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NATIONAL AERO-SPACE PLANE

Restructuring Future Research and Development Efforts

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International Affairs Division

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The Honorable Barbara Boxer
Chair, Subcommittee on Government
Activities and Transportation
Committee on Government Operations
House of Representatives

The Honorable Tim Valentine
Chairman
The Honorable Tom Lewis
Ranking Minority Member
Subcommittee on Technology
and Competitiveness
Committee on Science, Space,
and Technology
House of Representatives

The Honorable Ronald V. Dellums
Chairman
The Honorable Robert W. Davis
Ranking Minority Member
Subcommittee on Research
and Development
Committee on Armed Services
House of Representatives

This report responds to your requests that we review the National Aero-Space Plane (NASP) Program's costs and schedule as well as its program status, feasibility, and justification. In March 1992, we provided our interim assessment of the NASP Program in a statement for the record entitled National Aero-Space Plane: Key Issues Facing the Program (GAO/T-NSIAD-92-26, Mar. 31, 1992). The statement was used for authorization hearings by the Subcommittee on Technology and Competitiveness on the National Aeronautics and Space Administration's fiscal year 1993 aeronautical research and technology budget request.

This report discusses the status of the NASP Program's technology development; changes in the program's projected cost and schedule; the requirements for and the potential military, civil, and commercial mission applications of future operational NASP-derived vehicles; efforts to spin off NASP-developed technology; and issues to be decided in reassessing the direction of the program.

We are sending copies of this report to the Secretaries of Defense, State, Commerce, the Air Force, and the Navy; the Administrator, National Aeronautics and Space Administration; the Directors, Defense Advanced Research Projects Agency, Strategic Defense Initiative Organization, Central Intelligence Agency, Office of Management and Budget, and Office of Science and Technology Policy in the Executive Office of the President; the Chairman, National Space Council; and interested congressional committees. We will make copies of this report available to other interested parties on request.

This report was prepared under the direction of Brad Hathaway, Associate Director, Air Force Issues, who can be reached on (202) 275-4329 if you or your staff have any questions concerning this report. Major contributors to this report are listed in appendix II.

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Executive Summary

Purpose

U.S. efforts to develop and demonstrate an aerospace plane that could achieve low earth orbit using a single stage are focused in the National Aero-Space Plane (NASP) Program. However, the program faces an uncertain future as it competes with other programs for limited federal funding at the same time its costs have escalated and its technologies remain to be developed within an ambitious schedule.

Because of these and other concerns, three congressional committees asked GAO to examine various aspects of the NASP Program. This report discusses (1) the status of the program's technology development, (2) changes in the program's projected cost and schedule, (3) the requirements for and the potential mission applications of future operational NASP-derived vehicles and efforts to spin off NASP-developed technology, and (4) issues to be decided in reassessing the direction of the program.

Background

The NASP Program is a joint Department of Defense (DOD)/National Aeronautics and Space Administration (NASA) technology development and demonstration program to provide the basis for future hypersonic flight vehicles by developing critical technologies. Program plans call for building and testing a manned experimental flight vehicle, the X-30, to validate technologies by demonstrating single-stage-to-orbit space launch and sustained hypersonic cruise capability. The concept for the X-30 is to develop a vehicle that would take off horizontally from a runway, reach hypersonic speeds of up to Mach 25 (25 times the speed of sound in air), attain low earth orbit, and land on a runway.

The NASP Program currently consists of three phases. Phase I (1982 to 1985), which preceded the NASP Program, consisted of a feasibility study that defined the technical concept for an air-breathing aerospace plane. Phase II (1985 to 1994) is a technology development and maturation phase. The current Phase IID is intended to develop the critical technologies and manufacturing processes, build and test structural articles and components, establish the X-30 vehicle conceptual design, and test a subscale concept demonstration engine. At the end of Phase II, a decision will be made, based on cost and the maturities of the technologies, whether to proceed into Phase III to build and test the X-30. A decision to begin Phase III is currently scheduled for September 1993.

The NASP Joint Program Office manages the program. The National Contractor Team, consisting of five major aerospace contractors, is responsible for the majority of the technology development efforts. The NASP Steering Group, made up of DOD and NASA officials, is responsible for policy, guidance, and broad programmatic direction.

Results in Brief

The NASP Program's 7-year history has been characterized by turmoil, changes in focus, and unmet expectations. Even after a redirection of the program to keep it focused on research and technology development objectives, the program is again at a crossroad. Projected costs are increasing, technical progress is behind schedule, and funds are insufficient to implement the program as planned. The program will not be ready for the Phase III decision as scheduled.

As a research and technology development program, the NASP Program is intended to be unconstrained by operational requirements. However, given the magnitude and cost of this effort, discussions about the utility or cost/benefit of the NASP Program have prematurely evolved into efforts to justify the program through potential benefits from future operational aerospace vehicles and spin-off applications.

GAO believes that in responding to pressures to successfully compete for funding and show results in the face of reduced budgets, unrealistic expectations have been set regarding the time and cost required to achieve the program's goals and objectives. NASP Program officials, aware of the need to again redirect the program, have proposed several alternative development strategies in response to reduced DOD and NASA budgets. As of November 1992, the NASP Steering Group had not made a decision on which, if any, of the proposals would be approved.

Principal Findings

Despite Some Progress, Many Technology Development Challenges Remain

The NASP Program faces additional work to resolve technical problems before the requisite technologies are sufficiently mature to warrant a decision to build the X-30. The National Contractor Team has made some progress in satisfying the Phase II exit criteria established to measure technical progress. However, due to technical problems and budgetary constraints, nearly 25 percent of the planned critical tests or events will not have been completed by the scheduled decision in September 1993 whether to build the X-30. Tests indicate that while the engine design looks promising at high speeds, it does not produce sufficient thrust at lower speeds. Another problem is vehicle weight. If the X-30 is built according to the current design and weight, it may not be able to achieve single-stage-to-orbit.

Projected Costs Have Escalated Significantly, and Key Schedule Milestones Have Been Delayed

Initial contractor estimates indicate that the NASP Program could have cost as much as $17 billion—more than five times the 1986 estimate of $3.1 billion. When calculated in constant 1992 dollars to exclude the effects of inflation, projected program costs increased by more than four times from about $3.3 billion to about $14.5 billion. Although no official cost estimate has been prepared, preliminary contractor estimates indicate that a baseline program—consisting of building and testing two single-stage-to-orbit-capable X-30 vehicles—would cost between $13.2 billion and $15.1 billion, depending on the X-30's weight. Since these costs would be in addition to the $1.9 billion that was expected to be incurred during Phase II, total program costs could have reached $17 billion. Program officials attribute this increase to previous unrealistic assumptions about the X-30's weight and complexity and to schedule delays. These delays were largely due to technical problems, budget reductions, and programmatic changes. In March 1992, the Joint Program Office extended Phase II efforts until March 1994 (although some Phase IID technical efforts will not be completed until September 1994), or about 5 years later than anticipated under the program's 1986 schedule.

The objectives and time frames for building and testing the X-30 are uncertain due to unresolved concerns over affordability and technical risk. Under previous plans, annual funding requirements could have increased from the 1991 level of $258 million to $1 billion or more between fiscal years 1994 and 1996, with the X-30 airframe and engines to be developed and produced concurrently. However, this plan was considered technologically risky and too expensive, given DOD and NASA funding constraints.

Program officials have since proposed several options ranging from completing the baseline program to making fundamental changes that could, if implemented, significantly extend the program schedule, refocus the program largely as a propulsion system research and development effort, and indefinitely defer a decision to build the X-30. A subsequent proposal would eliminate the X-30 and focus on an unmanned, subscale, non-single-stage-to-orbit vehicle. Until DOD and NASA agree on how to resolve concerns about the affordability and technical risk inherent in the baseline program, it is uncertain whether the X-30 will be built, if it will be expected to achieve single-stage-to-orbit, when key program milestones are expected to be achieved, or how much the program will cost.

Potential Applications of NASP Technologies Should Not Be Used as Program Justifications

As the NASP Program demanded a larger share of decreasing budgets, pressures to justify its utility and cost benefits through potential applications to future aerospace vehicles and spin-off applications increased. Citing a future need for less costly launch systems, program officials have been comparing the operational benefits of NASP-derived vehicles with other launch systems. However, as a research and technology development effort, the NASP Program is intended to be unconstrained by operational requirements. In fact, potential user requirements that operational characteristics be incorporated into the X-30's design jeopardized the X-30's capability to achieve single-stage-to-orbit by increasing its size, weight, and complexity. Even if the X-30 is built and successfully demonstrates single-stage-to-orbit capability, follow-on programs would still be necessary to develop mission-specific operational vehicles. Future operational NASP-derived vehicles would not be operational until well into the 21st century.

Although the NASP Program has established the NASP Technology Transfer Program to facilitate the application of its technologies, GAO believes that the benefits of potential spin-off applications cannot be realistically assessed at this stage of the program. Significant technology transfer benefits have not yet been realized, and projections of future economic benefits from such transfers are based on overly optimistic assumptions.

Matters for Congressional Consideration

The Congress, in conjunction with the administration, should reassess the direction of the NASP Program and determine whether the goals of single-stage-to-orbit and sustained hypersonic cruise are worth pursuing on their own merits. If these goals are judged to be a worthwhile investment, the Congress should consider ways to ensure that the program remains properly focused and optimized for developing critical technologies. Options that could be considered include

- refocusing the program on efforts to develop key technologies (analogous to the current Phase II) and deferring the definition of future phases until the technical results are assessed;
- defining and implementing a research and development program with milestones based on successfully achieving technological goals rather than

meeting a predetermined cost and schedule (that is, a technology-driven rather than cost- or schedule-driven program) and with realistic, attainable annual funding goals; and

- reassessing the current NASP Program management structure—the NASP Joint Program Office and National Contractor Team—to determine if it is cost-effective and compatible with restructured program objectives and goals, available funding, and current technology development.

Recommendations

GAO recommends that the Secretary of Defense and the Administrator of NASA direct the NASP Steering Group to delay a decision to build and test the X-30 experimental vehicle until critical technologies are developed and demonstrated and decisions on program restructuring are made. Other recommendations to the Secretary of Defense and the Administrator of NASA are included in chapter 5.

Agency Comments

As requested, GAO did not obtain written agency comments on this report. However, GAO discussed its findings with agency officials and incorporated their comments where appropriate.

Contents

Abbreviations

DOD	Department of Defense
GAO	General Accounting Office
NASA	National Aeronautics and Space Administration
NASP	National Aero-Space Plane
NDV	NASP-derived vehicle
scramjet	supersonic combustion ramjet
SSTO	single-stage-to-orbit

Introduction

The National Aero-Space Plane (NASP) Program is a joint Department of Defense (DOD)/National Aeronautics and Space Administration (NASA) technology development and demonstration program. Its objective is to develop technologies to provide the foundation for future aerospace vehicles. Since its inception, the NASP Program has focused on building and testing a manned experimental flight vehicle, the X-30, to validate these critical technologies by demonstrating single-stage-to-orbit (SSTO) space launch and sustained hypersonic[1] cruise capabilities. The X-30 is being designed to take off horizontally from a runway, reach orbital velocity speeds of Mach 25 (25 times the speed of sound in air, or about 19,000 miles per hour),[2] attain low earth orbit, and land on a runway.

Currently, the NASP Program is at a crossroad. Program officials are considering proposals to restructure the program, since DOD and NASA consider the program, as presently structured, too technologically risky and expensive. The program faces a major, fundamental change in direction that could lead DOD and NASA to refocus developmental efforts on the propulsion system and indefinitely postpone a decision to build the X-30 experimental vehicle.

This report discusses (1) the status of the NASP Program's technology development, (2) changes in the program's projected cost and schedule, (3) the requirements for and the potential military, civil, and commercial mission applications of potential future operational vehicles and efforts to spin off NASP-developed technology, and (4) issues to be decided in reassessing the direction of the program. The objectives, scope, and methodology of our review are discussed in appendix I.

Program Overview

To achieve the NASP Program's objective of developing and demonstrating the technologies for a new generation of aerospace vehicles, several critical technologies must be developed. These technologies include (1) an air-breathing propulsion system using supersonic[3] combustion ramjet

[1]A range of speed that is five times or more the speed of sound in air (761.5 miles per hour at sea level). Hypersonic speed is about 3,800 miles per hour and above.

[2]Mach is a number representing the ratio of the speed of an object to the speed of sound in the surrounding atmosphere. An object traveling at the local speed of sound is traveling at Mach 1.

[3]A range of speed between about one and five times the speed of sound in air, or between 761.5 and about 3,800 miles per hour.

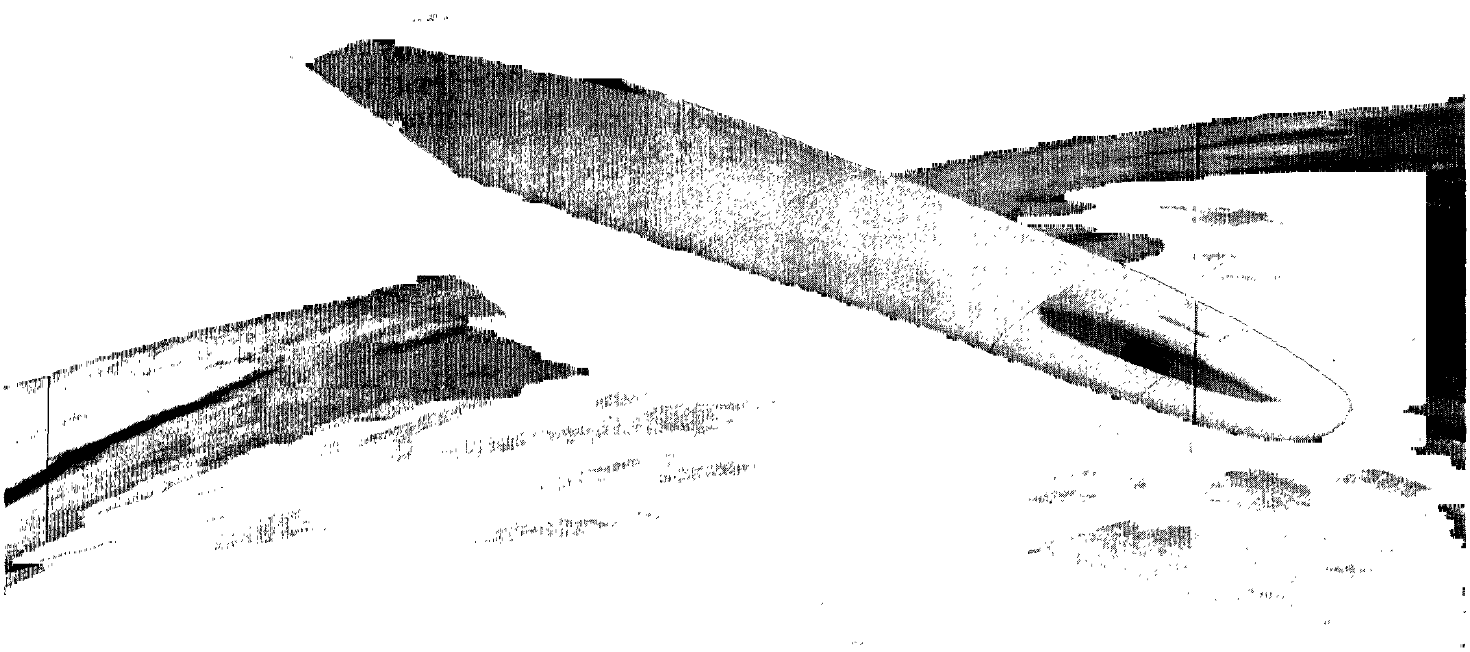
(scramjet) engines[4] ; (2) advanced materials that are high strength, lightweight, and resistant to high temperatures; (3) a fully integrated engine and airframe; (4) computational fluid dynamics[5] for aerodynamic, structural, and propulsion system design; and (5) hydrogen used both as a fuel for the engines and a coolant for actively cooled structures.

The X-30 would be expected to fly about eight times faster and far higher than any previous aircraft. The X-30's concept provides that the vehicle would achieve speeds of about Mach 16 using primarily air-breathing propulsion within the atmosphere and that speeds between Mach 16 and 25 would be achieved using rocket propulsion to augment the air-breathing scramjets. Figure 1.1 shows the X-30's conceptual design configuration. This design represents an early version of the shape of the vehicle. Chapter 2 discusses the X-30's design progress. As discussed in chapter 3, a proposed program restructuring could indefinitely postpone a decision to build the X-30.

[4]Air-breathing propulsion systems burn atmospheric oxygen during combustion instead of carrying an oxidant internally as is typical on rockets. All conventional aircraft engines are air-breathing engines. A scramjet is an air-breathing engine in which air flows through the combustion chamber at supersonic speeds. Hydrogen is injected into the combustion chamber where it is ignited by the hot air. The hot gases are further accelerated through the exhaust nozzle, creating the thrust. Ground tests of scramjet engines indicate that they could propel an aircraft to hypersonic speeds, but the X-30 would be the first aircraft to fully explore their potential in flight.

[5]A tool for predicting the aerodynamics and fluid dynamics of air flow around flight vehicles or within their engines by solving a set of mathematical equations with a computer. Computational fluid dynamics is used in the NASP Program to improve the understanding of hypersonic flow physics and as an aerospace plane design and analysis tool.

Figure 1.1: National Aero-Space Plane Conceptual Design Configuration



Source: Rockwell International Corporation.

The most important and technologically challenging design goal of the X-30 is to achieve orbit in a single stage, using primarily air-breathing engines[6] in a fully reusable flight vehicle. Whereas a rocket launcher ascends vertically and jettisons one or more propulsion stages during flight, an SSTO vehicle would reach low earth orbit without carrying expendable rocket boosters or external propellant tanks. No vehicle has ever achieved SSTO using an air-breathing, a rocket, or a combined-cycle engine.[7] Moreover, despite conducting research and development of scramjet engine technologies since the 1950s, the United States has not yet flight-tested a scramjet engine.

The X-30 is envisioned as an experimental test vehicle. It would not be a prototype or an operational vehicle, and it would carry only two crew members and test instrumentation. The X-30 was expected to be a "flying test bed" to validate the requisite technologies, since the United States does not have the hypersonic ground test capability or facilities capable of creating the combination of velocities, temperatures, and pressures necessary to fully simulate the entire range of the X-30's actual flight conditions. Moreover, the United States cannot currently simulate all flowfield parameters for tests of a subscale scramjet engine module for sustained periods above Mach 8.

While the NASP Program is expected to provide the basis for future operational aerospace vehicles, the program is not intended to develop or build them. Any potential future operational aerospace vehicles—often referred to as NASP-derived vehicles (NDV)—would require an additional development effort and would have to be independently justified and funded. Future NDVs are expected to have technical, cost, and operational advantages over existing space launch systems, such as the space shuttle, and military and commercial aircraft.

Program Management

The NASP Program was formally established in December 1985 as a joint DOD/NASA program. DOD is responsible for overall program management, while NASA has the major role for technology maturation and lead responsibility for civilian applications. The Air Force, as the program's executive agency, established the NASP Joint Program Office in January 1986 at Wright-Patterson Air Force Base, Ohio, to manage the program. The NASP National Contractor Team, consisting of five major

[6]One or more small rocket engines would augment the air-breathing scramjet engines. Rocket engines would be used primarily to provide propulsion for the X-30's final ascent maneuver into orbit as well as to supplement the air-breathing engine system during other phases of flight. Rocket engines would also be used as a backup propulsion system in the early stages of the planned flight test program in case the primary air-breathing scramjets fail.

[7]A combined cycle engine includes some combination of air-breathing and rocket components that are integrated into a single propulsion system.

aerospace contractors,[8] is responsible for the majority of the technology development efforts and for developing and refining the X-30's conceptual design. In January 1990, the five prime contractors, then in competition for the X-30 engine and airframe development, agreed to establish an interim teaming agreement and to form a joint venture (limited partnership) to design and build the X-30. The Team formally began in January 1991 when the Air Force awarded it the Phase IID contract.

The U.S. government has actively participated in developing key technologies, directly through the involvement of DOD laboratories and NASA research centers and indirectly by funding research at universities. For example, the development of the X-30's slush hydrogen[9] fuel and active cooling technologies, which would enable the X-30 to withstand the high temperatures generated by hypersonic flight, resulted primarily from in-house NASA research efforts.

The NASP Steering Group is responsible for policy, guidance, and broad programmatic direction for the NASP Program. The Group is chaired by the Under Secretary of Defense for Acquisition, and its Vice Chairman is NASA's Deputy Administrator. The National Space Council, chaired by the Vice President, is expected to review the NASP Program prior to initiation of vehicle development.

Program Schedule and Funding

As of November 1992, the NASP Program plan included three phases. Phase I (1982 to 1985) was a $5.5 million feasibility study, known as "Copper Canyon," that preceded the NASP Program's formal establishment. This highly classified, limited access concept definition program was conducted by the Defense Advanced Research Projects Agency with technical expertise provided by the Air Force, the Navy, and NASA. Program objectives were to define the technical concept of an air-breathing aerospace plane, evaluate key technologies, identify technical risks, and develop approaches to reduce those risks. At the end of Phase I, the Agency concluded that developing an aerospace plane and its technologies was feasible with proper focus and management. As a result, the Secretary of Defense formally established the NASP Program in December 1985. At this point, the program entered Phase II, a program of technology development and maturation.

[8]General Dynamics Corporation, McDonnell Douglas Corporation, and Rockwell International Corporation's North American Aircraft Division are the airframe contractors, and United Technology Corporation's Pratt & Whitney Division and Rockwell International Corporation's Rocketdyne Division are the engine contractors.

[9]A mixture of liquid and frozen hydrogen that is denser than liquid hydrogen.

Phase II work between 1985 and 1991 included individual contractors' efforts to develop initial vehicle design concepts and to design and test components for the engine and airframe. The program entered into the current Phase IID in 1991 when the Air Force awarded a single contract to the National Contractor Team. Phase IID efforts involve developing the critical technologies and manufacturing processes, building and testing structural articles and components, establishing the X-30's initial conceptual design, and testing a subscale concept demonstration engine.

As shown in table 1.1, DOD and NASA have received almost $1.7 billion in appropriations between fiscal years 1986 and 1993 for Phase II of the NASP Program. Although these agencies requested $255 million for fiscal year 1993, the Congress provided only $150 million for DOD. All fiscal year 1993 NASA funding for the NASP Program was denied. Prior to the ongoing restructuring activity, the Joint Program Office estimated that an additional $73 million would be needed in fiscal year 1994 to complete Phase IID activities.

Table 1.1: Phase II Funding for the National Aero-Space Plane Program

Dollars in millions

	Fiscal year								
Agency	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**Total**
DOD[a]	$45	$110	$183	$231	$194	$163	$200	$150[b]	$1,276
NASA	16	62	71	89	60	95	5	0	398
Total	**$61**	**$172**	**$254**	**$320**	**$254**	**$258**	**$205**	**$150**	**$1,674**

[a]Includes appropriations to the Air Force, Defense Advanced Research Projects Agency, the Navy, and the Strategic Defense Initiative Organization.

[b]A 3-percent across-the-board general reduction in all programs in the Air Force's research, development, test, and evaluation account was imposed by the Conference Committee on Appropriations. The effect of this anticipated $4.5 million reduction on the NASP Program is still being evaluated.

This funding does not include NASA's contributions in terms of personnel, facilities, and utility costs (estimated by NASA at about $450 million between fiscal years 1986 and 1994) or industry's reported contributions of $736 million between fiscal years 1986 and prior and 1990. NASA personnel, facility operations, and utility costs are not charged to the NASP Program, since these items are institutionally funded (appropriated by the Congress annually). In contrast, DOD civilian personnel, research facilities, and related costs are charged to the NASP Program, since use of DOD facilities is industrially funded (individual users, such as the NASP Program, are charged for their use). Costs for military personnel assigned to the NASP Program are charged to the military personnel account.

In 1991, the Joint Program Office and the Contractor Team established a refined set of critical Phase II technical demonstrations and accomplishments as exit criteria to measure whether sufficient technical progress has been made to proceed into Phase III of the program with an acceptable degree of risk. These criteria were in four broad categories: air vehicle design; engine performance and operability; demonstration that materials, structural design, and fabrication processes exist to build the X-30; and determination of the various properties and production of slush hydrogen as a fuel.

At the end of Phase II, a decision on whether to build and test the X-30 experimental vehicle would be based on cost and the maturation of the technologies. Phase II exit criteria would be used as the standard to measure technology maturation. According to the President's fiscal year 1993 budget request, the program schedule calls for the Steering Group to decide in September 1993 whether to proceed to Phase III, subject to the consent of the Secretary of Defense and the Administrator of NASA and approval by the National Space Council. As planned since 1986, Phase III would involve designing, building, and testing the X-30 and would also continue maturation of the critical technologies.

The NASP Program is not a major weapon system acquisition program. All of its phases precede the first milestone and phase in DOD's major weapon system acquisition process. The NASP Program involves more revolutionary technological advances than traditional DOD acquisition programs, in which technological advances are generally evolutionary. Moreover, the NASP Program will not result in the production of an operational vehicle.

Changes in Program Direction and Focus

Since its inception in December 1985, the NASP Program has undergone significant evolutionary changes. From its preliminary concept as a technology development and demonstration program between 1985 and 1988, the program took on an operational orientation from 1988 to 1989. The X-30's original concept of an experimental vehicle with a small payload, aircraft-like characteristics, and the objectives of demonstrating SSTO and hypersonic cruise capability evolved into a Joint Program Office baseline for an operational vehicle, the S-30,[10] with a large payload,

[10]In contrast to an "X," or experimental vehicle, the Joint Program Office-designated "S" vehicle is one that has utility.

increased performance reserves, and a focus on mission applications in space. According to program officials, the military users' requirements that operational characteristics, such as payload capacity, supportability, maintainability, and scalability,[11] be incorporated into the X-30's design jeopardized the X-30's capability to achieve SSTO by increasing its size, weight, and complexity.

In July 1989, the National Space Council redirected the NASP Program as a research program, eliminating from the X-30 the operational characteristics of an S-30 vehicle. It also extended the technology development phase by 2-1/2 years, established a new funding profile, clarified the program's technical direction, and reestablished its ultimate goal of achieving SSTO.

The Joint Program Office has proposed various options and alternative programs because of concerns over affordability and technological risk. In January 1992, several program options, which differed in the capability and size of the X-30 test vehicles and overall cost, were presented to the NASP Steering Group. However, none of the options in this proposal for Phase III were formally approved or adopted. In August 1992, the NASP Joint Program Office proposed another restructuring of the program, which, if implemented, could significantly extend the program schedule, refocus the program largely as a propulsion system research and development effort, and indefinitely defer a decision to build the X-30. In November 1992, the Joint Program Office developed yet another proposal that modifies the August 1992 proposal by focusing on flight test experiments using rocket boosters and subsequent flight testing of a subscale vehicle. At the conclusion of our review, no formal action had been taken on any of these proposals, and the future direction of the program remained uncertain. The Steering Group is scheduled to meet in December 1992 to discuss the future direction of the program.

[11]The ability of the X-30's design to be proportionately increased to incorporate operational requirements.

Despite Some Technical Progress, Many Challenges Remain

The NASP Program is a technologically challenging and high-risk program that consists of a range of advanced technologies, primarily in propulsion and materials. As of September 1992, the NASP Program had made some progress in satisfying the four Phase II exit criteria. Progress has been made in demonstrating its ability to produce slush hydrogen. In addition, the National Contractor Team has made mixed progress in the development and structural testing of materials; development and testing of airframe materials and structures has outpaced similar efforts for the engine. However, the Team has experienced delays in its efforts to develop an integrated vehicle design and demonstrate the viability of the propulsion system due to projected increases in the weight of the vehicle and the less-than-expected performance of low-speed and ramjet test articles. According to program officials, insufficient funding in fiscal years 1992 and 1993 played a large part in the delays.

The X-30's technology is currently not sufficiently mature to support the Phase III decision to build a test vehicle. Moreover, less than half of the program milestones established to meet the exit criteria will be achieved by the September 1993 Phase III decision. According to program officials, numerous changes to the current design of both the airframe and propulsion system are required, and these changes must then be incorporated and tested. Similarly, much of the airframe and engine materials development effort thus far has been confined to laboratory samples. Efforts to fabricate and test both small- and large-scale panels are just being initiated. These panels will be used to demonstrate that the materials can withstand the X-30's expected environment and be manufactured into usable components. Finally, as a result of funding cuts, the handling and maintenance of slush hydrogen as a fuel and coolant will not be fully developed on schedule.

Key Tests Will Not Be Completed Until After Planned Phase III Decision

Satisfying the Phase II exit criteria is considered essential before proceeding into Phase III with an acceptable degree of risk. However, recent schedule projections indicate that more than half of the interim milestones established to measure the National Contractor Team's progress toward meeting these criteria will have at least one critical test or event that will not be completed by September 1993, when the Steering Group is expected to decide whether to proceed into Phase III. Overall, nearly one-fourth of the critical tests or events currently planned for Phase IID will not be completed until after September 1993, when the Phase III decision is to be made. These later program activities include tests of structural integrity and the propulsion system's performance and a review to ensure that the X-30's overall design meets the Phase II exit criteria. Program officials attribute these delays in large part to budget constraints that led to a restructuring of the entire Phase IID test program.

To demonstrate satisfaction of Phase II technical objectives and measure the program's readiness to enter into Phase III with an acceptable degree of risk, the Joint Program Office and the National Contractor Team agreed in 1991 to the following four basic exit criteria:

- development of an integrated vehicle design;
- demonstration of sufficient engine performance and operability to achieve program goals;
- demonstration that materials, structural design, and fabrication processes exist to build the X-30; and
- demonstration of the capability to produce and use slush hydrogen as a fuel.

As part of these criteria, the National Contractor Team was to

- design an X-30 vehicle that had a maximum gross takeoff weight of 425,000 pounds or less;
- develop and test a large-scale engine up to Mach 8 and conduct sufficient subscale tests and simulations to predict the X-30's performance and operability throughout its flight envelope; and
- build and test a structural section of sufficient scale to validate the design concept, manufacturing processes, assembly, and weight of the X-30.

The Joint Program Office and the National Contractor Team currently have 38 interim program milestones that measure the Team's progress toward achieving the Phase II exit criteria. According to the Team's June 1992 schedule projections, key tests or events in only 17 of the 38 milestones will be completed by September 1993. As shown in table 2.1, each of the four exit criteria categories will have at least one milestone for which key tests or events have not been completed.

Table 2.1: Milestones Scheduled for Completion by September 1993

Exit criteria	Milestones planned	Milestones completed
Air vehicle design	6	3
Propulsion system performance	11	7
Materials characterization and structures development	19	6
Slush hydrogen development	2	1
Total	**38**	**17**

The National Contractor Team's June 1992 schedule projections indicate that completion of planned Phase IID technical efforts will be delayed from June 1993 to March 1994 (although some Phase II technical efforts will not be completed until September 1994). These efforts would overlap initial Phase III activities. Additionally, several activities were either deferred until later in Phase III or eliminated completely. Overall, more than 24 percent of the tests or events planned for Phase IID will be completed after September 1993. These tests or events include

- testing of the concept demonstration engine (Mar. 1994),
- testing of large-scale active cooling panels (Feb. 1994), and
- completion of the fourth and final Phase IID design cycle (Feb. 1994).

These tests or events were once considered essential for demonstrating the Phase II exit criteria. For example, the concept demonstration engine test, which is to evaluate a subscale ramjet/scramjet engine at various speeds up to Mach 8, is considered essential to demonstrate the viability of the engine concept. Similarly, the large-scale active cooling panels will be tested under conditions that more accurately represent the X-30's expected flight environment, whereas earlier tests of smaller-scale panels are to be tested under less rigorous conditions. The goal of the fourth design cycle is to produce and document an X-30 design that meets the Phase II exit criteria and is sufficiently detailed to enter Phase III.

In February 1992, the Office of the Secretary of Defense's Director of Defense Research and Engineering tasked the Defense Science Board, in part, to determine (1) if the current Phase II exit criteria were adequate and (2) whether the planned Phase II technical efforts would satisfy the criteria or provide sufficient information to justify a decision to proceed to Phase III. Although the Board was expected to report its findings in June 1992, its report had not been released by the completion of our review.

Status of Development of NASP Technologies

Using the 38 interim program milestones as a measure, the Team has made some progress in meeting the exit criteria. At least one milestone from each of the four criteria and 9 of the 13 milestones that were to be finished by June 1992 under the Phase IID baseline schedule have been completed. These milestones include documenting design work accomplished prior to the January 1991 teaming agreement, preparing initial vehicle and propulsion system design concepts, selecting materials for the airframe and engine, demonstrating the capability to produce slush hydrogen, and preparing plans for software development and vehicle flight control. According to program officials, the remaining four milestones, which were to be completed by June 1992, have been delayed due to technical problems or budget constraints. These four milestones involve engine material characterization, certain propulsion system performance requirements, and the fabrication of small panels.

X-30 Vehicle Design

During Phase IID, the X-30's initial conceptual design is intended to be refined in four design cycles. At the end of the fourth cycle, the goal is to produce and document an X-30 design that meets the Phase II exit criteria and is sufficiently detailed to enter Phase III. A considerable amount of additional design work is planned in Phase III. For example, in January 1992, prior to the current proposal to restructure the program, the NASP Joint Program Office estimated that the X-30's preliminary design review, a key development milestone, would occur in 1997. The purpose of the review is to assess the technical adequacy of the selected design approach and its ability to meet the X-30's performance requirements.

The National Contractor Team has continued to refine its initial design proposal for the X-30, in part due to the need to address concerns about the X-30's projected gross takeoff weight. The vehicle's weight is an important design parameter, since it plays a key role in determining whether the X-30 can achieve SSTO. To measure its progress in meeting the exit criteria, the Team establishes weight goals for each design cycle and tracks the vehicle's projected weight against those goals. Potential problems with the X-30's projected gross takeoff weight emerged in April 1991 at the conclusion of the first design cycle. At that time, the National Contractor Team established an initial conceptual design for the X-30 and projected that the vehicle's gross takeoff weight would be close to satisfying the exit criteria. However, the Team cautioned that its projection did not include any allowance for design and safety changes, performance uncertainties, or increases in weight. Consequently, some uncertainty existed as to whether the projected weight could be achieved.

By a November 1991 review to complete the second design cycle, concerns had heightened over increases in the projected gross takeoff weight. To achieve its weight goal for this cycle, the National Contractor Team froze the vehicle's size and gross takeoff weight, and consequently reduced its projection of the amount of fuel the X-30 could hold. However, if the X-30 were built according to this design, the vehicle would not contain sufficient fuel to achieve SSTO. Program officials estimated that if the size of the X-30 were increased to carry sufficient fuel to achieve SSTO, the vehicle would weigh at least 550,000 pounds—more than 50 percent heavier than the National Contractor Team's goal and more than 25 percent heavier than the exit criterion's maximum weight of 425,000 pounds.

In April 1992, a National Contractor Team design review team recommended numerous changes to the X-30's aerodynamic, propulsion, and structural design. These recommendations included

- refining the vehicle's external shape,
- changing the shape of the fuel tank, and
- incorporating changes to the engine flowpath.

The vehicle's weight problem may not be resolved by these changes. Program officials estimate the X-30's gross takeoff weight could vary from 320,000 to 490,000 pounds after the proposed changes are incorporated. If the X-30's weight were at the upper end of this range, an X-30 based on the April 1992 design would be unable to achieve SSTO without scaling-up the vehicle's size. According to program officials, the National Contractor Team was to complete a detailed assessment of the impact of the proposed changes on the X-30's overall design and projected performance in November 1992. Program officials noted that variations in vehicle weight in research and development programs, such as the NASP Program, are typical and are to be expected.

Propulsion System Performance

Developing a propulsion system that provides sufficient thrust and efficiency has been considered the primary challenge in achieving SSTO. The X-30's integrated engine is to operate in three modes—low speed (from takeoff to Mach 3), ramjet (Mach 3 to 6), and scramjet (Mach 6 to 16)—and use rocket propulsion to achieve orbit. To reduce drag at low speeds, the X-30 is expected to externally burn hydrogen under its aft end. Through June 1992, initial scramjet and external burning tests have generally been successful, but performance of the initial ramjet and low-speed systems have not met expectations. In addition, only a limited amount of work has been conducted on the use of rocket propulsion in the X-30, since rocket technology is well known. Additional testing is still needed to determine the extent to which external burning will reduce the X-30's drag.

According to program officials, tests of subscale engines and components have demonstrated scramjet efficiencies between 80 and 95 percent of expected performance at Mach 8. While the test articles did not reflect the revised scramjet design recently proposed by the National Contractor Team, program officials believe these tests show satisfactory progress in developing a scramjet engine that will meet program requirements. Initial tests of the revised scramjet design are scheduled to be initiated in early 1993.

Testing of the National Contractor Team's initial ramjet design proved less successful. Analysis of the proposed ramjet design conducted in mid-1991 revealed that this initial design would not allow a sufficient amount of fuel to be injected into the combustor, which would prevent the X-30 from accelerating past Mach 3. A Team report indicated that the cause of the problem was the failure of the Contractor Team members to communicate information on airflow and fuel requirements independently developed before the joint Team was established.

The National Contractor Team established a special review team in September 1991 to identify changes needed in the propulsion system design to correct the ramjet performance problem. In April 1992, this team recommended numerous design changes to the inlet, combustor, and nozzle to improve thrust and airflow stability. Program officials believe that the proposed changes should resolve the ramjet problem without adversely affecting scramjet performance. The team is addressing how the proposed changes will affect specific propulsion system components by incorporating these changes into several test articles to demonstrate that they will have the desired effect. Program officials told us the first test of the revised ramjet combustor design was scheduled to be completed in November 1992. Additional tests of other design changes will continue through 1993.

According to initial results of tests completed in February 1992, the low-speed system's performance is also below requirements. For example, under test conditions between Mach 0 and 1.7, the low-speed system's thrust was 16 percent below requirements, while at test conditions of

Mach 2.7, the system produced thrust at 4 percent below requirements. The National Contractor Team and Joint Program Office are still analyzing the test results to understand what caused this lower performance and how it will affect the vehicle's projected performance. As of June 1992, program officials had not yet determined what changes would be needed to the low-speed system. Program officials said shortfalls in engine performance are not unusual at this early stage in a development program. They indicated that engine design in any development program is an iterative process and that repeat testing is not unusual.

External burning—which consists of igniting hydrogen under the X-30's aft end—has been incorporated into the X-30's conceptual design to reduce the drag created by the X-30's nozzle at lower speeds. Program officials estimated that by using external burning, the gross takeoff weight of the X-30 has been reduced by 16 to 20 percent. Without external burning, the Team would have to make further design changes that could increase the X-30's weight, such as incorporating a more powerful low-speed system or additional rockets, to overcome the drag.

Testing has shown that external burning could reduce drag. However, these tests were conducted using the contractor's pre-teaming designs, generic models that were not representative of the X-30's design, or small-scale models. According to a program official, the extent to which external burning actually reduces the X-30's base drag will not be determined until additional testing is completed in early 1994.

Due to higher priorities and a large preexisting base of information, only a limited amount of work in Phase IID is being devoted to evaluating how rocket technology will be incorporated into the X-30. The work accomplished thus far largely consists of evaluating whether to use or modify an existing rocket or develop a new rocket and to determine how to integrate the rockets on the X-30.

Materials Development

To be capable of SSTO flight, vehicle materials must be lightweight and resistant to the stress and heat generated by hypersonic flight. The NASP Program intended to develop a variety of more advanced materials to minimize vehicle weight and still meet other technical requirements. However, the development of some of these advanced materials was discontinued to concentrate on nearer-term options. Program officials explained that the decision to concentrate on these options was in part due to a 1991 plan to begin building the X-30 experimental vehicle in

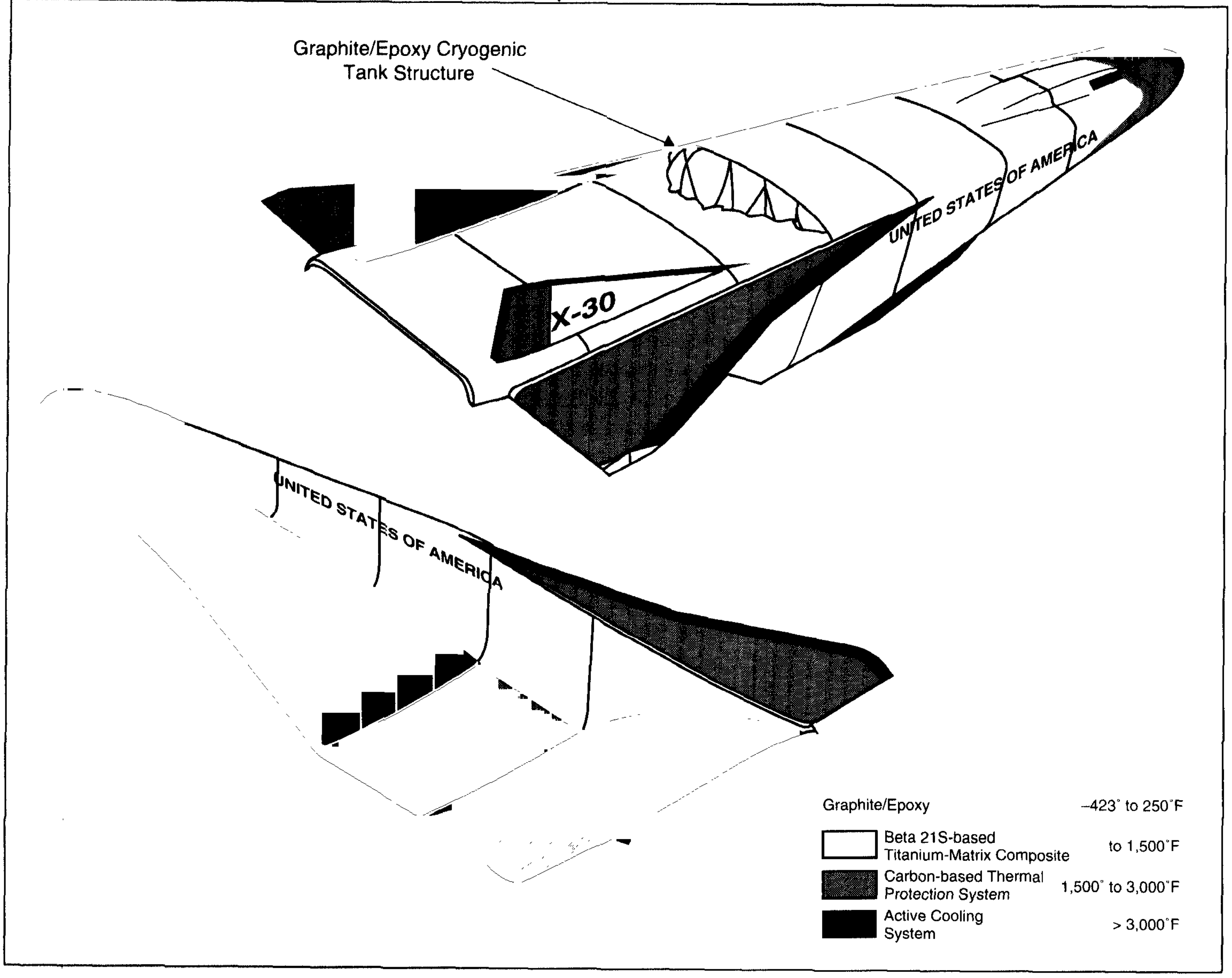
April 1993, which did not allow sufficient time to develop all of the more advanced materials.

Developing suitable materials for the X-30 involves two separate but related activities: characterization and structural testing. Characterization consists of documenting the strength of the basic properties of potential airframe and engine materials, the materials' behavior under various temperatures and pressure levels, and the materials' resistance to hydrogen and oxygen. Characterization is determined almost entirely by using small-sized samples of materials. Structural testing is designed to assess whether the materials' properties are properly utilized in the design, ensure that the materials can be reliably fabricated into usable components, and verify structural integrity. Structural testing involves the application of known loads to representative structures that are sized or scaled to provide the required data at a reasonable cost. Development and structural testing of advanced materials has shown mixed progress. As of June 1992, identifying and testing of potential airframe materials had outpaced similar efforts for engine materials.

Airframe Materials

In March 1991, the airframe's baseline materials were selected based on work completed prior to the establishment of the National Contractor Team. As shown in figure 2.1, the materials used will depend on the temperature that the X-30 is expected to encounter.

Figure 2.1: Selection of Airframe Materials Based on Temperature



Source: Joint Program Office.

A titanium-matrix composite, based on Beta 21S (a titanium alloy that is also known as Timetal 21S), is expected to comprise about 50 percent of the X-30's empty weight, which excludes, for example, fuel, subsystems, and payload. This composite material will be used in areas where temperatures are not expected to exceed 1,500 degrees Fahrenheit. In areas with higher temperatures, either a carbon-based thermal protection layer or an active cooling system will be needed to protect the airframe.

Program officials were confident that components could be manufactured from these materials, although only 8 percent of the key structural tests or events had been completed as of June 1992. Program officials noted that prior to Phase IID, contractors had fabricated components from Beta 21S as well as materials not currently selected for use on the X-30. Officials told us that the properties of closely-related, non-baseline materials can be indicative of predicted structural behavior of baseline materials. They said the previous work confirmed the feasibility of using titanium metal matrix composites in the vehicle's structural design.

Program officials also noted that a large-scale model of the X-30's cryogenic[1] fuel tank, a major component, was fabricated from its baseline material. A 900-gallon insulation-wrapped, multibubble graphite-epoxy cryogenic fuel tank was inserted inside a fuselage structure made of a titanium matrix composite for testing. In 1991, this tank successfully met test objectives by containing liquid hydrogen at a temperature of –423 degrees Fahrenheit while subjected to thermal and mechanical loads testing, including external heat of 1,300 degrees Fahrenheit (simulating Mach 16 loads). Program officials consider the test a significant accomplishment.

Engine Materials

Engine materials currently include cobalt and copper alloys and MolyRhenium, a molybdenum and rhenium compound. Progress in developing and fabricating these materials has been delayed due to concerns whether MolyRhenium can withstand the rigors of the X-30's engine environment. Officials told us that a decision was made in July 1992 to evaluate a new process to protect the material from oxidizing. Initial tests using small laboratory samples are under way, but more rigorous testing needed to assess the suitability of the material is not expected to be completed until late 1992.

As of June 1992, testing of engine structures has been limited, due in part to the reassessment. For example, most completed tests on engine materials were conducted on small samples measuring 1 inch by 4 inches or smaller. Fabrication and testing of small-scale panels that will provide basic information on manufacturability and coating development are just

[1]Operating at extremely low temperatures.

being initiated. Fabrication of large-scale panels (measuring 20 by 20 inches) has been delayed until a decision is made on whether to replace MolyRhenium as an engine baseline material. Program officials told us the large-scale panels are necessary to more fully evaluate the ability to manufacture usable components from these materials and to demonstrate that the materials can withstand the extreme environment that is expected in the X-30's propulsion system.

A materials and structures review committee, established by the Director of Defense Research and Engineering at the request of the Joint Program Office, expressed concerns over the rate of progress in developing suitable engine materials. This committee noted in February 1992 that engine material development posed a significant risk to satisfying Phase II exit criteria and in achieving the X-30's performance goals, including SSTO flight. The committee recommended that additional emphasis be placed on developing and testing engine materials.

Slush Hydrogen Characterization

Considerable progress has been made in characterizing slush hydrogen, which is being evaluated for use as both a fuel and coolant for the X-30. Test results indicate that the requirement to routinely produce slush hydrogen at the required consistency is feasible. Additional tests are scheduled to begin in fiscal year 1993 to evaluate the handling and maintenance aspects of using slush hydrogen.

In the current design, the X-30 will use slush hydrogen for fuel, since slush hydrogen is denser than liquid hydrogen. Consequently, more fuel, and thus more energy, can be carried in the X-30's fuel tank. The goal is to produce slush hydrogen at a consistency of 55-percent frozen hydrogen and 45-percent liquid hydrogen.

Tests conducted by NASP Program researchers in 1990 and 1991 demonstrated the feasibility of producing slush hydrogen at the required consistency. In 1990, researchers produced 40 test batches, of which 17 exceeded the goal of 55-percent frozen hydrogen. Program officials noted that many of the early tests did not achieve the desired results, since the production processes were still evolving. Subsequent tests conducted in 1991 showed significant improvements in production capability. For example, 73 of the 75 tests conducted in 1991 met or exceeded the goal of 55 percent, and 41 of the 75 tests met or exceeded 60 percent.

Program officials stated that budget constraints have led the Joint Program Office to defer many activities concerned with slush hydrogen until at least fiscal year 1993. The purpose of this deferred work is to provide additional data on handling and maintenance issues, such as transferring and recirculating slush hydrogen between the production facility and fuel tanks. Phase III will also include work to develop and test the subsystems and components that will control the flow of slush hydrogen within the X-30 and to determine the facilities, equipment, and procedures required once construction and testing of the X-30 begins.

Conclusions

While some success can be reported in meeting each of the four Phase II exit criteria, insufficient information is available to demonstrate that the exit criteria have been met. Problems concerning vehicle weight and the propulsion system's performance are among the technical issues that have not yet been resolved.

Schedule and technical risks remain. While the National Contractor Team has proposed numerous changes to the vehicle and propulsion system design to improve performance, these changes have not been verified by testing. Several key tests that were considered essential for satisfying Phase II exit criteria are not scheduled to be completed until after the planned decision in September 1993 to proceed with Phase III. If further schedule delays are encountered, whether due to budgetary constraints or additional technical problems, then less information than originally planned will be available to decisionmakers. Consequently, committing to Phase III in September 1993 would involve greater technical risk than previously anticipated and would be premature.

NASP Program Costs and Schedules Are Uncertain

As of November 1992, the NASP Program's cost[1] and long-term schedule were not known. Most significantly, the objectives and time frames for Phase III—when the X-30 is supposed to be built and tested—are uncertain, and no official cost estimates have been developed. However, initial contractor estimates reported in January 1992 indicated that the baseline program—consisting of building and testing two SSTO-capable X-30 vehicles—could have cost as much as $17 billion, or more than five times the $3.1 billion estimated in 1986.[2]

In 1992, because of concerns about the baseline program's affordability and technical risk, the Joint Program Office developed various options that ranged from completing the baseline program to making fundamental changes that could, in effect, limit efforts to basic research on the propulsion system and indefinitely defer a decision to build the X-30. As of November 1992, no decision had been made on which, if any, of these options would be pursued. Consequently, it is uncertain whether the X-30 as currently envisioned will be built, if it will be expected to achieve SSTO, when key program milestones are expected to be achieved, or how much the program will cost.

An underlying factor in the decision to explore alternative programs was a concern that the baseline program was no longer affordable. Balancing increasing costs with projected funding will play an increasingly significant role in determining the scope and pace of the NASP Program. DOD funding constraints and increasing demands on NASA's budget will require the NASP Program to compete with other DOD and NASA programs.

Projected NASP Program Costs Exceed Initial Estimates and Remain Uncertain

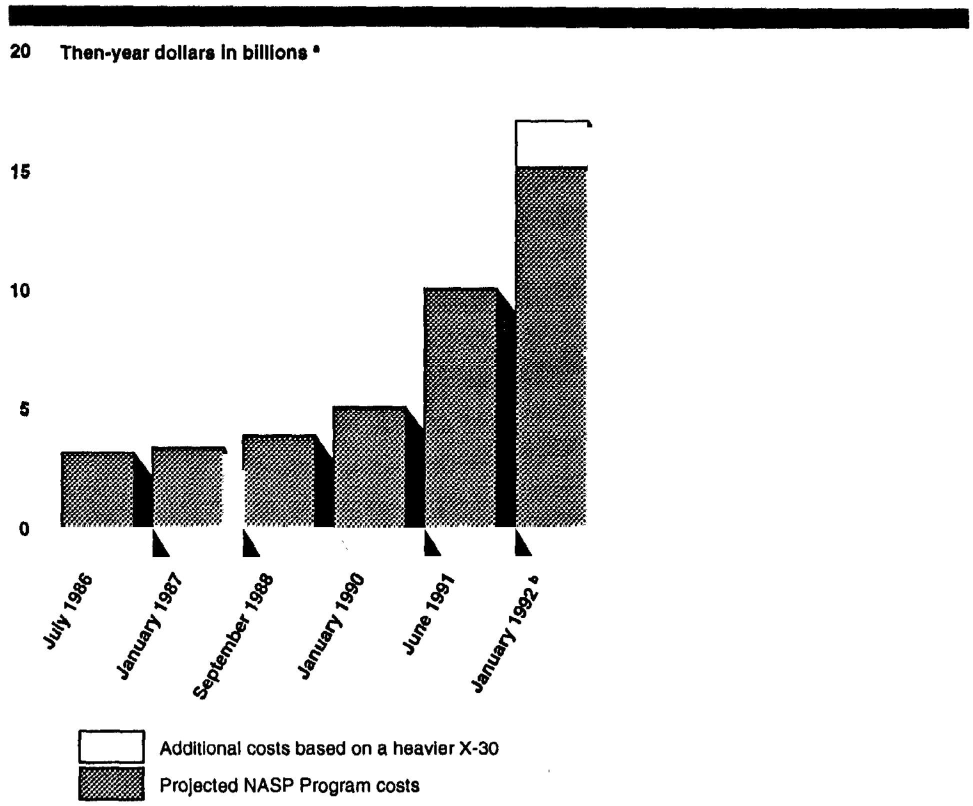
Due to uncertainty regarding the program's objectives and schedule, no current official estimate of the program's cost has been developed. However, preliminary contractor estimates indicate that if the baseline program were completed, program costs could have reached $17 billion—more than five times the $3.1 billion estimated in 1986. Program officials attribute this increase to previous unrealistic assumptions about the weight and complexity of the X-30 and to schedule delays caused by reduced funding and technical concerns.

[1]Total program costs include those incurred to develop and test the necessary technologies and to design, manufacture, and flight test the X-30.

[2]These figures are reported in then-year dollars, which reflect the total funds required to procure goods or services at the time expenditures are made. When calculated in constant 1992 dollars to exclude the effects of inflation, projected program costs would have increased by more than four times from about $3.3 billion to about $14.5 billion.

As shown in figure 3.1, between 1986 and 1992, projected costs of the baseline program consisting of two SSTO-capable vehicles increased significantly.

Figure 3.1: Changes in Projected National Aero-Space Plane Program Costs, 1986 to 1992



[a]Detailed expenditure rates are not available for some of these estimates. Therefore, we have not calculated these estimates in constant dollars.

[b]The January 1992 estimate ranged from $15.1 billion to $17 billion, depending on the X-30's weight.

Source: NASP Joint Program Office.

In July 1986, NASA and DOD reported that the NASP Program would cost about $3.1 billion between fiscal years 1986 and 1993. In 1991, the Acting Under Secretary of Defense for Acquisition reported to the Congress that projected costs could be on the order of $10 billion. Using preliminary estimates from the National Contractor Team, the Joint Program Office reported in January 1992 that completing the baseline program would cost from $13.2 billion to $15.1 billion, depending on the X-30's weight. Since these costs would be in addition to the $1.9 billion that was expected to be incurred in Phase II, the estimated cost of the baseline program could have reached $17 billion.

Joint Program Office representatives told us the earlier estimates were not supported by a detailed cost analysis and were based on unrealistic assumptions regarding the availability of advanced technology and the potential size and complexity of the X-30 vehicle. For example, DOD officials stated that the $3.1 billion figure represented the cost to design, build, and test a 50,000 pound vehicle—a weight that is about one-seventh of the X-30's current weight goal. Similarly, they noted that in 1986, the program's schedule called for completing the development, construction, and flight-testing of the X-30 in 7 years. Under the current schedule, Phase III would start—not conclude—at about the 7-year point. Program officials estimated that under some of the options proposed in January 1992, the program could be extended until 2006, or about 20 years after it was initiated.

Although the Joint Program Office had initiated efforts to prepare an official, detailed estimate of the costs to complete the baseline program, program officials discontinued work on this estimate in mid-1992 after receiving direction to evaluate the cost of alternative programs.

NASP Program Schedule Delays and Uncertainties Continue

The NASP Program's schedule has slipped significantly since 1986 and continues to change as the Joint Program Office adjusts to near-term budget constraints and concerns about affordability and technical risk. As of November 1992, no current official schedule existed due to the absence of guidance on the program's technical objectives. The Joint Program Office proposed in August 1992 to make fundamental changes that could indefinitely defer a decision to build and test the X-30.

Phase II Extended to 1994 to Address Near-Term Budget Constraints

The Joint Program Office has extended Phase II efforts until 1994, or about 5 years later than anticipated under the program's 1986 schedule. In 1986, the program's schedule called for completing Phase II in 1989. However, technical problems, budgetary constraints, and programmatic changes, including the decision by the National Space Council in July 1989 to extend Phase II by about 2-1/2 years until early 1993, added about 4 years to the program's schedule. In 1991, the Joint Program Office anticipated that Phase IID technical efforts would be completed in June 1993.

In March 1992, the Joint Program Office restructured Phase IID and further extended the effort to March 1994 (although some Phase IID technical efforts will not be completed until September 1994). According to program officials, this action was taken primarily to reflect fiscal year 1992 and 1993 funding levels, which were anticipated to be about $147 million (24 percent) less than were expected when the Phase IID program began in early 1991. At that time, the Joint Program Office projected that combined DOD and NASA funding for the NASP Program would be about $304 million in fiscal year 1992 and $303 million in fiscal year 1993. However, the Congress reduced the NASP Program's fiscal year 1992 budget to $205 million partly because of declining DOD and NASA budgets, the need to fund other higher priority programs, and the inability of DOD to quantify the costs and benefits of a NASP-derived operational vehicle. Similarly, the President's fiscal year 1993 budget requested only $255.5 million, or about $48 million less than previously projected. Most of this reduction resulted from NASA's reduction of $40 million in its fiscal year 1993 budget request.

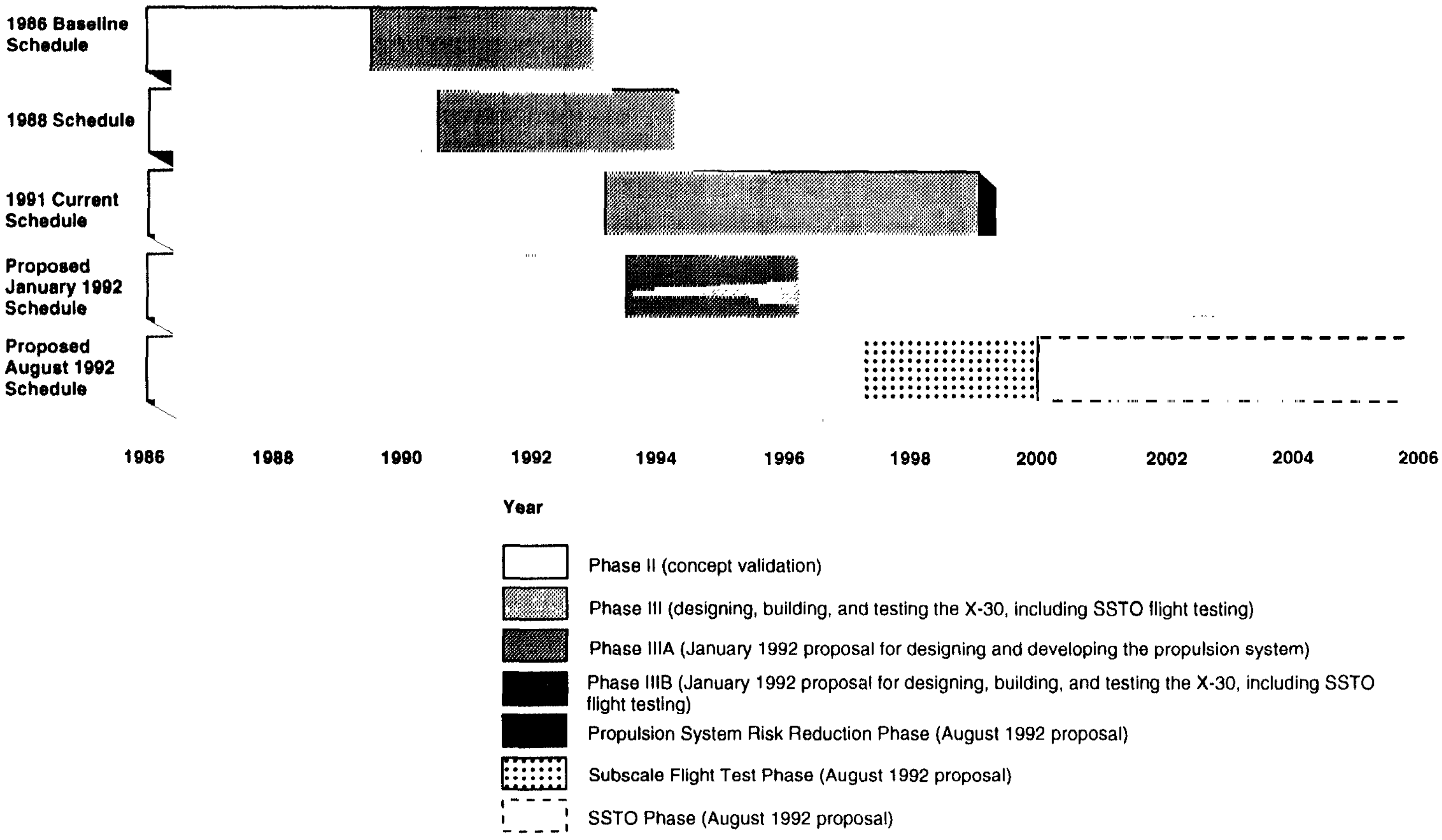
In October 1992, the Congress reduced the NASP Program's fiscal year 1993 budget to $150 million for DOD and denied all NASA funding for the program.[3] Thus, while program funding was expected to be $607 million for the 2 fiscal years, actual funding totaled $355 million. In anticipation of this funding cut, the Joint Program Office had initiated efforts to further revise the Phase IID program. According to program officials, these actions would also enable the program to focus the remaining Phase IID efforts on developing and testing the propulsion system.

Phase III Objectives and Time Frames Uncertain Due to Technical and Affordability Concerns

The objectives and time frames for Phase III—when the X-30 was to be built and tested—are uncertain. Since 1991, the Joint Program Office has proposed three general long-term development strategies to address concerns over the baseline program's affordability and technical risk. These strategies, which are shown in figure 3.2 in comparison to previous schedules, include options ranging from completing the baseline program to making fundamental changes that could, in effect, limit efforts to basic research on the propulsion system and indefinitely defer a decision to build the X-30. As of November 1992, no decision had been made on which, if any, of these options would be pursued.

[3]This reduction resulted in fiscal year 1992 and 1993 funding that is about 42 percent less than was expected in early 1991.

Figure 3.2: Comparison of National Aero-Space Plane Program Schedules and Options



Source: NASP Joint Program Office.

Under the 1986 schedule, Phase III was to begin in 1989, with flight-testing of the X-30 beginning in 1993. However, as the Phase II efforts were delayed, the Phase III milestones were also rescheduled. The Joint Program Office estimated in 1991 that a decision to proceed with Phase III would be made in April 1993. Once approved, the National Contractor Team would begin concurrent development and fabrication of both the X-30's engine and airframe. Under the 1991 schedule, the X-30's first flight would be in 1997, and its first SSTO flight would be in 1999.

Joint Program Office representatives told us that at an August 1991 technical review, Air Force and NASA officials expressed concern about the Phase III strategy as then planned. Program officials told us the Air Force and NASA officials questioned whether sufficient funding would be available to carry out this strategy, for which the estimated annual funding requirements between fiscal years 1994 and 1996 could exceed $1 billion.

Modified Phase III Strategy Proposed

In January 1992, the Joint Program Office proposed to the Steering Group a modified Phase III strategy that would eliminate the concurrency inherent in the previous strategy and significantly reduce near-term funding requirements. Under this proposal, the Phase III decision would be delayed 5 months until September 1993, which was subsequently reflected in the President's fiscal year 1993 budget request. Initial Phase IIIA (1993 to 1996) efforts would focus on designing and developing the X-30's propulsion system. Program officials estimated that annual funding requirements between fiscal years 1994 and 1996 would be reduced to less than $600 million. As part of this modified strategy, a second decision, tentatively scheduled for 1996, would be needed to proceed into Phase IIIB, which would involve designing, building, and flight-testing the X-30.

As indicated by table 3.1, program officials proposed several Phase IIIB options, which differed in the capability and size of the X-30 test vehicles and overall cost. Program officials estimated that under these options, the X-30's first flight would be by 2000 and its first SSTO flight would be by 2002.

Table 3.1: Alternative Program Options Presented in January 1992 to the NASP Steering Group

Then-year dollars in billions

Option	Number of vehicles	Size of vehicle	Conduct SSTO flight test?	First flight test date	First SSTO flight date	Projected cost
Baseline	2	Full scale	Yes	2000	2003	$13.2 - 15.1[a]
1	1	Full scale	Yes	2000	2002	12.5
2	1	Full scale	No	1999	[b]	10.3
3	1	Subscale	No	1999	[b]	8.5

[a]The variation in the projected cost for the baseline program is due to differences in the projected weight of the vehicles.

[b]Not applicable.

According to program officials, these options were prepared at a conceptual level, and additional changes were likely as the options were more fully developed. For example, they said in April 1992 that the flight test milestones shown in table 3.1 could be delayed until 2004 and 2006, respectively.

Although the Joint Program Office presented these options to the Steering Group in January 1992, as of November 1992, the Steering Group had made no decision on which, if any, of these options would be accepted. In the meantime, Air Force officials tasked the Joint Program Office to develop an alternative program that could be carried out at significantly reduced funding levels.

August 1992 Proposal Refocuses Program on Propulsion System Research and Development

In response to the Air Force tasking, the Joint Program Office proposed to Air Force and NASA officials in August 1992 significant changes to the NASP Program that would stretch the overall schedule, refocus short-term efforts largely toward propulsion system research and development, and potentially eliminate the X-30 experimental vehicle. Program officials told us this proposal would continue the program at the reduced funding levels and address some of the technical concerns expressed by Defense Science Board members toward the conclusion of their review in July 1992.

This proposal calls for both a near-term effort to reduce the risk associated with the propulsion system and a long-term development strategy to demonstrate SSTO capabilities. Near-term efforts to develop the propulsion system would continue, but work in other areas, such as materials and slush hydrogen, would be limited. As part of this strategy, a subscale vehicle flight test phase would be tentatively scheduled to begin in fiscal year 1998. Among the objectives of this phase would be to demonstrate scramjet operation in flight at high Mach numbers and further develop the conceptual design of an SSTO-capable vehicle. Designing, building, and flight testing an SSTO vehicle would not begin until fiscal year 2001. Program officials said a decision to build and test the X-30 as previously planned could be deferred indefinitely. Moreover, they told us that a vehicle built under this proposal could be considerably different from the current X-30 design.

According to program officials, the August 1992 proposal would allow the program to continue at the funding levels projected by Air Force officials. Program officials indicated that total funding for the near-term effort would be about $918 million, with funding between fiscal years 1994 and 1996 limited to about $618 million. In comparison, the Joint Program

Office's 1991 development strategy could have required $3 billion or more between fiscal years 1994 and 1996, while the January 1992 proposals required about $1.4 billion during this period. Program officials indicated that their August 1992 proposal would allocate approximately 90 percent of the required funding toward developing the propulsion system.

Program officials indicated that, in addition to responding to the reduced funding levels, their proposal would alleviate the technical concerns expressed by members of the Defense Science Board in July 1992 at the conclusion of their technical assessment of the program. While the Board's report has not been released, program officials told us Board members expressed concern that the concurrency of development of the engine and airframe in the Joint Program Office's previous strategy posed too great a technical risk. Board members concluded that the scramjet engine needed more development and testing before DOD and NASA committed to build a vehicle. Some options that have been proposed include flight-testing a scramjet engine using a booster rocket or building a subscale, unmanned test vehicle.

November 1992 Proposal Eliminates X-30 and Focuses on Non-SSTO Vehicle

In November 1992, the Joint Program Office developed yet another proposal. While details of this latest strategy were not available, it would eliminate the X-30 vehicle as currently envisioned and focus on the development and flight testing of an unmanned, subscale, non-SSTO vehicle referred to as the X-30X. This approach would call for conducting flight test experiments with Minuteman II rocket boosters. It would provide for integrating the technologies in a subscale demonstrator vehicle that would lead directly to separate future operational NDV programs without first demonstrating SSTO capability.

Questionable Availability of Adequate DOD and NASA Funding Is Contributing to Program Uncertainties

The ability and willingness of DOD and NASA to meet the NASP Program's future funding requirements will play a significant role in determining the scope and pace of the NASP Program and in developing an achievable and realistic schedule. As exemplified by the direction to develop options to continue the program under significantly reduced funding levels, the availability of such funding is not ensured. Both agencies face increasing budget demands that may result in further schedule delays.

Competition among programs for DOD funding is likely to increase as DOD adjusts to a changing threat environment. The Secretary of Defense reported in February 1992 that while projected DOD funding will increase from $267.8 billion in fiscal year 1994 to about $270.4 billion in fiscal year 1996, this change represents a decrease of over 6 percent when expressed in constant dollars. Our analysis of DOD's future budget requests indicates that even greater real declines are expected in both the Air Force's overall budget and in its research and development budget.

Similarly, while NASA has reported that it intends to provide $445 million between fiscal years 1994 and 1996, its ability to meet this commitment is questionable. We reported in March 1992 that NASA's preliminary projected funding requirements through fiscal year 1996 were likely to exceed available funding by about $13 billion to about $21 billion.[4] During this period, NASA funding is also required to continue programs such as the space shuttle, the space station, and the National Launch System.[5] The elimination of NASA's fiscal year 1993 funding for the NASP Program indicates the seriousness of the funding problem.

Conclusions

Completing the baseline NASP Program would have been significantly more expensive and taken far more time to complete than projected in 1986. No official cost estimate has been prepared, but the contractor's initial cost estimate of $17 billion represents a five-fold increase from the 1986 estimate. Similarly, under some schedules, key milestones such as the first flight could have been delayed up to 11 years.

How much the NASP Program will ultimately cost and when it will demonstrate its goal to achieve SSTO are uncertain. The Joint Program Office has proposed various options that range from continuing the baseline program to making fundamental changes that could, in effect, restructure the program largely into a propulsion system research and development effort and indefinitely defer a decision to build the X-30. The lack of direction and guidance on how to resolve concerns over the affordability and technical risk inherent in the baseline program is the primary contributor to the uncertainty of the program's objectives and schedule.

[4] NASA Budget: Potential Shortfalls in Funding NASA's 5-Year Plan (GAO/T-NSIAD-92-18, Mar. 17, 1992).

[5] In October 1992, the Congress directed the Air Force to halt work on its portion of the National Launch System. The Air Force requested $125 million for fiscal year 1993, but the Congress provided the Air Force with $10 million to shut down its portion of the program. For its work on the National Launch System, NASA requested $125 million for fiscal year 1993, but the Congress appropriated only $10 million.

Potential Applications of NASP-Derived Vehicles and Spin-Off Technologies

As a research and technology development program, the NASP Program is intended to be unconstrained by operational requirements. However, given the magnitude and cost of this effort, discussions about the utility or cost/benefit of the NASP Program have prematurely evolved into efforts to justify the program through potential benefits from future operational aerospace vehicles and spin-off applications.

Even if the X-30 experimental vehicle is built and successfully demonstrates SSTO and hypersonic flight, follow-on programs would still be necessary to develop mission-specific operational vehicles. The primary use of first-generation NASP-derived vehicles would probably be space launch—a capability that NASP Program proponents believe would provide more flexible and less costly access to space. However, the NASP Program and potential follow-on programs must compete with other existing and planned space launch systems for limited federal funding.

Since operational vehicles derived from the NASP Program are decades away, in justifying the current program, DOD and NASA officials have emphasized near-term benefits they expect to achieve through the transfer of NASP-developed technologies to industry and other government organizations. Efforts to gain spin-off benefits are focused on a technology transfer program. While benefits are expected, it is still too early to expect evidence of large-scale tangible benefits from this effort. Furthermore, projections of future economic benefits that have been reported to the Congress and other program decisionmakers are based on overly optimistic assumptions.

Potential Mission Applications for NASP-Derived Vehicles

NASA and DOD have identified a need for a space transportation system that provides routine, reliable access to space at lower costs than current systems. However, if built, the X-30 would not be designed to perform specific operational missions or meet user requirements. Follow-on programs would be necessary to develop operational vehicles to address specific operational requirements. Potential users of NDVs—the U.S. Air Force Space Command, Air Combat Command,[1] and NASA—as well as NASP Program officials believe first-generation vehicles would be used primarily for space launch.

Some Air Force officials believe commercial use of space launch NDVS might be economically beneficial in the long term. However, government

[1]As of June 1, 1992, the newly formed Air Combat Command took over NASP- related activities formerly performed by the Strategic Air Command, which was dissolved.

users would first have to prove them reliable and cost-effective. Additionally, according to NASP Program officials and aerospace industry representatives, flight at hypersonic speeds is not considered economically viable or practical for a first-generation U.S. high-speed civil transport aircraft. These officials and representatives believe that a follow-on supersonic transport to the Concorde is a more likely alternative.

Military and Civil Uses

Air Force and NASA officials indicated that the need for a space transportation system that provides routine, reliable, and lower-cost access to space could potentially be fulfilled in the long term by NDVs. They believe that a totally reusable, air-breathing, SSTO space launch vehicle with airplane rather than rocket-like characteristics could eventually reduce space launch costs by decreasing the expensive manpower and facility requirements that are necessary for launching and controlling rocket-booster systems. NASA officials also noted that another consideration is the potential flexibility provided by NDVs for such capabilities as wide launch windows and launch on demand. However, the potential value of NDVs will have to be weighed against the ability of existing and future alternatives to meet national space transportation needs at the time. Even though a diversified space launch capability is a major goal of U.S. space policy, both DOD and NASA face increasing demands on their budgets. Thus, the NASP Program and follow-on NDV programs would have to compete with these other systems for funding in both agencies.

Even if the X-30 successfully demonstrates SSTO capability and hypersonic flight, NDVs would require design changes to incorporate operational capabilities, such as payload capacity and the upgrading of avionics, electronics, and materials. Officials from the Joint Program Office, Air Force Space Command, Air Combat Command, and NASA agree that first-generation NDVs would be used primarily for space launch or missions conducted in orbit. As currently envisioned, DOD and NASA officials believe NDVs could provide routine access to space for a variety of missions, including (1) space launches for small- and medium-size payloads; (2) support, repair, and/or retrieval of satellites and other space assets in orbit; (3) crew exchanges for manned space stations; (4) emergency responses for manned space station or space vehicle missions; and (5) limited-duration missions similar to scientific missions currently performed by space shuttle crews.

However, several planned space transportation systems, including the National Launch System[2] and the Strategic Defense Initiative Organization's Single-Stage Rocket Technology vehicle,[3] could perform some of the same missions as NDVs. According to NASP Program officials, existing space transportation systems, such as the space shuttle and expendable launch vehicles, will be obsolete before NDVs become operational. While NDVs are not expected to be operational until well into the 21st century, the space shuttle and expendable launch vehicles are currently operational, and the National Launch System is projected to be operational by early in the 21st century. Also, since NDVs are expected to launch only medium-weight payloads (20,000 pounds) into low earth orbit, vehicles with heavy-lift capability (40,000 to 50,000 pounds) would still be required.

In addition to potential space launch and missions conducted in orbit, the Air Force has also identified requirements for a manned military aerospace vehicle for space defense and other classified missions. These requirements were documented in 1979 and 1984 statements of operational need that pre-date the NASP Program. Although they are currently being reviewed by both the Air Force and DOD's Joint Requirements Oversight Council, as of November 1992, these statements were still being revalidated as formal requirements. Until these needs are formally approved by DOD, they are not considered a validated DOD requirement. According to Air Force officials, a military aerospace vehicle with hypersonic cruise capabilities could also have military applications by providing rapid global response. However, since the X-30 is not being designed to demonstrate sustained hypersonic cruise capability, additional development would be needed before building a vehicle with that capability.

Commercial Uses

At present, aerospace companies' interest in using NDVs appears to be limited. It is envisioned that eventually the commercial space launch and aircraft transport companies might own and operate NDVs in commercial ventures. However, Air Force officials believe NDVs would not be used commercially until their capabilities have been tested, demonstrated, and proven reliable by DOD and NASA. According to commercial launch officials, funding allocated for the NASP Program might be better applied to more near-term launch vehicles like expendable launch vehicles and the

[2]The National Launch System has been proposed as an acquisition program incorporating limited technology development for a near-term rocket booster system.

[3]Formerly called the Strategic Defense Initiative Organization's Single-Stage-to-Orbit vehicle.

National Launch System. They believe investments in projects with more near-term expected profit would assist U.S. companies in remaining competitive with the launch capabilities of foreign competitors, such as the European Arianespace and Russian Proton launch vehicles. Also, aerospace industry officials have noted that long-range hypersonic cruise transports do not appear economically viable in the near future. As a result, commercial use of NDVs might not occur until well into the 21st century.

Officials from Boeing Commercial Airplane Group and Douglas Aircraft Company told us their studies indicate that the significant economic, environmental, and technical challenges of a hypersonic vehicle would likely preclude earlier commercial use. For instance, hypersonic transports would have a very limited market because the time and distance necessary to achieve hypersonic speeds would make them attractive only for very long-range flights. Also, cryogenic fuels required by hypersonic aircraft would need special production and handling facilities. Both of these factors contribute to aerospace industry concerns that hypersonic vehicles may not be economically feasible for many years. Industry officials told us that supersonic aircraft that could fly at speeds between Mach 1.6 and 2.5 appear to offer the greatest potential for first-generation U.S. high-speed civil transports.

Potential Near-Term Benefits of NASP Technologies

NASP Program officials are attempting to transfer NASP-developed technologies to industry and other government organizations through a technology transfer program to provide more near-term benefits. These officials believe U.S. international competitiveness will be enhanced by transferring technologies developed or advanced in the NASP Program. While NASP research and development efforts are expected to have spin-off benefits, it is too early to expect evidence of large-scale benefits as a result of these efforts. Additionally, our analysis indicates that projections of future benefits that have been reported to the Congress and other NASP Program decisionmakers are based on overly optimistic assumptions.

Efforts to Transfer NASP-Developed Technology Initiated

Since 1980, the Congress has passed several laws aimed at promoting technology transfer from government-funded programs.[4] In April 1987, the President signed an executive order facilitating access to government-sponsored science and technology. Also, in 1988 and 1990,

[4]These laws include the Stevenson-Wydler Technology Innovation Act of 1980, the Bayh-Dole Act (1980), the Federal Technology Transfer Act of 1986, the Omnibus Trade and Competitiveness Act of 1988, and the National Competitiveness Technology Transfer Act of 1989.

respectively, DOD and the Air Force issued regulations to provide further direction in this area. Current Air Force regulations require all research, development, test, and engineering programs to include efforts to transfer unclassified technology from the Air Force to the commercial marketplace and other governmental organizations.

NASP Program officials consider technology transfer as the use of NASP-developed technologies for any purpose other than those directly related to building or flight-testing the X-30 experimental vehicle. For example, the technology may be directly applied to another aerospace program or adapted as a spin-off for different uses. The crucial aspect in a successful transfer is the actual use of the product or process. Without such use, full benefits are not achieved. However, it may be many years before information about a new technology results in a product or process.

In January 1991, the NASP Joint Program Office established the NASP Technology Transfer Program to expedite the transfer of NASP-developed technologies to industry and other governmental organizations. Projects undertaken as a part of this program include the following. First, program officials are working with and using established technology transfer programs, such as those of NASA and the Strategic Defense Initiative Organization. Second, program officials are sending surveys to companies, government organizations, and academic institutions associated with the NASP Program in an effort to identify cases where NASP-developed technologies have been transferred and areas where they might be able to satisfy an existing need. Third, program officials are developing and distributing NASP technology description instruments, such as computer data bases, technology description documents, and technical papers. Fourth, program official are establishing a network of individuals, communication links, and incentives for transferring technology. Finally, program officials are conducting public outreach and technology exposition programs to which both aerospace and non-aerospace industry representatives are invited.

Status of Technology Transfers

While NASP technologies have potential for many spin-off applications, as of November 1992, few tangible benefits had been directly attributed to the NASP Program. This is due in part to several factors that slow or inhibit the technology transfer process, such as the high cost of applying new technologies, industries' reluctance to share new and innovative technologies, and the current inapplicability of many of the technologies to the commercial sector. Also, developing, demonstrating, and disseminating new technologies and achieving and documenting transfer benefits will likely take more time than has yet passed.

According to program officials, only a few technology transfer cases have been completed. Beta 21S (a titanium-matrix composite) and AlBeMet (an improved aluminum-beryllium alloy) are examples of transfers currently used in a commercial product or process. Beta 21S is being used as a component in a proprietary chemical process and for several uses in the production of future Boeing commercial aircraft. AlBeMet is being used as the material for a computer disk drive actuator arm.

Some other cases cited by NASA and the Joint Program Office of transfers of technology from the NASP Program represent potential uses rather than actual transfers. For example, in response to a congressional request[5] for a study on the potential civil benefits that could result from the NASP research program, NASA reported that specific technology spin-offs had already begun to appear and that certain NASP materials could also be used in prosthetic devices for increased durability and elimination of harmful interactions with the body.[6] During a subsequent hearing, NASA officials showed a sample prosthetic hip joint made from a NASP-developed titanium alloy.[7] However, years of testing by the Food and Drug Administration would be required before the material could be approved for this use.

Program officials also reported that NASP-developed computational fluid dynamic codes are being used by an engine contractor in the Advanced Tactical Fighter Program. We found no evidence to confirm this transfer. According to a contractor official, the codes being used are generic codes that have been available for several years and were not developed for the NASP Program.

Projections of Economic Benefits Appear Unrealistic

The NASP Joint Program Office commissioned four macroeconomic impact studies to project the economic benefits of NASP-developed technologies. Collectively, these studies concluded that the NASP Program would be economically profitable and beneficial to the United States. One study

[5]House Report 101-763 to accompany H.R. 5649, the National Aeronautics and Space Administration Multiyear Authorization Act of 1990.

[6]Civil Benefits of the National Aero-Space Plane (NASP) Program, NASA Report to the Committee on Science, Space, and Technology, House of Representatives (June 17, 1991).

[7]1993 NASA authorization hearing before the Subcommittee on Technology and Competitiveness, Committee on Science, Space, and Technology, U.S. House of Representatives, No. 128 (Feb. 19, 1992).

determined that the U.S. gross national product would be increased by $50 billion over the next 20 years (1991 to 2010) as a result of U.S. investment in the NASP Program. Another study concluded that U.S. participation in the NASP Program would result in 650,000 new jobs and an increase of $6.5 billion in tax revenues in 1999.

The results of the four studies, which were presented to other NASP Program decisionmakers, are questionable, since all four used overly optimistic assumptions. For example, one study assumed that technological progress would benefit the public good if the same amount of benefit could be counted repeatedly for various sectors.[8] Another study assumed that if the government did not spend a given amount of money on the NASP Program, the money would not be spent on another program that might also generate economic benefits.[9] None of the studies considered potential problems associated with investing in such a high-risk program. For instance, technology may fail to achieve the anticipated results, and the technology may not be disseminated as planned.

In addition, the economic benefits of the NASP Program, based on one of these studies,[10] were presented to the Congress in the previously cited report on civil benefits of the NASP Program. Several of the assumptions on which this study was based appear unrealistic. For example, the study (1) assumes that there will be no offsetting government fiscal policies (like increasing taxes or decreasing expenditures for other programs), leading to upward-biased results; (2) assumes that for every dollar spent on the total program, rather than on research and development, the gross national product will see an $8 return benefit, allowing for a 6-year lagtime; and (3) uses a multiplier effect for government spending on a military purchase.

Conclusions

Because of the magnitude and cost of the research and development effort that is required before an experimental air-breathing SSTO vehicle could be built, NASA and DOD face pressure to rationalize and justify NASP Program expenditures. However, the operational vehicles that might evolve from this effort are decades away. While the need for more cost-effective space

[8] A Macroeconomic Assessment of Hypersonic Technology, prepared by Princeton Economic Research, Inc., for the NASP Joint Program Office (Sept. 18, 1991).

[9] Rockwell Economic Benefit Analysis/Objectives, prepared by Rockwell International Corporation for the NASP Joint Program Office (1990).

[10] An Analysis of the National Benefit of NASP/NDV Expenditures: 1990 Through 2010, prepared by DRI/McGraw-Hill and General Dynamics for the NASP Joint Program Office (Jan. 1990).

launch vehicles is recognized, various developmental efforts with more near-term potential could also reduce space launch costs.

Efforts are under way to ensure that research and development dollars expended on the NASP Program will benefit U.S. competitiveness. However, predicting and quantifying areas that are expected to benefit from NASP-developed or enhanced technology are difficult at this stage of development. Additionally, claims of successful technology transfers have been premature, and program proponents' projections of potential economic benefits have been overly optimistic.

It is premature to quantify tangible economic benefits that may be generated by the NASP Program. We believe these potential applications, while important, cannot and should not become justification for the NASP Program.

Key Issues Facing the NASP Program

The NASP Program's 7-year history has been characterized by turmoil, changes in focus, and unmet expectations, partly the result of the overly optimistic projections in the past and funding cuts. Even after a redirection of the program in 1989 to keep it focused on research and technology development objectives, the program is again at a crossroad. Projected costs are increasing, technical progress is behind schedule, funds are insufficient to implement the program as planned, and there are concerns that the Congress may not adequately fund the program in future years. In August 1992, the Joint Program Office proposed a refocusing amid concerns that congressional funding in fiscal year 1993 would be severely cut or denied and that eliminating the original goal of the program—demonstrating SSTO—could jeopardize support for the program.

The NASP Program is being driven by pressures that have resulted in unrealistic expectations regarding the time and cost required to achieve the program's goals and objectives. These pressures include

- high initial expectations that the NASP Program would lead to the development of the "Orient Express" hypersonic commercial transport and a hypersonic military aircraft,
- an acceleration of the pace to develop technology to meet the demands of a flight test schedule,
- the need to demonstrate that future operational aerospace vehicles will have cost-effective advantages over other existing and planned space launch systems in meeting mission needs, and
- the need to show that NASP technology can be readily applied to other areas and generate unrealistically high economic benefits.

The pressures to successfully compete for funding and show results impede achievement of program objectives and goals. Some of these difficulties are similar to those we have observed in major weapon system acquisition programs. For example, the program contains unnecessary concurrency, as the Phase III decision point is now scheduled before Phase II testing can be completed. In some cases, technological alternatives were discontinued in favor of nearer-term options to meet an aggressive schedule. For example, more readily available—and heavier—materials were selected for the X-30's engine while development of some lighter, more advanced materials was discontinued, since the schedule did not allow sufficient time to develop them. These decisions contributed to the vehicle's increased weight, which may jeopardize the ultimate program goal of achieving SSTO. Also, technology tradeoffs and program decisions are being made to reduce costs to fit within shrinking funds. Moreover, there may be no realistic basis for estimates of ultimate program schedules or costs.

Unlike major weapon system acquisition programs, the objective of the NASP Program is not to develop an operational capability but rather to develop and demonstrate requisite technologies with the ultimate goal of achieving SSTO. The NASP Program does not and should not be expected to fit the mold of an acquisition program. The program requires revolutionary breakthroughs to achieve the goals of SSTO and sustained hypersonic cruise. Such advances are neither guaranteed nor predictable. In fact, the NASP Program outstrips current computational and test capabilities. Also, there is no comparable historical cost, schedule, or performance data on which to base projections of time and cost for technology development and maturation. Consequently, projections of potential launch capabilities, operating costs, and technical transfers are speculative and premature at this point.

If the ultimate goal of achieving SSTO is reaffirmed, we believe the NASP Program's strategy and approach must be restructured. The research and technology development efforts should be considered simply on the merits of advancing aerospace plane capabilities rather than as a cost-effective program to deliver competitive launch services or a hypersonic cruise vehicle. Recent proposals to refocus the NASP Program could be a step in the right direction—a step that could lead the way to optimizing the program for achieving desired breakthroughs by decoupling it from future experimental vehicle phases. This refocusing could have the effect of relieving the NASP Program of the acquisition-like pressures that can compromise its basic long-term technology development goals.

Reaffirming the orientation of the NASP Program around the SSTO goal would require the Congress and the administration to determine whether the program is a worthy investment on the basis of its technological merits—rather than on current (and unpredictable) estimates of its potential benefits. If judged to be worthwhile, a reliable funding plan could be developed that would enable the critical technologies to develop to the point where the program's future could be reassessed with more concrete information in hand. The definition of future phases (beyond Phase II) should await the outcomes of the research efforts.

Matters for Congressional Consideration

Issues to be decided in reassessing the direction of the NASP Program include the following:

- Does the United States wish to pursue research and technology development efforts with the ultimate goal of developing an air-breathing, SSTO vehicle or hypersonic cruise vehicle?
- If so, what priority and funding should be assigned to this effort relative to other DOD and NASA programs?
- Should these efforts be continued through the NASP Program, and if so, what is the appropriate management and technical structure?

The Congress, in conjunction with the administration, should reassess the direction of the NASP Program and determine whether the goals of SSTO and sustained hypersonic cruise are worth pursuing on their own merits. If these goals are judged to be a worthwhile investment, the Congress should consider ways to ensure the program remains properly focused and optimized for developing critical technologies. Options that could be considered include

- refocusing the program on efforts to develop key technologies (analogous to the current Phase II) and deferring the definition of future phases until the technical results are assessed;
- defining and implementing a research and development program with milestones based on successfully achieving technological goals rather than meeting a predetermined cost and schedule (that is, a technology-driven rather than cost- or schedule-driven program) and with realistic, attainable annual funding goals; and
- reassessing the current NASP Program management structure—the NASP Joint Program Office and National Contractor Team—to determine if it is cost-effective and compatible with restructured program objectives and goals, available funding, and current technology development.

Recommendations

Since technological development efforts to date do not provide a sufficient basis to proceed with the scheduled September 1993 decision to build and test the X-30 experimental vehicle, we recommend that the Secretary of Defense and the Administrator of NASA direct the NASP Steering Group to delay a decision to build and test the X-30 experimental vehicle until critical technologies are developed and demonstrated and decisions on program restructuring are made.

We also recommend that, in restructuring the program, the Secretary of Defense and the Administrator of NASA direct the NASP Steering Group to provide guidance and direction to the NASP Joint Program Office regarding (1) program objectives and technical goals for aerospace research, development, and testing efforts to be conducted through the NASP Program; (2) funding availability; (3) technical priorities; and (4) development of a program strategy that is technology- or event-driven that can be implemented within available funding.

Objectives, Scope, and Methodology

The Chair of the Subcommittee on Government Activities and Transportation, House Committee on Government Operations, asked us to examine the cost, feasibility, and justification for the NASP Program. In a separate request, the Chairman and Ranking Minority Member of the Subcommittee on Technology and Competitiveness, House Committee on Science, Space, and Technology, and the Chairman and Ranking Minority Member of the Subcommittee on Research and Development, House Committee on Armed Services, jointly asked us to review the NASP Program's costs, schedule, and status of the technology development plan. In this report, we discuss the status of the NASP Program's technology development; changes in the program's projected cost and schedule; the requirements for and the potential military, civil, and commercial mission applications of potential future operational vehicles and efforts to spin off NASP-developed technology; and issues to be decided in reassessing the direction of the program.

As requested by the Subcommittee on Technology and Competitiveness, House Committee on Science, Space, and Technology, we submitted a statement for the record as part of the Subcommittee's authorization hearing on NASA's fiscal year 1993 aeronautical research and technology budget request, including the NASP Program.[1] This testimony provided our interim assessment of the NASP Program and addressed key issues facing the program.

To determine changes in the program's projected costs, we compared preliminary cost estimates prepared by the National Contractor Team in January 1992 to previous estimates. Since the NASP Joint Program Office terminated efforts in mid-1992 to complete a detailed cost estimate, we were not able to determine the reasonableness or completeness of the cost estimate.

To address the extent and impact of changes to the program's projected schedule, we compared current schedule projections to the program's 1986 baseline and subsequent schedules. We compared the projected completion of key tests with the program's planned September 1993 go-ahead decision. We also evaluated the impact of constrained DOD and NASA funding on the program's schedule and milestones.

To determine the status of the program's technology development, we reviewed Phase II exit criteria, evaluated selected test results and engineering assessments, and identified progress made and problems

[1]See National Aero-Space Plane: Key Issues Facing the Program (GAO/T-NSIAD-92-26, Mar. 31, 1992).

encountered in meeting the test schedule. We also visited selected U.S. government, industry, and university test facilities used for the NASP Program.

To determine the requirements for and the potential military, space, and commercial mission applications of future operational vehicles, we discussed military and space launch requirements with the Air Force and NASA—the two most likely users of future NDVs and those which have identified requirements. We also discussed spin-off applications with U.S. government, industry, and industry association representatives.

We conducted our work in Washington, D.C., at the Departments of Defense and the Air Force, NASA Headquarters, and NASP Interagency Office. We also met with representatives of the Strategic Defense Initiative Organization Single-Stage Rocket Technology Program, formerly known as the Single-Stage-to-Orbit Program Office.

We also conducted work at the NASP Joint Program Office and Wright Aeronautical Laboratories at Wright-Patterson Air Force Base in Dayton, Ohio, and the NASP National Program Office in Seal Beach, California (now located at Palmdale, California). We also visited each member of the NASP National Contractor Team, including General Dynamics Corporation in Fort Worth, Texas; McDonnell Douglas Corporation in St. Louis, Missouri; Rockwell International Corporation's North American Aircraft Division in Downey, California; United Technology Corporation's Pratt & Whitney Division in West Palm Beach, Florida; and Rockwell International Corporation's Rocketdyne Division in Canoga Park, California.

We visited NASP Program offices and U.S. government test facilities at NASA's Ames Research Center at Moffett Field, California; NASA's Dryden Flight Research Facility and the 6510th Test Wing of the U.S. Air Force Flight Test Center at Edwards Air Force Base, California; and NASA's Langley Research Center in Hampton, Virginia.

We visited selected industry laboratories and universities involved in testing components of the X-30, including a NASP Engine Test Facility and air-breathing propulsion test cells at The Marquardt Company and The Marquardt Jet Laboratory in Van Nuys, California; the low-speed oxidizer test rig and Nonintegral Fuselage Test Article (cryogenic fuel tank) at Wyle Laboratories in Norco, California; and the T-5 Shock Tunnel Laboratory at the Graduate Aeronautical Laboratories of the California Institute of Technology in Pasadena, California.

We visited potential military users of future operational NDVs, including the U.S. Air Force Space Command in Colorado Springs, Colorado, and the former U.S. Air Force Strategic Air Command at Offutt Air Force Base in Omaha, Nebraska.

We did not obtain written agency comments on this report. However, we discussed the information presented in this report with DOD and NASA program officials and incorporated their technical and editorial comments where appropriate.

We conducted our review between June 1991 and September 1992 in accordance with generally accepted government auditing standards.

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National Aero-Space Plane: Key Issues Facing the Program (GAO/T-NSIAD-92-26, Mar. 31, 1992).

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