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Report to Congressional Requesters

May 1994

SPACE SHUTTLE

Incomplete Data and Funding Approach Increase Cost Risk for Upgrade Program

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National Security and
International Affairs Division

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May 26, 1994

The Honorable William S. Cohen
Ranking Minority Member
Subcommittee on Oversight of
Government Management
Committee on Governmental Affairs
United States Senate

The Honorable James A. Hayes
Chairman, Subcommittee on
Investigation and Oversight
Committee on Science, Space,
and Technology
House of Representatives

The space shuttle is the only U.S. launch system capable of carrying people to and from space. It has operated for over 10 years and is likely to be used well into the next century. As the shuttle ages, the National Aeronautics and Space Administration (NASA) will be faced with increased need to update and replace various components due to obsolescence or to enhance safety. At your request, we reviewed the shuttle program to determine (1) the assumptions NASA has made regarding the length of time the current shuttle fleet will be in operation and (2) NASA's processes and criteria for selecting needed safety and obsolescence upgrades.

Background

The space shuttle is the world's first reusable space transportation system. It consists of a reusable orbiter with three main engines, two partially reusable solid rocket boosters, and an expendable external fuel tank. It is also NASA's largest program; it will consume about one-fourth of the agency's fiscal year 1994 budget. Since it is the nation's only launch system capable of transporting people, the shuttle's viability is important to other space programs, such as the international space station.

In fiscal year 1992, NASA established the Safety and Obsolescence Upgrade program (formerly the Assured Shuttle Availability program) to identify and fund improvements and enhancements needed to keep the shuttle flying.[1] Current plans are to fund specific, large upgrades and modifications that exceed a total cost of $15 million from the Safety and

[1]Appendix I contains a brief status of each currently approved safety and obsolescence project.

Obsolescence Upgrade program. Smaller upgrades and modifications will be funded from other parts of the shuttle operations budget.

Prior to establishing the program, NASA made incremental improvements to the shuttle as hardware experienced problems or vendors could no longer supply components. As the shuttle continues to age, NASA believes that these incidents will occur more frequently. The Safety and Obsolescence Upgrade program is intended to allow needed upgrades and modifications to be evaluated and approved on a priority basis.

Safety upgrades are designed to increase overall shuttle operational safety margins. For example, NASA estimates that five planned upgrades to the shuttle's main engines will improve the shuttle's safety margin by a factor of two. Obsolescence upgrades are designed to replace components that may become unavailable or whose costs have increased because contractors no longer manufacture them or because of technology advancements. For example, the shuttle cockpit uses dials and gages based on 1970s technology. The Multifunction Electronic Display Subsystem is designed to replace that obsolete technology with a modern "glass" cockpit similar to those in commercial and military aircraft.

Results in Brief

NASA has not made explicit assumptions about how long the current shuttle fleet will remain in operation. However, based on its budget projections and approach to defining a new launch system, the current fleet cannot be replaced for at least another 12 to 15 years. NASA's projections of its likely budgets through fiscal year 1999 will not support simultaneous development of the space station and a new launch vehicle.

NASA has a process for identifying and assessing needed upgrades. However, NASA does not use life-cycle cost[2] as a criterion for evaluating potential safety upgrades, and it does not always consider alternatives when selecting an approach to implementing an improvement. Without life-cycle cost estimates, NASA cannot determine whether an upgrade project is affordable within the context of the program and the agency's overall budget and out-year plans. Therefore, it is possible that inappropriate program decisions on upgrades may be made.

NASA managers do not have a precise basis for estimating life-cycle costs for decision purposes because of uncertainty about how long the current

[2]Unless stated otherwise, all costs in this report are expressed in current dollars—the dollar value of a good or service in terms of prices estimated to be current at the time the good or service is sold.

fleet will remain in operation. Since the shuttle fleet must operate for at least another 12 to 15 years, it would seem logical that NASA officials could use that time period as a minimum basis for estimating life-cycle costs.

NASA's approach to funding the Safety and Obsolescence Upgrade program may increase programmatic risks. The program manager believes that funding is adequate to develop upgrade projects that have already been approved. However, recent budgets have not included funds for early design studies of other potential upgrades or to cover unforeseen contingencies. Not conducting early design studies to establish the feasibility of a potential upgrade could mean that projects are not started when they are needed or projects are initiated before they are adequately defined. Also, the lack of contingency funds means that if approved projects encounter unexpected problems, the projects may have to be stretched out and costs may increase. This situation raises questions as to whether the decision to start two new projects in fiscal year 1995 adequately reflect budget constraints and inherent technical and cost risks.

In commenting on a draft of this report, NASA said that it agreed in principle with our recommendations. The agency stated, however, that some safety upgrades are made without a full life-cycle cost analysis because of the emphasis on safety. Safety is NASA's highest priority, and relative cost is a lesser consideration. We agree that NASA must heavily weigh safety considerations in such decisions. We believe, however, that prudent management requires an estimate of total costs to ensure that NASA managers understand the full implications of their decisions and that the projects are affordable within the context of NASA's total budget and future plans.

NASA Does Not Plan to Decide Future Shuttle Requirements Before 1998

Although NASA has begun to study new launch system alternatives, it has not established how long the shuttle will remain in operation, but based on its stated plans, the agency will have to rely on the shuttle for at least another 12 to 15 years. In testimony before the Congress in April 1993, the NASA Administrator stated that the agency does not plan to decide on a shuttle replacement until at least 1998. Once a decision is made, NASA estimates that it will take 7 to 10 years to develop a shuttle replacement. NASA's budget projections through fiscal year 1999 do not include funds for a new launch vehicle. However, the projections include about $900 million—primarily in fiscal years 1998 and 1999—to develop and demonstrate technologies that will be needed for an eventual shuttle replacement.

NASA Is Studying Replacements for the Shuttle

NASA has begun to study options for replacing the shuttle. In January 1993, the agency initiated an "Access to Space" study to define launch requirements and the alternatives for meeting these requirements through 2030. The study considered three options: (1) continue primary reliance on the shuttle until about 2030, (2) develop a new launch system using today's technology that would replace the shuttle around 2005, and (3) develop an advanced technology, next-generation launch system that would begin replacing the shuttle around 2008. The study considered Department of Defense and commercial launch requirements as well as NASA requirements.

Option 1—continued reliance on the shuttle—could require significant modifications to the current shuttle design. For example, the team recommended developing improvements such as a flyback reusable liquid fuel booster. Option 2 would require developing a launch system based on today's technology, such as the national launch system, which has now been terminated. Option 3 would include developing new technology leading to the next generation launch system—the so-called "leap frog" approach.

The Access to Space study concluded that the most beneficial option would be to develop and deploy a fully reusable single-stage-to-orbit launch vehicle fleet incorporating advanced technologies and to phase out the shuttle beginning around the 2008 time period.[3] While requiring a large up-front investment—about $37.6 billion, according to the study team's estimate[4]—this new launch system was forecast to eventually reduce annual operating costs by up to 80 percent while increasing vehicle reliability and safety by about an order of magnitude. In addition, the study team concluded that it would place the United States in an extremely advantageous position with respect to international competition and would leapfrog the United States into a next-generation launch capability.

The study team recommended that the development of an advanced technology single-stage-to-orbit launch vehicle become a NASA goal and

[3]NASA Office of Space Systems Development, Access to Space Study Summary Report (Jan. 1994).

[4]NASA's Special Assistant for Access to Space testified before the Subcommittee on Space, House Committee on Science, Space, and Technology, on March 23, 1994, that new ways of doing business, such as private financing of development costs, may allow NASA to reduce this up-front investment.

that a focused technology maturation and demonstration be undertaken. Adopting this recommendation could place the United States on a path to recapture world leadership in the international satellite launch marketplace, as well as enable much less costly and more reliable future government space activities, according to the study team.

In addition to NASA's Access to Space study, the Office of Science and Technology Policy initiated a study in December 1993 to develop strategies for modernizing U.S. launch capability. The study group will consider investment strategies for improving current systems, developing new systems, and upgrading the nation's launch infrastructure. According to a NASA official, its Access to Space study is being used as a database to support the Office of Science and Technology Policy study that is scheduled for completion by June 1994.

NASA Will Have to Use the Current Shuttle Fleet for at Least 12 to 15 Years

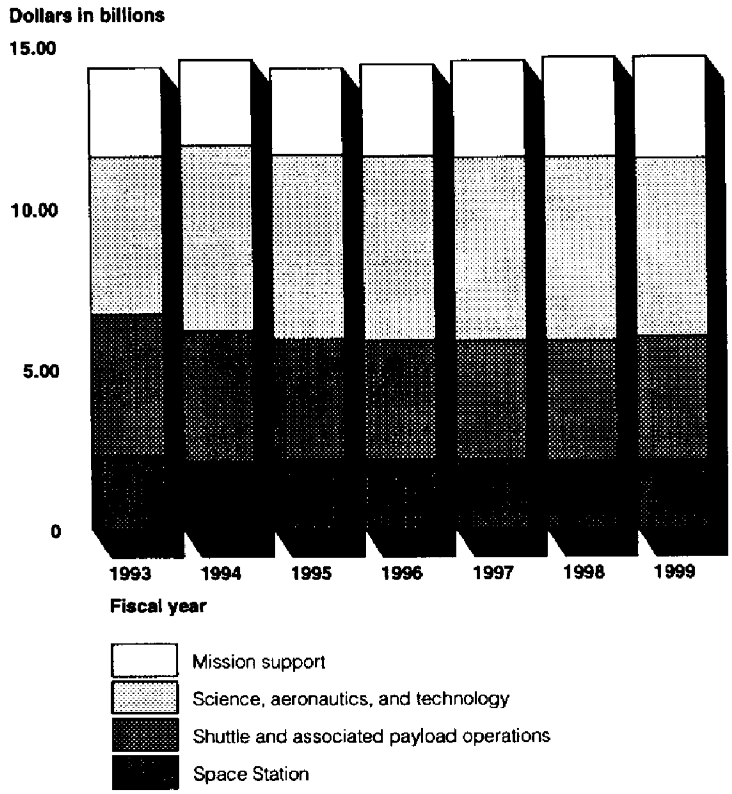
Given NASA's current budget projections and plans for addressing access to space requirements, the current shuttle fleet will not be replaced for a minimum of 12 to 15 years, no matter which option is chosen. The NASA Administrator has not yet accepted the Access to Space study team recommendations and indicated that it may be as long as 5 years before the agency decides how to meet future launch requirements. After a decision is made, NASA estimates it will take 7 to 10 years to develop a new launch vehicle. According to an Office of Space Systems Development official, this is still NASA's plan.

According to the Administrator's testimony in April 1993, NASA needs a "few years" to thoroughly study different approaches for meeting future access to space requirements. During this time, a detailed strategy and a technology plan would be prepared to support development of a new launch system.

NASA officials told us that the agency budget cannot realistically support simultaneous development of the Space Station and a new launch system. According to NASA estimates associated with the President's fiscal year 1995 budget request, the agency does not anticipate any significant increase in annual funding through fiscal year 1999. The fiscal year 1995 budget request was $250 million less than the amount the Congress appropriated in fiscal year 1994. In projecting future years' funding, the agency has assumed increases of less than 1 percent a year through fiscal year 1999.[5] Figure 1 shows NASA's funding projections.

[5]In real purchasing power or constant fiscal year 1994 dollars, future budgets are projected to decline.

Figure 1: NASA's Fiscal Year 1995 Budget Projections



According to NASA officials, there is no funding to begin developing a new launch system within the next 5 years. NASA estimates that Space Station development and assembly will cost about $1.8 billion a year through 1999. Space shuttle costs are estimated to average about $3.4 billion a year for fiscal years 1995 through 1999. In addition, the NASA Administrator has committed to maintaining a balanced program of human space flight and science, aeronautics, and technology. Consequently, funding for science, aeronautics, and technology is projected to be about $6 billion a year. Mission support costs are projected to increase from about $2.7 billion in the fiscal year 1995 budget to about $3.1 billion in fiscal year 1999.

NASA has programmed about $900 million over the next 5 years (fiscal years 1995 through 1999) to develop and demonstrate technologies for the eventual shuttle replacement. The fiscal year 1995 budget includes

$93.8 million for technology assessment, development, and maturation. This amount would increase to about $277 million in fiscal year 1999.

NASA's Process for Determining Needed Upgrades Does Not Always Consider Life-Cycle Costs or Alternative Approaches

NASA has established a process for identifying and assessing needed safety and obsolescence improvements to the current shuttle fleet. However, the agency does not always estimate or use life-cycle costs in its assessment of potential safety upgrades. In addition, NASA does not always evaluate alternative solutions before deciding how to resolve a problem. Therefore, it has no assurance that the agency is taking the most cost-effective approach to resolving problems.

Safety and Obsolescence Program Sets Priorities for Shuttle Upgrades

The Safety and Obsolescence Upgrade program consists of two categories of upgrades to the shuttle fleet. Safety upgrades are designed to improve the operating safety margins of the shuttle. Obsolescence upgrades are designed to replace components that are obsolete and components that are not available because they are no longer manufactured and are costly to maintain.

NASA annually reviews all shuttle subsystems to identify potential improvements to hardware, software, and processes. The agency uses a process called vulnerability assessment and a risk ranking methodology to assess the merits of proposed upgrades to shuttle equipment and to prioritize projects for funding. The vulnerability assessment process is used to assess candidate obsolescence upgrades and includes four general steps: (1) identify potential threats to the shuttle program and consider the urgency of a proposed upgrade, (2) determine potential upgrades to address the identified threats, (3) assess any other benefits of the proposed change, and (4) provide a final recommendation.

The risk ranking methodology is used to evaluate candidate safety improvements. The safety criterion is based on identifying candidate improvements that have the overall ability to reduce the risk associated with operating the shuttle. The criterion prescribes a formula for calculating risk rankings and assists management in making decisions on which projects to fund. Reducing the risks associated with potential loss of vehicle and crew receive the highest priority.

Potential safety and obsolescence upgrades are evaluated separately. According to NASA officials, this prevents the two categories of improvements from competing for the same funds. NASA officials believe that if safety and obsolescence improvements competed for the same funds, safety would always win and there would not be sufficient funds to implement obsolescence improvements.

Life-Cycle Cost Estimates Are Needed for Determining Affordability of Safety Upgrades

NASA considers only investment costs in approving safety upgrade projects. According to NASA's acquisition policies, life-cycle costs should be estimated to ensure that appropriate trade-offs are accomplished among investment costs, ownership costs, schedules, and performance. However, NASA does not always estimate life-cycle costs for its shuttle safety upgrades. Without life-cycle cost estimates, NASA managers do not have complete information on the impact of their decisions and cannot determine whether the upgrades are affordable within the context of the agency's overall budget and out-year plans.

In October 1993, we reported that NASA did not consider life-cycle costs when it decided to resume development of the alternate high pressure fuel turbopump.[6] In commenting on our report on the alternate fuel turbopump program, NASA said that while a life-cycle cost analysis can be a valuable and effective tool for programmatic decisions, it is not appropriate for the strong safety program to which NASA is committed. While we understand safety considerations must be heavily weighed in making program decisions, we cannot agree that cost data is not needed. Having such information is necessary to fully compare competing programs and determine how the cost of selected approaches will affect the affordability of other NASA programs.

Life-cycle costs can be important for determining the priority for upgrades. For example, according to the project manager, the Multifunction Electronic Display Subsystem probably would not be cost-effective if a decision were made to phase out the shuttle by about 2005. The upgrade is estimated to cost about $230 million and is designed to reduce shuttle operations cost. However, one study showed that the payback would take 5 to 10 years at a rate of 12 to 14 flights a year. NASA has not estimated how long it will take for a payback at the current rate of eight flights a year. The display is currently scheduled to become operational in fiscal year 1998.

[6] Space Shuttle Main Engine: NASA Has Not Evaluated the Alternate Fuel Turbopump Costs and Benefits (GAO/NSIAD-94-54, Oct. 29, 1993).

Since NASA does not know how long the shuttle will remain operational, the agency does not have a precise basis for estimating the life-cycle costs of candidate improvements. However, as we discussed, the 12- to 15-year period would be appropriate as the minimum life cycle for estimating the costs involved. A sensitivity analysis to determine the effects of a possible shorter or longer life cycle on costs may also be appropriate.

Alternatives Are Not Always Considered

According to NASA's policies on the acquisition of major systems, decisions should be based on competition between system design concepts throughout the entire acquisition process, whenever economically feasible and beneficial. However, NASA does not always evaluate the various alternatives available for making improvements. For example, in October 1993, we reported that NASA did not conduct a cost and benefit evaluation of the alternate high pressure fuel turbopump before resuming development of the turbopump, and therefore, had no comparative information to assess alternative approaches to improving the shuttle's main engines.

Even though a 1991 study by NASA's Office of Safety and Mission Quality recommended continued development of the alternate turbopump, it concluded that design solutions were available to correct major safety concerns with the current fuel pump as an alternative to continued development of the alternate turbopump. For example, the contractor has developed methods to improve the current pump's producibility and eliminate cracking in the sheet metal used in certain areas of the pump. Also, according to the study, new turbine blades can be installed that could provide safety margin increases. However, NASA officials told us that the alternate fuel pump eliminates all sheet metal and provides a better margin for safe main engine shutdown in case the turbine blades fail.

NASA's main engine project manager told us that NASA has not performed an in-depth study of the potential for further improvement in the current pump. According to this official, the only way to eliminate all remaining safety concerns is to develop the alternate fuel pump. This official pointed out that any further major upgrade to the existing pump would require a full certification test program that would be expensive.

NASA officials told us that over the years, the current fuel turbopump has been upgraded 12 times in an effort to make it safer. Each of those upgrades required certification testing. The officials also said that further upgrading of the current fuel pump could disrupt the schedule of other ongoing main engine improvements and delay the agency's plans to close several test stands by 1997.

Approach to Funding Safety and Obsolescence Upgrade Program May Increase Risk

NASA's approach to funding the Safety and Obsolescence Upgrade program may increase overall programmatic risks. NASA reduced fiscal year 1993 funding for safety and obsolescence upgrades by about 36 percent to help achieve an overall agency funding cut. In addition, according to the program manager, neither the fiscal year 1994 budget nor the fiscal year 1995 budget request included funds for early design studies of potential future upgrades or program reserves to cover contingencies during those years. According to the program manager, funding for approved projects includes a small amount of reserves, but additional program reserves are needed in the event of unforeseen problems. Our past work identified inadequate project definition and insufficient funding as leading causes for cost growth and schedule stretch-outs in NASA programs.[7]

NASA reduced fiscal year 1993 funding for the Safety and Obsolescence Upgrade program from about $139 million to $89.5 million to help achieve an overall agency funding reduction. The almost 36-percent reduction in funding for the program in fiscal year 1993 essentially eliminated the program's ability to conduct early design studies of candidate upgrades and modifications. The program manager said the reduction affected his ability to develop comprehensive project designs. He said, for example, that once a potential need is identified, NASA's experience is that it costs up to about $100,000 to conduct a thorough vulnerability assessment to characterize the potential problem. Then, up to an additional $400,000 is needed to conduct comprehensive design work and some limited testing to ensure that a proposed solution will work. The fiscal year 1993 reduction also caused NASA to reduce planned funding of the Multifunction Electronic Display Subsystem, but total estimated cost of the project was not affected since some fiscal year 1992 funds were available for carry over because the contract was awarded later than originally planned.

According to the program manager, funds budgeted for fiscal years 1994 and 1995 are to develop currently approved upgrades. No funds are budgeted for early design studies of potential future upgrades or to pay for any significant problems that may occur in an approved project. NASA requested and received $140.2 million for fiscal year 1994, but that request did not include any funds for early design studies or contingency reserves.

[7] NASA Program Costs: Space Missions Require Substantially More Funding Than Initially Estimated (GAO/NSIAD-93-97, Dec. 31, 1992).

The program's fiscal year 1995 budget request increased to about $227 million because NASA plans to begin two new upgrade projects and resume development of the alternate high pressure fuel turbopump. The first project is a $77-million health monitoring system safety upgrade to provide more accurate information on the status of the shuttle main engines before launch and during flight. The second project is a $103-million reaction control system direct acting valve obsolescence upgrade to reduce emissions and improve the performance of the shuttle's reaction control system.

The fiscal year 1995 budget request also does not include funds for early design studies or reserves for contingencies. Eliminating early design studies could mean that upgrade projects are not started when they are needed or projects are initiated before they are adequately defined, thereby increasing overall program technical and cost risk. For example, according to the Safety and Obsolescence Upgrade program manager, NASA has not completed design definition studies for either of the two programs it plans to start in fiscal year 1995. The manager cited the lack of study funds as the reason for not completing the studies.

We reported in December 1992 that a lack of definition of projects before they are initiated and inadequate funding are leading causes for cost growth and schedule stretch-outs in NASA programs. Two NASA studies conducted over a decade apart emphasized the importance of thorough definition studies. The first study, NASA's Project Management Study in 1980, concluded that one of the most significant contributors to cost and schedule growth was inadequate definition of technical and management aspects of a program prior to seeking approval to proceed with development. The study recommended that sufficient funding be included in NASA budgets for thorough definition studies. The second study, NASA's Roles and Mission Report in 1991, documented the need for increased emphasis on technological readiness and requirements on the front end of a program. In response to this report, the NASA Administrator directed the agency to implement more rigorous definition studies. The purpose of the studies was to understand all implications of a program's technical content in order to prepare an implementation plan that includes the cost, schedule, and performance contingencies necessary to make internal and external commitments.

Reserves for contingencies are included in a program's cost estimates so that its budget reflects potential resource needs. Reserves are established to fund significant changes in the definition or scope of the project, new requirements, engineering changes, schedule slips, increases in technical or management complexity, and known issues with uncertain cost impact. The level of reserves should vary from program to program, depending on the level of uncertainty and risk associated with a particular project.

Recommendation

Since NASA will have to use the shuttle for at least 12 to 15 years, we recommend that the NASA Administrator direct shuttle program managers to use that time frame as a basis for estimating the life-cycle costs of proposed upgrades. However, if circumstances change where the shuttle would be used for a shorter or longer time frame, it may be necessary to reevaluate life-cycle costs of the upgrades. We also recommend that the Administrator require (1) decision justifications that include life-cycle cost analysis of alternatives before requesting authority to start new shuttle upgrade projects and (2) an assessment of the risk associated with not providing funds for early design studies and contingency reserves and consider whether in light of these risks the agency should begin two new upgrades in fiscal year 1995.

Agency Comments and Our Evaluation

In commenting on a draft of this report, NASA took exception to some items described in the report and expanded on others. However, the agency agreed in principle with our recommendations. NASA said that it has always followed the principles of estimating life-cycle costs, comparing competing alternatives, and providing adequate funding and will continue to do so in its decision-making process. We disagree that NASA has always followed these principles because we found instances where these principles were not followed.

While agreeing in principle with our recommendations, NASA stated that some safety upgrades are made without a full life-cycle cost analysis because of the emphasis on safety. Safety is NASA's highest priority, and relative cost is a lesser consideration. We agree that safety is NASA's highest priority and must be heavily weighed in decisions. We believe, however, that managers must be provided total life-cycle cost estimates so that they understand the full implications of their decisions and can ensure that projects are affordable within the context of NASA's total budget and future financial plans.

Regarding our recommendation that the NASA Administrator require program officials to use the 12- to 15-year time frame as a basis for estimating life-cycle costs for proposed shuttle upgrades, NASA agreed that using that time period is proper. The agency also stated that it would update the time frame for estimating life-cycle costs when future shuttle replacement plans are formalized.

Regarding our recommendation that the Administrator require decision justifications that include life-cycle cost analysis of alternatives before obligating funds for shuttle upgrade projects, NASA stated that its managers use life-cycle cost analysis where appropriate in the decision process for proposed shuttle upgrades. We believe that it is always appropriate to estimate life-cycle costs and to conduct cost and benefit analyses of competing alternatives. We believe that such analyses are essential for NASA to ensure that proposed upgrades are affordable within the context of the agency's overall financial plans and budget.

NASA cited two examples of life-cycle cost estimates that had been prepared for shuttle upgrade projects. The projects are long-life fuel cells that provide electrical power for the orbiter and the alternate high pressure turbopumps. The long-life fuel cell life-cycle cost estimate cited by NASA is for an obsolescence upgrade. We agree that NASA estimates life-cycle costs for such projects. The alternate turbopump life-cycle cost estimate was prepared in 1991, about 5 years after the project was initiated. Further, according to an Office of Space Flight official, NASA did not update the estimate prior to the decision to restart development of the fuel turbopump in fiscal year 1994, even though estimated development and implementation cost for the alternate pumps had increased significantly.

In addition, we found that NASA has not estimated life-cycle costs for the large throat main combustion chamber, which it started developing in fiscal year 1994, or the shuttle main engine health monitoring system, which it plans to begin developing in fiscal year 1995. An Office of Space Flight official told us that NASA always looks at operations costs for proposed projects during the definition study phase. However, NASA did not provide documentation to support its claim.

We reported in October 1993 that NASA did not consider the alternative of further upgrading the current fuel turbopump before deciding to restart development of the alternate fuel turbopump. NASA's response to that report was that further upgrading the current fuel pump would not resolve all of the safety concerns related to the current high pressure fuel turbopump. The agency's Office of Safety and Mission Quality performed a study in 1991 that showed that further upgrades to the current pump are feasible and would eliminate many of the safety concerns. The safety office recommended continuing development of the alternate fuel turbopump, but also recommended that a life-cycle cost estimate be prepared.

Regarding our recommendation that the Administrator require an assessment of the risk associated with not providing funds for early design studies and contingency reserves, NASA stated that design studies and requirements definition tasks are currently in progress for the two projects it has requested authority to start in fiscal year 1995. The studies are being funded out of fiscal year 1994 safety and obsolescence budget reserves. NASA officials told us that the safety and obsolescence program has been able to save some planned funding on approved projects and that those funds have been used for program reserves. However, the officials acknowledged that funding for definition studies and contingency reserves was deleted from the program in fiscal year 1993 and no such funding was approved in the fiscal year 1994 budget or requested in the fiscal year 1995 budget. The officials said that the agency has been able to provide needed funding for the safety and obsolescence program and believes that it can continue to do so in the future. However, we question the prudence of a strategy that relies on saving money in the future from its approved projects to provide funding for definition studies and contingencies. Unless contingency reserves are available to fund resolution of problems as they arise, NASA may be forced to stretch schedules, thus increasing cost of the upgrades.

NASA's comments are reprinted in full in appendix II.

Scope and Methodology

To determine how long NASA plans to operate the space shuttle, we reviewed the agency's Office of Space Flight strategic plan for 1993, the Access to Space study, budget justifications, and records of congressional testimony by the Administrator and other NASA officials. We evaluated NASA's processes and criteria for selecting needed modifications by reviewing vulnerability assessment and risk ranking methodologies, vulnerability assessments of individually approved projects, and the Orbiter Project Office's 2005 study. We also reviewed annual reports and a special assessment team report issued by NASA's Aerospace Safety Advisory Panel.

We also analyzed cost estimates for the approved Safety and Obsolescence Upgrade program projects and NASA's 5-year program budget estimates. In addition, we discussed various aspects of the shuttle program with officials at Marshall Space Flight Center, Kennedy Space Center, Johnson Space Center, and NASA Headquarters.

We conducted our assessment from November 1992 through April 1994 in accordance with generally accepted government auditing standards. NASA reviewed a draft of this report, and we incorporated its comments where appropriate.

Unless you publicly announce this report's contents earlier, we plan no further distribution until 30 days from its issue date. At that time, we will send copies to other interested congressional committees, the Administrator of NASA, and the Director of the Office of Management and Budget. We will also provide copies to others upon request.

Please contact me on (202) 512-8412 if you or your staff have any questions concerning this report. Major contributors are listed in appendix III.

Donna Heivilin

Donna M. Heivilin
Director, Defense Management
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Abbreviations

NASA National Aeronautics and Space Administration

Status of Approved Safety and Obsolescence Projects

The National Aeronautics and Space Administration (NASA) has approved two safety and three obsolescence projects as a part of the Safety and Obsolescence Upgrade program. The projects each require several years to develop, and the development and production costs are incrementally funded each year. The five projects are estimated to cost about $1.5 billion at completion. The projects are (1) alternate high pressure oxygen and fuel turbopumps for the shuttle's main engines, (2) multifunction electronic display subsystem for the orbiter's cockpit, (3) replacement of cables at Kennedy Space Center, (4) replacement of hardware interface modules at Kennedy Space Center, and (5) development of a large throat main combustion chamber for the main engines. Table I.1 provides cost and schedule information on each of the approved projects.

Table I.1: Approved Safety and Obsolescence Upgrade Projects—Estimated Cost and Schedule

Dollars in millions

Project	Estimated development and production cost	Scheduled to become operational
Alternate turbopumps		
Oxygen pump	$563.60	October 1997
Hydrogen pump	512.50	October 1997
Multifunction Electronic Display Subsystem	229.60	February 1998
Cable plant upgrade	35.80	September 1998
Hardware interface module	39.20	June 1998
Large Throat Main Combustion Chamber	102.80	October 1997
Total	**$1,483.50**	

Source: GAO compilation based on NASA documents.

Space Shuttle Main Engine Alternate Turbopumps

The alternate turbopump development program consists of upgrading the shuttle main engine's high pressure oxygen and hydrogen turbopumps. The turbopumps pump oxygen and hydrogen fuel into the engine's combustion chamber where they mix and burn to generate power. The original design goal for the high pressure turbopumps was 55 flights. However, the pumps failed to meet that goal and had to be overhauled after every two flights. The turbopumps have been difficult to manufacture and caused several main engine failures during testing, some of which would have been catastrophic if the failures had occurred during flight.

NASA contracted with Pratt & Whitney in 1986 to develop alternate turbopumps for the engines. The goal for the alternate turbopumps was also 55 flights, but that goal has been reduced to 30 flights.

The alternate turbopumps are expected to eliminate many features of the current design that cause safety concerns. For example, the new pump housing will be a single casting, thereby eliminating nearly all welds where fuel leaks could develop. The new design will also reduce the number of rotating parts and eliminate the need for protective coatings on such components as turbine blades to protect them against heat and hydrogen embrittlement. In addition, the new pumps are to have better bearings and a design that permits easier assembly and disassembly.

In its fiscal year 1992 report, the Appropriations Conference Committee stated it believed the alternate fuel pump development should be terminated. The Committee cited the success of upgrades to the current fuel pump and the substantial cost increase in the alternate turbopump program as reasons for its conclusion. Development cost estimates for the turbopumps had increased from $198.2 million to $649.3 million.

Rather than cancel the program, NASA suspended fuel pump development to concentrate on developing the oxygen pump and initially planned to resume development of the fuel pump in fiscal year 1995. Even though not included in the President's fiscal year 1994 budget request, NASA now plans to restart the development program in fiscal year 1994 to improve the program's efficiency. On April 14, 1994, the Appropriations Committees granted NASA permission to restart the fuel turbopump development in fiscal year 1994, but capped the turbopump program total cost at $1.056 billion, or $20 million less than NASA estimated. The Committees directed that the reduction be taken from any remaining award fee available to the contractor and that the reduction should not be taken from any program reserves.

Development of the alternate oxygen turbopump is nearly complete and certification testing was scheduled to begin in January 1994, and its first flight is scheduled for June 1995. However, a cracking problem at the pump's turbine inlet recently developed, and NASA and its contractor are currently evaluating designs to solve the problem. The pump must undergo further development testing to verify the selected design solution. NASA now estimates that certification testing will begin in June 1994, with the first flight still scheduled for June 1995. NASA plans to begin using the fuel turbopump in October 1997. NASA estimates that development and production of the alternate turbopumps will cost about $1.1 billion.

Multifunction Electronic Display Subsystem

The orbiter currently provides flight control information to shuttle crew members through a cathode ray tube display, instruments, and meters. The current system consists of hardware based on 1970s technology, which creates ongoing logistics support problems because of mechanical wear out, aging, and component obsolescence. The current display system has been susceptible to failures and is becoming unreliable. In addition, many of the displays, instruments, and meters are becoming obsolete and could become unsupportable from a spare and repair standpoint in the next 5 to 7 years. According to an orbiter project official, many of these items are unique to the shuttle. The Multifunction Electronic Display Subsystem is being designed to simplify orbiter operations, increase the life of the orbiter's displays, and increase reliability of the subsystem. The new displays will be primarily digital—similar to cockpit displays in commercial and military aircraft.

The upgrade includes design and production of modification kits for the four orbiters, purchase of new ground support equipment, and modification of test and training facilities. NASA awarded a development contract to Rockwell International in July 1992 and expects Rockwell to begin production in April 1994. The subsystem will be implemented in two phases. The first flight of phase I hardware is scheduled for fiscal year 1996, and the first fully implemented flight is scheduled for February 1998. NASA estimates that the display subsystem will cost about $230 million for development, production, and installation.

Cable Plant Upgrade

Cables support a wide variety of functions at the Kennedy Space Center. For example, they are used for communications, data transmission, and transmission of video information. The cable plant upgrade project was initiated to replace miles of obsolete copper cables with more modern fiber optic cabling. NASA's first priority is to replace cables between the launch control center and launch pads A and B. Many of the copper cables were installed in the 1960s and are no longer manufactured; therefore, availability of spare cables is becoming a problem. According to NASA, replacement of the copper cables will reduce the possibility of launch delays, increase communication system spares availability, and enhance the reliability of data, instrumentation, voice, and video communication information.

Lockheed is performing the cable plant upgrade under a modification to its shuttle processing contract. The contractor began replacing cables in fiscal year 1993 and plans to complete the project by September 1998. NASA estimates the cable system upgrade will cost about $36 million.

Hardware Interface Module

Hardware Interface Modules are a part of the checkout control and monitoring subsystem used for monitoring the shuttle as it is prepared for launch. They connect the ground computers at the Kennedy Space Center and the shuttle system's ground support equipment. NASA is replacing the modules because they are obsolete and have experienced an increased failure rate and repair cost over the past several years. The Hardware Interface Module upgrade will replace all existing equipment with state-of-the-art "off-the-shelf" hardware to improve system reliability and maintainability.

NASA issued a request for proposals in September 1993 for the production of 250 modules. NASA awarded a production contract on March 22, 1994, and expects the upgrade to be completed by June 1998. The agency estimates the program will cost about $39 million.

Large Throat Main Combustion Chamber

Liquid oxygen and hydrogen fuel mix and burn in the space shuttle main engine combustion chamber to generate the engine's power. The large throat main combustion chamber is an advanced design of the current combustion chamber that would increase capacity of the chamber's throat by about 11 percent. The increased capacity would provide a more benign operating environment for major components of the engines. The large throat main combustion chamber is being designed to (1) eliminate welds in the current combustion chamber—potential fuel leak paths that could cause an engine to explode, (2) increase main engine reliability by reducing causes of potential failures, (3) reduce fabrication time from 63 months to 41 months, and (4) require less maintenance and inspection than the current combustion chamber. With the larger throat, temperature and pressure within the engine would be reduced by about 9 percent, thereby relieving pressure and reducing temperatures on components such as the high pressure turbopumps. According to NASA, the large throat main combustion chamber would increase turbopump operational margins through lower pump speeds, temperature, and pressure.

NASA began development of the large throat main combustion chamber in fiscal year 1994 and plans its first flight in October 1997. NASA estimates that development and production of the large throat main combustion chamber will cost about $103 million.

Comments From the National Aeronautics and Space Administration

Note: GAO comments supplementing those in the report text appear at the end of this appendix.

National Aeronautics and
Space Administration
Office of the Administrator
Washington, DC 20546-0001

APR 11 1994

Mr. Frank C. Conahan
Assistant Comptroller General
General Accounting Office
Washington, DC 20548

Dear Mr. Conahan:

We believe that our current safety and obsolescence program is very well conceived. It is proceeding properly and at the right pace in line with funding which can be expected in future years. We use a rational prioritization scheme which treats safety improvements separately from other types of changes. This approach will keep the Space Shuttle flying safely for the 12 to 15 years the GAO mentions is necessary. We have and will continue to take life-cycle costs into account whenever we analyze the safety and obsolescence upgrades required. However, life-cycle cost is not as important a factor for high priority safety improvements (i.e., alternate turbopump development) as it is for other upgrades.

Life-Cycle Cost - Life-cycle cost is a methodology to address total costs of an action and compare them to an alternative. The selection criteria for obsolescence upgrades specifically addresses all the elements of life-cycle cost. Life-cycle cost is, in fact, the primary consideration. Some safety upgrades are made without a full life-cycle cost analysis because of the emphasis on safety. Safety is NASA's highest priority, and relative cost is a lesser consideration.

See comment 1.

We have looked at operations costs for every safety upgrade. There were at least two life-cycle studies done on the alternate pumps--one by Pratt & Whitney and one by NASA. Those analyses only assessed the direct costs of the upgrade and did not attempt to quantify the value of improved safety. That was done separately as part of the safety analysis.

See comment 2.

Alternate Turbopump (ATP) Development - The 1991 study did consider design solutions but strongly recommended restart of the ATP fuel pump program. The design solutions cited in the GAO draft report are very immature and have high development risk as compared to the ATP fuel pump (which has already been tested on a Space Shuttle Main Engine (SSME)). As the 1991 study points out, "only limited upgrade is possible without changing the centerline design."

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See comment 3.

The implied GAO rationale is that it will be less expensive to redesign the current pump than to continue development/certification of the ATP pump. This is not necessarily true. If a redesign of the current pump were initiated today (to incorporate the ATP blade design, for example), a full certification test program would be required and would very likely impact the implementation schedule of current safety improvements and/or the Agency's plans to deactivate several test stands by 1997. It should also be pointed out that the current fuel pump has undergone 12 redesigns (each requiring certification testing) resulting in a service life of only 2 to 3 flights.

See comment 4.

See comment 5.

Approach to Funding Safety and Obsolescence Program Upgrades - NASA takes exception to the GAO conclusion that there is a history of "inadequate project definition" associated with the development of Space Shuttle safety and obsolescence upgrades. In the FY 1995 budget, there are two new upgrades included--the reaction control system Direct Acting Valve (DAV) and the Shuttle engine health monitoring system. The FY 1993-94 budget provided feasibility and definition studies for the DAV prior to the start of FY 1995 development activities. The DAV was originally proposed to overcome obsolescence and provide improved performance. However, its technical enhancement will also be required to support the Space Station to minimize particle impingement on the Station's solar panels.

See comment 6.

See comment 7.

The engine health monitoring system resulted from the main engine safety improvement studies. Although the specific formal definition study is still to be completed, a significant investment has been made in test bed activities involving main engine monitoring and diagnostic activities at the Marshall Space Flight Center's science and engineering laboratories.

Regarding other programs noted in the report, the alternate turbopump invested $13.4 million in the early 1980's toward definition and design prior to a development program commitment. The Large Throat Main Combustion Chamber applied $2.7 million in definition, design, and completion of a prototype prior to initiating development.

See comment 8.

With regard to the GAO conclusion that inadequate reserves were budgeted for safety and obsolescence upgrades, each project carries a level of reserves within the estimated cost at completion consistent with the risk associated with development. In addition, reserves are also carried and managed by the Headquarters program office for application to programs on an as-required basis.

3

Summary - In every case, the basis for upgrade funding was carefully and thoroughly established prior to approval. We will continue this process as future upgrades become necessary. As a result, the projects proceeding under the safety and obsolescence program have been, and will continue to be, properly studied, designed, provided with contingency funds, and scheduled to meet the Shuttle's urgent needs in the coming 12 to 15 years.

GAO Recommendations - Although we have taken exception to some items described in the GAO report, and expanded on others, we agree in principle with the three recommendations made by GAO. In fact, we have always been following these principles and will continue to do so. We are happy that GAO also believes we should continue to proceed in this manner (see enclosure). In addition, we have communicated our viewpoint to the GAO auditors since receiving their draft report, and they have agreed to include some of our suggestions in their final report.

Sincerely,

J. R. Dailey
Associate Deputy Administrator

Enclosure

GAO Draft Report - Safety and Obsolescence Program

**Activities Proceeding in Agreement With
GAO Recommendations**

Recommendation 1:

"Use...12 to 15 years...time frame as a basis for estimating the life-cycle costs of proposed upgrades."

Response:

NASA agrees that 12 to 15 years is a proper timeframe for estimating proposed Space Shuttle upgrade life-cycle costs. This timeframe will be updated when future Shuttle replacement plans are formalized.

Recommendation 2:

"That the Administrator require decision justifications that include...life-cycle cost analysis of alternatives before obligating funds for Shuttle upgrade projects."

Response:

NASA managers do use life-cycle cost analysis where appropriate in the decision process for proposed Space Shuttle upgrades. Development of long-life fuel cells by the Orbiter and Government Furnished Equipment Projects Office is a good example of life-cycle cost analysis being used for Shuttle upgrade decisions. Long-life fuel cells save money in refurbishment costs over the current fuel cells that are used to generate electrical power for the Shuttle's system.

The alternate high-pressure fuel turbopump program is an example of an upgrade decision where life-cycle cost analysis is not the most significant factor. Life-cycle cost analysis for proposed upgrades to the current high-pressure fuel turbopumps was performed. These upgrades were rejected because they do not accomplish the safety margin improvement objectives for the high-pressure fuel turbopump. The safety margin improvement objectives are (1) eliminate uninspectable welds using a cast housing, (2) improve bearing performance, (3) reduce the number of rotating parts, and (4) reduce material susceptibility to hydrogen embrittlement. Therefore, a decision to redesign the high-pressure turbopump was made. We have reviewed this decision, based on your October 1994 report, and still conclude that an alternate fuel turbopump is the best way to improve the safety margin of the Space Shuttle main engine turbo machinery.

See comment 9.

See comment 10.

Recommendation 3:

"That the Administrator require...an assessment of the risk associated with not providing funds for early design studies and contingency reserves and consider whether in light of these risks the Agency should begin two new upgrades in fiscal year 1995."

2

See comment 11.

Response:

Design studies and requirements definition tasks are currently in progress for the SSME Health Monitoring System and the Reaction Control System Direct Acting Valve upgrades proposed for FY 1995 new starts. The studies are being funded out of FY 1994 safety and obsolescence budget reserves. Results of the studies will be reviewed by Space Shuttle Program management and the Associate Administrator for Space Flight before issuing authority to proceed on the proposed new starts in FY 1995.

The objective of these studies is to ensure a comprehensive definition of the project requirement, cost, and schedule prior to issuing authority to proceed. Adequate contingency funds will be included in the project cost estimates.

The following are GAO's comments on NASA's letter dated April 11, 1994.

GAO Comments

1. NASA said that it had "looked at" operations costs for every safety upgrade. However, agency officials could not provide documentation of current operations cost estimates. One official told us that NASA considers operations costs, but does not follow the regimen of life-cycle cost estimating. Our review found that NASA had not estimated life-cycle costs of the large throat main combustion chamber, a safety upgrade project that started in fiscal year 1994, or the main engine health monitoring system proposed for a new start in fiscal year 1995. The alternate turbopump contractor had prepared a life-cycle cost estimate for that project, but the estimate was prepared about 5 years after the project began and was not updated to reflect circumstances existing in fiscal year 1994 when the alternate fuel turbopump development was to resume.

2. NASA said that the 1991 study did consider design solutions but strongly recommended restart of the alternate fuel turbopump program. We agree that the study recommended restarting the alternate fuel turbopump development program. However, the report also recommended that the decision to restart be evaluated on a life-cycle cost basis. The study identified potential upgrades to the current pump as an alternative to restarting the alternate fuel pump. NASA has not conducted an in-depth study of the potential improvements.

3. NASA said that our report implies that it will be less expensive to redesign the current pump than to continue development/certification of the alternate turbopump. Our report does not say that redesigning the current pump would be less expensive. Our report says that NASA should estimate and compare the total life-cycle costs of both the alternative turbopump and a redesign of the current pump.

4. Space shuttle main engine project officials who are responsible for designing and maintaining the turbopumps told us that the current pumps are expected to last for seven to eight flights and then can be overhauled and used again.

5. This report does not conclude that inadequate project definition has caused schedule stretch-out or cost overruns of safety and obsolescence projects. The report does point out that inadequate definition has led to schedule stretch-outs and cost overruns in other NASA programs. Our point is that unless NASA performs adequate definition studies prior to initiating

safety and obsolescence projects, the same thing could occur in that program.

6. NASA was able to conduct definition studies of the direct acting valve in fiscal years 1993 and 1994 by making funds available from other approved projects. While NASA has been able to provide some definition study funding from its approved programs in the past, there is no assurance that it can continue to do so in the future. We believe that such a funding approach creates additional risks for the safety and obsolescence upgrade program.

7. NASA said that a significant investment has been made in test bed activities involving main engine monitoring and diagnostic activities at the Marshall Space Flight Center. While we do not disagree with this statement, our basic concern remains that a final definition of the main engine health monitoring system is not complete, even though NASA has requested authority to start hardware development in fiscal year 1995. We believe that this approach increases program risks from a cost and schedule standpoint.

8. NASA said that each approved project includes some funding for contingencies, and additional reserves are carried and managed by the shuttle program office at NASA Headquarters for application to programs on an as-required basis. Our draft report recognized that funding for approved projects includes a small amount of reserves, but according to the Safety and Obsolescence Upgrade program manager, additional program reserves are needed in the event of unforeseen problems. A March 1994 analysis by shuttle program officials forecasts no shuttle-level reserves will be available in fiscal year 1995. According to this analysis, substantial program changes will be needed to conduct the shuttle program within the budgeted resources, even if the Congress appropriates all of the funds requested for the program in fiscal year 1995.

9. The alternate turbopump contractor prepared a life-cycle cost estimate in 1991, about 5 years after the turbopump development began. The estimate was not updated to reflect conditions current in 1994, when the fuel turbopump development was to resume. There were significant changes between 1991 and NASA's decision to restart the fuel turbopump development. For example, estimated turbopump development and production costs had increased by over $600 million. Again, we did not conclude that life-cycle costs should be the most important factor in the decision to restart the fuel turbopump development. Our point is that full

cost information should be part of such a decision and help ensure that necessary changes are made to other programs to accommodate future budget constraints.

10. NASA has not conducted a cost and benefit analysis as recommended in our October 1993 report. We are not taking issue with NASA's judgments about safety improvement needs, rather we believe that cost and benefit information is needed in the decision-making process because budget resources are finite.

11. NASA officials told us that the fiscal year 1994 budget reserves were made available through savings in other approved projects. NASA did not provide contingency reserves for the Safety and Obsolescence Upgrade program in its fiscal year 1994 budget. A March 1994 analysis forecasts that significant program changes will be needed just to operate the shuttle within resources required for fiscal year 1995, even if the Congress provides all of the funds requested for that year.

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