representative of space launch components. The ongoing test program has confirmed the operability and controllability of guiding components in the 17,000 to 20,000 pound range to a soft landing. A prototype system has been designed and built for a 60,000 pound payload. Testing of this system is planned to be complete in FY93.

Future Program Options

The benefits of a proposed aeroassist (aerobraking) technology program include a substantial reduction in mass and/or an increased payload for atmospheric capture, direct entry from planetary missions, and reentry from orbital missions. The program should focus on the long-term maturation of aerobraking technology and methods for potential application in Lunar and Mars exploration missions in the post-2000 time frame.

To understand the flow phenomena of hypervelocity flight at very high altitudes, a high-energy aeroassist flight experiment should be conducted. An extensive technology base, including ground tests, computational fluid dynamic flow fields, and instrumentation, was developed in the 1980s for such a flight-test program. The proposed program would focus on aerocapture at very high energy levels (i.e., simulating return from planetary missions).

Experimental Facilities: New ground-test facilities and instrumentation are needed to provide the data required to substantially improve understanding of the flow physics that forms the basis of computer models. For some problems, facilities simply do not exist at all (e.g., high-enthalpy, large-scale integrated aero/propulsion tests). The NASP program will provide national options for aerothermodynamic research. Characterization of combustion heating could be complete in the mid-1990s and available for use in the full-scale development of the NLS family.

The flow fields for maneuverable, high lift-to-drag ratio, unpowered hypersonic vehicles differ significantly from hypersonic vehicles powered by airbreathing engines. Viscous and inviscid interactions, nonequilibrium effects, and (possibly) ablating thermal protection systems must be modeled for these vehicles. Therefore, to support code validation exercises, DoD, DOE, and NASA have joint and individual plans for facility development, instrumentation development, and flight tests. Examples are the Hypersonic Technology Initiative at the Wright Laboratories, in which a series of four flight tests are proposed.

Funding

The nation is currently spending approximately $42 million for aerothermodynamics and recovery technology activities in FY92, or about 8 percent of the total investment in space launch technology (Figure 3-1). More than 60 percent of the funds are directed toward systems-focused technology development in which the majority of spending is on the NASP, NLS, and SSRT programs. Most of the approximately $18 million in generic R&D is supported by NASA through the Hypersonic Research Program. Over the next ten years, the investments in aerothermodynamics and recovery should grow to about 10 percent.

3.4.6. Operations and Processing

Overview

The efficiency of launch operations determines such attributes as crew size, facilities and equipment quantities, hardware production rate, vehicle fleet size, and payload backlog and storage costs. As such, operations and processing have a tremendous leveraging effect on overall launch costs. Current U.S. launch systems have fallen victim to this leveraged efficiency-cost relationship.

Present-day launch processing consists of slow, painstaking, expensive operations to prepare vehicles and payloads for launch. The time required to process launch vehicles ranges from 100 to 240 serial shifts. Accordingly, the system cost of these programs is extremely high. This problem has occurred for a number of reasons. Existing launch system vehicle and ground segments are based on 20- to 30-year old technologies. Vehicle systems are complex and have been optimized for minimum weight rather than for ground operations. As a result, these systems lack robustness. They are easily affected by adverse weather. They require specialized flight hardware, handling procedures, and equipment. They involve the use of hazardous materials such as ordnance, exotic fuels, cryogenic liquid hydrogen and oxygen, and high-pressure gases. This lack of robustness also drives the need to (1) conduct extensive mission-related structural and flight analyses to determine if margins will be violated, and (2) perform extensive and time-consuming testing of all subsystems to establish launch readiness.

The Operations and Processing Technology Program establishes a plan to overcome these obstacles by developing the means to normalize launch processing operations, while enhancing reliability. This should be accomplished by developing methods and technologies for the purpose of designing vehicles and ground systems that require substantially reduced test, checkout, and special handling and analysis requirements.

The benefits of developing the correct operations-related technologies apply to both new and existing launch systems. However, the greatest potential benefits relate to new programs, where the opportunity exists to employ technologies to create inherently operable designs—thus obtaining significant cost reduction through efficient operations.

Current Program

DoD, NASA, and DOE are developing a number of operations-related technologies for new expendable and reusable launch systems. Some of these technologies are intended to reduce operational impacts from safety and reliability problems. Examples include the development of alternative pyrotechnics to eliminate present-day ordnance hazards. Advanced hazardous gas detection system concepts are being developed to isolate hazardous propellant leaks. Autonomous navigation, on-orbit rendezvous and docking, and telerobotics technologies are also being pursued to improve the reliability and safety of on-orbit docking and hardware handling operations. Weather and lightning forecasting and protection systems are being studied to reduce weather-related impacts to launch-processing operations.

Automation: Other technology areas involve the automation of present-day processes, including testing, field site scheduling, flow management, vehicle loads analysis, and mission planning. Largely funded through NLS, these efforts include autonomous launch operations and automated launch processing, load cycle simplification, development of an advanced object-oriented database, development of vehicle and engine health management systems, and development of remote cable transducers to remotely identify system components. Many of these involve the use of artificial intelligence and advanced software.

Still other areas are intended to develop operable vehicle subsystems. Electromechanical actuators and thrust vector control power source systems are under development to replace troublesome hydraulic systems and to supply power to electromechanical actuators. NASP has successfully developed small-scale hydrogen slush production and transfer capability. Finally, methods to better predict vehicle acoustic signatures and weather are also being developed.

Future Program Options

Test Facilities and Instrumentation: Considerable launch-site time is spent performing electronic continuity, isolation, and functional tests. Tests can be streamlined or eliminated by developing and implementing the appropriate technologies. Fiber optics for vehicle and ground segments would eliminate wire cables and their associated work. Ring laser gyros resistant to the effects of launch processing and handling would ease test requirements. Built-in test to provide go/no-go indications of flight readiness would reduce the data and analysis burden. The development of autonomous systems could decrease dependence on ground-based equipment and personnel. Fiber optics, laser gyros, and built-in test technologies should be developed for implementation in NLS-generation vehicles. Autonomous systems have larger payoff potential for reusable aerospace vehicles.

In the area of mechanics and testing, new technologies are clearly needed. New nondestructive testing techniques will be required to nondestructively test newly developed materials. Enhanced ground and space hardware handling systems, perhaps robotic, must be developed to replace antiquated (ground) crane operations and to routinize in-space construction. To decrease development test costs, integrated simulation testing capability should be developed which integrates all technical disciplines in a unified analysis. Nondestructive testing and enhanced ground handling should be pursued for NLS-generation vehicle development, while space hardware handling and integrated simulation testing are required for the operable implementation of reusable aerospace vehicles.

Propellant Systems: To field operable vehicles, several generic problems must be solved relative to all cryogenic propellants. Cryogenic propellants present hazards that complicate both vehicle and ground support system design and operation. Leakage of such propellants is a serious concern, because of the potential explosion and thermal stress hazards. Sealing of these systems is extremely important, although historically difficult. Programs employing cryogenics expend hundreds of hours performing leak checks before each flight. Thus, the nation must develop leak-proof cryogenic seals and connections. These should be developed for reliable long-life in both flight and field site conditions, to eliminate leak testing requirements.

Additionally, high-efficiency, low-maintenance insulation should be developed so that both flight and ground system cryogenic insulation will no longer interfere with leak checking and repair or require maintenance. Rugged cryogenic instrumentation must be developed. The development of inexpensive miniature leak detection sensors should be pursued to establish reliable self or remotely operated hydrogen/oxygen leak detection systems for both ground and flight modes. These technologies are required to support both expendable vehicle objectives (NLS) and those established for fully reusable vehicles. Additionally, if the United States is to proceed with slush hydrogen vehicles, such as NASP, then the current small-scale laboratory efforts must be upgraded to obtain normalized large-scale slush hydrogen capabilities.

Funding

The National investment in Operations and Processing technology is about $47 million in FY92, or about 9 percent of the total space launch technology investment. Most of this relates to focused-technology programs. Operations and Processing should grow over the next ten years so that it captures about 10 percent of the total technology investments.

3.5. Investment Benefits

A prudent technology plan is based upon a system level understanding and assessment of the benefits that can accrue from applying the technology. The technologies described in the plan will impact recovering launch systems costs in three basic areas:

- Hardware Acquisition
- Operations and Maintenance Costs
- Failure and Replacement Costs

Hardware Acquisition is the cost of the system hardware. This cost is composed of raw material costs and manufacturing costs. Since the system hardware is thrown away for ELVs, it must be replaced for each mission. As a result, hardware costs represent the bulk of ELV mission costs. The majority of the hardware costs associated with a fully reusable vehicle can be amortized over the life of the vehicle; therefore, the hardware costs are largely controlled by the number of missions flown.

Operations and Maintenance Costs include the costs to operate and maintain the fleet of space launch vehicles and the ranges and facilities. The design of the vehicle, the amount of prelaunch vehicle build up and integration testing, the degree of vehicle autonomy and vehicle sensitivity to unique payload characteristics (such as weight and balance) all affect the number of people and number of shifts required to prepare a vehicle for launch. Since each ELV is a "new" vehicle, extensive prelaunch testing and verification is required. A reusable vehicle, designed to aircraft-like design criteria and using modern technology, could potentially reduce prelaunch processing.*

Failure and Replacement Costs are a function of the vehicle reliability. They include the costs to replace the lost payload and launch vehicle, the cost to repair any collateral damage to the launch site, the costs to conduct expensive failure analysis and corrective actions, and the expense of the standdown times after failure (storage and maintenance of backlogged satellites and support of the launch processing team until launches are reactivated). The costs of these failures typically are not budgeted.

Detailed analysis has shown that although product improvements are required to maintain a U.S. launch capability, the above ***cost areas will not be significantly reduced unless new launch system are developed using new technologies and design approaches.***

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* Improvements to the existing fleet of launch vehicles are required to maintain the U.S. launch capability. However, detailed analysis has shown that the cost of space operations will not be significantly reduced unless new launch systems are developed using new technology and design approaches. Previous vehicles have been modified at considerable expense trying to upgrade them for performance, reliability, safety, capacity, etc. The fact that these modifications worked from existing designs, were constrained to work in existing facilities, and were never tasked to be operational until after the fact must be considered when discussing this subject.

In the case of ELVs, the largest cost reductions are realized by reducing the cost of the flight hardware. The technology programs to reduce these costs, basically in the areas of propulsion, structures, and manufacturing are being performed in the NLS program. Operations costs can be reduced by designing the ELV to be more easily prepared for launch (i.e., a vehicle that requires only 60 eight-hour shifts for launch vice 100 eight-hour shifts.) Finally, failure costs can be reduced by increasing reliability (e.g., from 96 to 98 percent or one failure in 50 rather than one failure in 25). In economic terms, reusable vehicles can amortize the additional redundancy and design margins required for higher reliability over many flights.

For reusable vehicles, hardware costs are substantially reduced by increasing the vehicle life via improved reliability and increased design margins. Modern propulsion and structural technologies could enable fully reusable designs. With increased vehicle and subsystem design margins and robustness, it becomes practical to increase reliability goals from 98% to 99.6% (i.e., from one failure in 50 to one failure in 250 missions).

Operations cost improvements result from new technology oriented to improve accessibility, standardize interfaces, provide robust design margins and improve propellant seals, actuators, and autonomy. For the reusable vehicle, the launch processing requirements could potentially be reduced by an order of magniture.

Robust design margins, combined with features such as intact abort following an inflight engine or critical subsystem failure and incremental flight tests, allow greatly increased vehicle reliabilities, thus greatly reducing failure costs. Fully reusable designs employing characteristics and technologies discussed above can reduce costs significantly when compared to our current partially reusable system.

This Ten Year Space Launch Technology Plan could allow realization of the benefits of early investments in the technology base. From 1992 to 2020 the United States, based on the planned national mission models, will spend on average over $9 billion annually (including estimates for unbudgeted failure costs) to operate our current fleet of space launch vehicles. This does not include any significant payload traffic growth which would be required to support Space Station Freedom, the Space Exploration Initiative or Strategic Defense Initiative missions. If funds are specifically allocated for technology investments and new launch systems are developed, significant improvements in launch costs can be obtained.

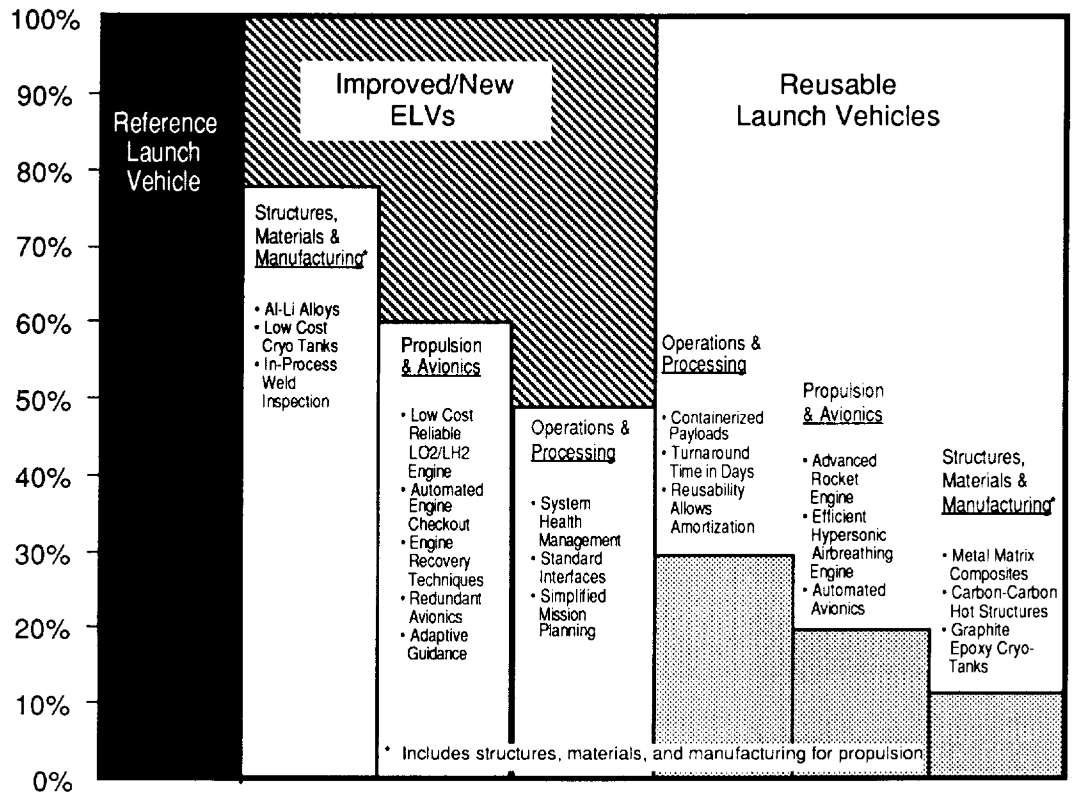
The National Launch System is a major step toward controlling launch costs. However, it is only one of the needed steps. A program to develop advanced technology applicable to a fully reusable, operable, and highly reliable launch vehicle also is needed. This technology could enable further reduction in cargo delivery costs and provide a responsive manned capability. Launch vehicles derived from this technology could be part of a future launch vehicle family beyond NLS.

An assessment of the potential savings gained through the application of technology to lower launch costs is presented in Figure 3-3. It is based upon a notional cost reduction model. The reference vehicle is representative of the current U.S. launch fleet. As shown, the introduction of a reusable capability holds the potential to significantly reduce launch. The absolute magnitude of the cost reduction will be determined by the technology applications and other program considerations.

When fully implemented, transition from current expendable launch systems to NLS should reduce the annual operations costs significantly. This savings should payback the investments in technology and the resultant new launch systems. It should also allow the United States. to again be competitive in the international launch market, provide a substantial

Figure 3-3

Notional Cost Reduction Model



number of jobs, and improve the balance of trade payments.

3.6. Funding and Priorities

The technology program outlined in previous sections supports the development of a new family of highly optimized launch systems and supporting infrastructure. It is a vigorous program of high technical and scientific value, having a directed technology component as well as a generic one, focused on launch system applications.

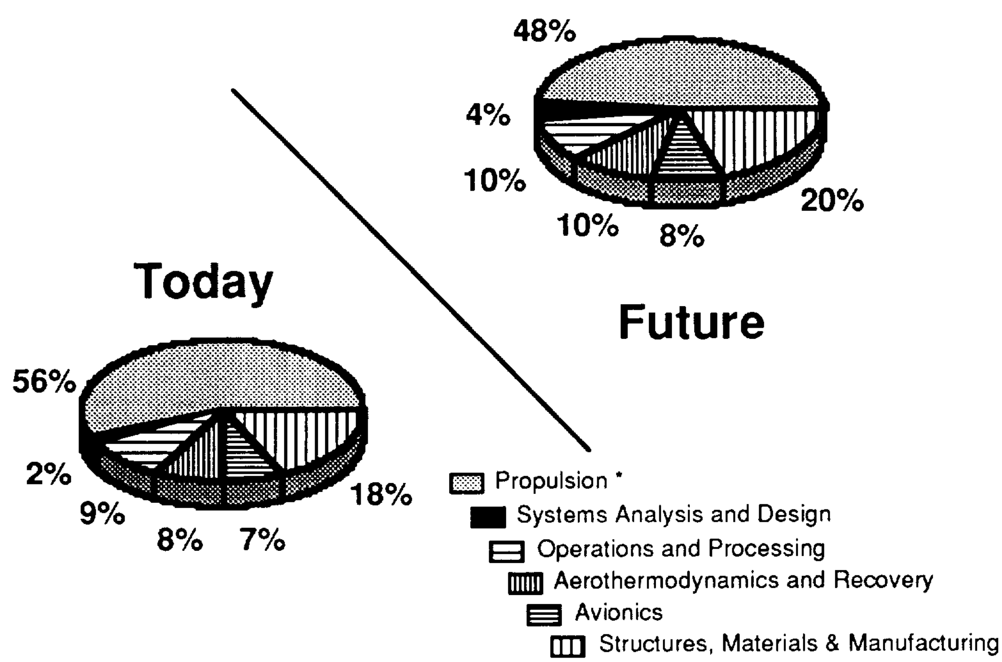
As stated in the beginning of this section, the combined agency funding identified for space launch technology in FY92 totals $512 million. Over the next ten years, as NASP and NLS transition from technology development to their next phase, their funds allocated to technology should continue to support broad technology developments. At initiation, these programs absorbed most of the launch technology activities being conducted within the generic research and technology programs. Government and commercial applications require this minimal investment level to evolve a truly cost effective ELV system and upper stages and reusable aerospace vehicles. A substantially greater investment will be required to support nuclear-based space transfer vehicles, if required for new space exploration or DoD missions.

Today non-propulsion technologies are critically under-funded. To correct this deficiency, a greater percentage of funding should be targeted to non-propulsion technology discipline areas. Over the next ten years as programs change and/or new funding becomes available, the percentage of funds allocated to each area should change toward that reflected in Figure 3-4. Monitoring the distribution of funding among the technology discipline areas and comparing it to potential payoffs in system attributes is imperative. Corrections to the distribution allocation is mandatory when warranted. Allocation of future budgets, or technology discipline focus, among the participating agencies was not part of this initial joint planning effort, and will be left to future interagency coordination.

Finally, it should be emphasized that while the cost of new launch vehicles is many billions of dollars (the NLS vehicles plus an MLV-class RAV alone cost about $20 billion), so, too, is the potential for reducing the cost of launch operation and, especially, failure.

Figure 3-4

Technology Discipline Investment Distribution



* Funding for a focused nuclear propulsion technology effort at a level required to mature this technology for application in the next decade not considered.

This plan sets forth the following ordered technology priorities:

- Complete the critical technology investments embodied in the NLS and NASP programs.
- Develop broad technologies that will enable truly affordable reusable launch systems.
- Develop technologies that will significantly improve upper and transfer stage performance. A significant investment will be required to mature nuclear propulsion options.
- Continue to make modest investment in technology suitable for insertion to improve the existing launch fleet.
- Increase the number of new concept test beds and flight test demonstrations when needed.
- Increase the funding of non-propulsion technologies, as future program options are implemented, especially in areas not sufficiently covered by the current focused programs.

3.7. Updating the Plan

The DoD, DOE, and NASA recognize that this technology plan needs to be expanded and updated annually, and intend to do so as part of their individual budget preparation efforts. This joint plan was developed by an ad hoc group drawn from the three agencies. Future planning efforts need to be institutionalized. A ready mechanism is available to assist in this process.

The Space Technology Interdependency Group (STIG) is an existing forum whose membership includes DoD, NASA, and DOE. Its purpose is to monitor and coordinate agency space technology programs and to promote new opportunities for cooperative relationships. The STIG's goal is to provide advocacy, oversight, and guidance that will encourage and facilitate new technology development programs while avoiding duplication of resources and efforts. As updates to the Space Launch Technology Plan are required, the STIG can be used as a resource for providing launch technology program data, identifying cooperative programs, and in seeking opportunities for further coordinated agency technology projects. The process for budgeting and program implementation will remain with the individual agencies.

Acronyms

ADP	Advanced Development Program
AETB	Advanced Expander Test Bed
AFSPACECOM	Air Force Space Command
Al-Li	Aluminum-Lithium
AMLS	Advanced Manned Launch System
CERMET	Ceramic Metalic
CFD	Computational Fluid Dynamics
CIS	Commonwealth of Independent States
CONUS	Continental United States
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense
DOE	Department of Energy
ELITE	Electric Insertion Transfer Experiment
ELV	Expendable Launch Vehicle
FY	Fiscal Year
GEO	Geosynchronous Orbit
GN&C	Guidance, Navigation, and Control
GPS	Global Positioning System
GTO	Geosynchronous Transfer Orbit
HEDM	High-Energy Density Matter
IME	Integrated Modular Engine
IR&D	Independent Research and Development
IUS	Inertial Upper Stage
klb	Kilo-pounds (thousand pounds)
kW	Kilowatts
lbs	Pounds
LaRC	langley Research Center
LEO	Low Earth Orbit
LH_2	Liquid Hydrogen
LO_2	Liquid Oxygen
MAV	Military Aerospace Vehicle
MLV	Medium-class Launch Vehicle
NASA	National Aeronautics and Space Administration
NASP	National AeroSpace Plane
NDE	Non-Destructive Evaluation
NEP	Nuclear Electric Propulsion
NERVA	Nuclear Engine for Rocket Vehicle Applications
NLS	National Launch System
NSPD	National Space Policy Directive
NTP	Nuclear Thermal Propulsion
PAM	Payload Assist Module
PLS	Personnel Launch System
R&D	Research and Development
R&T	Research and Technology
RAV	Reusable Aerospace Vehicle
SDIO	Strategic Defense Initiative Organization
SEALAR	Sea Launch and Recovery
SEI	Space Exploration Initiative
SNTP	Space Nuclear Thermal Propulsion
SPIP	Solid Propulsion Integrity Program
SRM	Solid Rocket Motor
SRMU	Solid Rocket Motor Upgrade
SSF	Space Station Freedom
SSME	Space Shuttle Main Engine
SSRT	Single Stage Rocket Technology
SSTO	Single-Stage-to-Orbit
STIG	Space Technology Interdependency Group
STME	Space Transportation Main Engine
TSTO	Two-Stage-to-Orbit
U.S.	United States
VHSIC	Very High Speed Integrated Circuit

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