REPORT TO THE CONGRESS

BY THE COMPTROLLER GENERAL OF THE UNITED STATES

Status And Issues Relating To The Space Transportation System

National Aeronautics and Space Administration

NASA's revised development plan is introducing risks that could result in increased costs, schedule delays, and performance degradations that were not originally envisioned. The development plan embodies such factors as reduced testing, compressed schedules, and concurrent development and production.

Also important to the current development situation is the recurring question of whether the system will fulfill the space transportation needs of the Nation.

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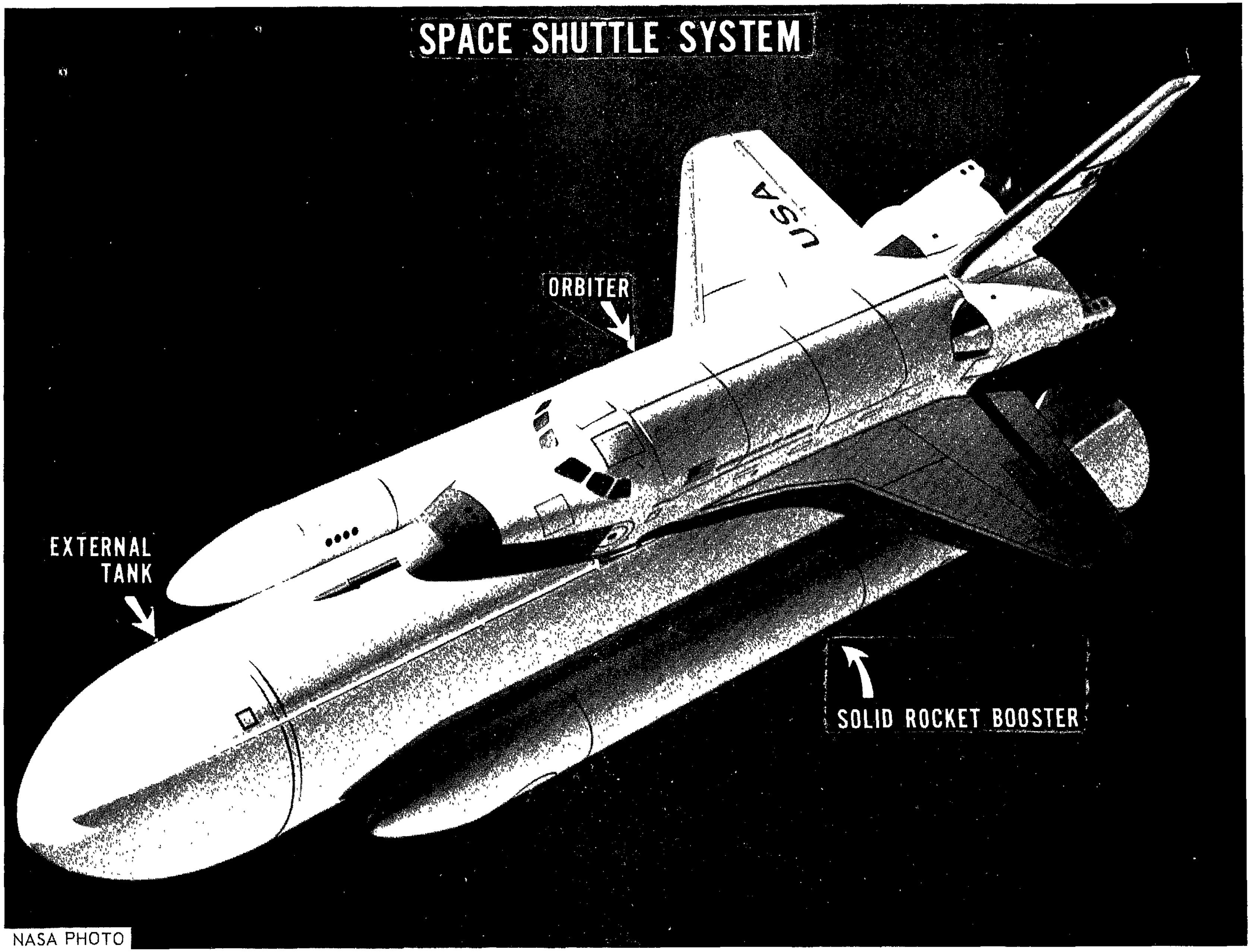
SPACE SHUTTLE SYSTEM
USA
ORBITER
EXTERNAL TANK
SOLID ROCKET BOOSTER
NASA PHOTO

COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON, D.C. 20548

B-183134

To the President of the Senate and the
Speaker of the House of Representatives

We made a study of the National Aeronautics and Space Administration's Space Transportation System. The study was primarily concerned with the space shuttle's status and progress related to cost, schedule, and performance and the rationale and assumptions inherent in the 1973 mission model. The 1973 model was used to compare the revised Space Transportation System program's cost effectiveness with expendable launch systems. This study also reports unverified status data of other major space transportation elements as obtained from the National Aeronautics and Space Administration.

This is our fifth study of the project and because of its significance, we are addressing the report to the Congress to assist it in exercising its legislative and review functions. A copy of this report was reviewed by agency officials associated with the management of the project and their comments are incorporated as appropriate.

We made our study pursuant to the Budget and Accounting Act, 1921 (31 U.S.C. 53), and the Accounting and Auditing Act of 1950 (31 U.S.C. 67).

We are sending copies of this report to the Administrator, National Aeronautics and Space Administration; the Secretaries of Defense and the Air Force; the Administrator, Environmental Protection Agency; and the Director, Office of Management and Budget.

Elmer B. Staats

Comptroller General
of the United States

Contents

ABBREVIATIONS

DDT&E	design, development, test and evaluation
DOD	Department of Defense
GAO	General Accounting Office
IUS	interim upper stage
JSC	Johnson Space Center
KSC	Kennedy Space Center
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
psf	pound per square foot
SAMSO	Space and Missile Systems Organization
SRR	shuttle requirements review
STS	Space Transportation System

COMPTROLLER GENERAL'S REPORT TO THE CONGRESS

STATUS AND ISSUES RELATING TO THE SPACE TRANSPORTATION SYSTEM
National Aeronautics and Space Administration

D I G E S T

The primary objective of the Space Transportation system is to provide a new space transportation capability that will substantially reduce the cost of space operations and support a wide range of scientific, defense, and commercial uses. Of the several contractors involved in the effort, Rockwell International's Space Division is responsible for developing and fabricating five orbiter vehicles and for supporting the National Aeronautics and Space Administration's (NASA's) overall shuttle integration.

PROGRAM COSTS

NASA has developed firm cost estimates for four System elements. The original estimates in 1971 dollars were (1) $5.15 billion for space shuttle design, development, test, and evaluation, (2) $300 million for NASA's space shuttle facilities, (3) $1 billion for production of three orbiters and refurbishment of two development orbiters, and (4) an average cost per flight of $10.45 million. NASA considers estimates for the tug, interim upper stage, spacelab, and operating costs to be preliminary and likely to change when final configurations have been established.

NASA and the Department of Defense plan to request funds from the Congress for fiscal year 1978 to begin the production phase of the System. Costs for refurbishment of two development orbiters, acquisition of three production orbiters, Defense facilities at the western test range, the interim upper stage, and the space tug could eventually amount to about $4.8 billion (real year dollars). Several billion dollars more will be needed for actual operation of the space transportation system during the 1980s. The program has been under development since

1971, and through fiscal year 1976, about $3.1 billion has been authorized and appropriated to NASA and $46 million to Defense. Total acquisition costs of the System are estimated by NASA to exceed $12 billion (real year dollars). Operating costs through 1990 are estimated in excess of $18 billion (real year dollars).

NASA's position is that $5.2 billion in 1971 dollars will be sufficient to meet its revised target dates of March 1979 for the first manned orbital flight and July 1980 1/ for the initial operational capability unless major problems are encountered. According to NASA, the $5.2 billion development estimate equals about $6.9 billion in real year dollars if a 7-percent inflation rate is applied.

Expected cost growth

GAO estimates that the development program will experience cost growth of more than $1 billion as shown in the schedule on page iii.

It is important to recognize that some cost growth is not controllable by NASA as is the case with the $524 million resulting from increases in inflation. The remaining $621 million also contains inflation which could be categorized as controllable because that inflation would not have been incurred if NASA had not decided to delay certain actions to the later years of the program. The increases of $50 million and $376 million as shown in the schedule represent such controllable factors. A primary objective of NASA's decision to delay work was to reduce funding requirements for the early period to stay within overall agency funding limitations imposed by the Office of Management and Budget. Other work planned for the early development years and estimated at $195 million was deleted or transferred to other budgets and to the production and operational phases of the program,

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1/In February 1976, NASA informed us that the July 1980 date for the initial operational capability has been changed to May 1980.

Expected Cost Growth Identified on Space Shuttle Design, Development, Test, and Evaluation Portion of the Space Transportation System

	Cost estimates	
	(billions)	
Original NASA estimate in 1971 dollars		$5.150
Expected inflation at 5 percent (note a)		.832
Subtotal		5.982
Expected cost growth:		
Inflation using 7 percent rate instead of 5 percent rate (note b)	$.524	
Increase in NASA's 1971 dollar estimate caused by rephasing work to later years	.050	
Increased costs caused by the effect of inflation on expenditures deferred by NASA to later years	.376	
Additional development costs included in other budgets and not reported by NASA as System costs	.195	
Subtotal		1.145
Current estimate for design, development, test, and evaluation		$7.127

a/Not reported by GAO as cost growth. During fiscal year 1972 congressional budget hearings for approval of space shuttle development, NASA stated that it expected additional costs would be incurred because of inflation. Although the inflation rate was not specified, NASA's internal records and subsequent congressional testimony indicates that a 5-percent inflation rate was expected.

b/NASA assumed a 7-percent annual inflation rate for fiscal year 1974, 8.3 percent for fiscal year 1975, and 9.3 percent for fiscal year 1976. A 7-percent rate is used for fiscal year 1977 and beyond.

but NASA did not reduce its total program cost estimate by the cost of the work deleted or transferred.

NASA does not agree with the $1 billion cost growth projection primarily because it has never taken an official position on the amount of inflation which will be experienced. In addition, it believes total budget transfers are only $111.7 million. (See pp. 48, 52, and 53.)

NASA has not estimated additional cost growth which can be expected from the change in its development plan.

Changes in other System elements

The status of other program elements, including production, cost per flight (operations), construction of facilities, upper stages, and the spacelab have changed since our February 1975 report. (See ch. 4.) Generally, budget limitations have caused reductions and delayed starts in the other program elements. These, in turn, have increased costs because of inefficiencies in the revised development plan and the additional inflation which may be experienced because of the delays. For example, a NASA study showed that certain actions considered during the shuttle requirements review to reduce early year funding by an estimated $476.1 million was expected to increase the total System cost by an estimated $793.9 million. While most of the actions were taken, some were implemented in a different manner than proposed. Thus, NASA considers these costs as misleading but has not determined the total impact of actual changes.

RECOMMENDATIONS

--The Administrator, NASA, should estimate and total all costs, including those funded from other budgets. This would result in more complete and realistic estimates of the cost to develop the Space Transportation System.

--The Administrator, NASA, should present estimates to the Congress in real year dollars. These estimates should be compared to the real year dollar amounts anticipated at the time the 1971 estimate was prepared. This would allow a more meaningful analysis of the program's status and permit specific identification of reasons for cost changes.

OTHER ISSUES

Changes in the shuttle design, development, test, and evaluation plan

Office of Management and Budget funding constraints have resulted in changes in NASA's development plan for the space shuttle design, development, test, and evaluation program. In addition to the cost impact discussed above:

--The development completion date has been extended by 16 months 1/.

--Development schedules have been compressed. As a result, less time will be available to solve major technical problems that may occur. (See pp. 39 through 42.)

--Development testing has been reduced to the extent that there is less testing planned than on past programs. (See pp. 39 and 42 through 44.)

--Significant contingency reserves have already been allocated. In total, program reserves have declined by over 55 percent since NASA initiated the development program while only 30 percent of the projected funding had been obligated as of October 31, 1975. This could result in additional funds being needed before the program is completed. (See pp. 37 through 39.)

NASA believes the program adjustments discussed above have been reasonable and have not resulted in unacceptable cost, schedule, or technical risks.

1/See footnote on page ii.

Although the effect of the interaction of the above factors on design, development, test, and evaluation is not precisely predictable, historical evidence suggests the probable outcome will be increased cost and reduced performance coupled with a longer period of uncertainty as to whether the space shuttle can reliably carry out its space transportation mission.

Justification for the System uncertain

NASA estimated total economic benefits of $14.1 billion (1972 dollars) for the System over expendable vehicles. For these benefits and other justifications to become a reality, it would be necessary for NASA to have a stable budget level ($3.3 billion in 1972 dollars), to greatly reduce space operations costs, and to increase transportation capabilities. Achievement of these goals is uncertain because (1) NASA's and other Government agencies' future funding levels cannot be precisely predicted and (2) changes in the shuttle's development plan have reduced the probability of meeting cost, schedule, and/or performance goals. (See chs. 2 and 3.)

GAO did not validate NASA's projected benefits because NASA's cost estimating techniques and analogies were similar to those in its 1971 cost-benefit study previously analyzed and reported by GAO (B-173677, June 1, 1973). At that time GAO did not place too much confidence in NASA's projected cost savings due to the uncertainty of its cost estimates. Subsequent GAO reviews have generally substantiated its previous findings.

NASA believes the space shuttle offers the greatest capability of satisfying the Nation's space transportation needs in the most economical manner.

Environmental effects

NASA's July 1972 "Environmental Statement for the Space Shuttle Program" concluded that the potential effects would be environmentally acceptable, localized, of short duration, and controllable. Continuing studies by NASA, however, show that there is much uncertainty as to the extent to which shuttle operations will affect the environment. (See p. 64.) For example, sonic booms have been predicted to be more than double the level originally cited in 1972 statement as acceptable. According to NASA, however, operational and design changes are being considered that will keep them to the originally predicted level. It has not yet been determined whether NASA will be subject to statutes prohibiting sonic booms over the United States. NASA does not believe it is subject to these statutes because it does not define the space shuttle as an aircraft. Other uncertainties include

--the rate of ozone depletion in the stratosphere;

--the effects of ozone redistribution;

--the medical and ecological effects of ozone depletion, such as increased skin cancer and decreased agricultural productivity due to increased ultraviolet radiation; and

--the potential hazards of shuttle exhaust emissions near the launch sites.

According to NASA it has done considerable work in the last year on the potential uncertainties and believes them to be even less of a problem than previously stated.

Range safety

Problems related to range safety for development flights seem to be near solution. An open issue remains regarding applications of range safety systems to operational flights. (See ch. 6.)

Defense-NASA interface

The Department of Defense is committed to use the space shuttle as its primary launch vehicle after 1980. The scope and the schedule of Defense participation is contingent on a number of factors including

--NASA's ability to successfully accomplish program milestones leading to an initial operational capability of mid-1980 for the space shuttle;

--the number and cost of orbiters, if any, to be procured by Defense (Defense and NASA have agreed to resolve the issue of funding for additional orbiters by the fiscal year 1978 budget cycle.);

--the amount and nature of user charges; and

--availability of funds.

The total investment cost of Defense participation, excluding orbiters, is estimated at $1.8 billion in 1975 dollars but is being further refined as the program progresses and Defense requirements become more definitive. If Defense funds two orbiters, its participation is estimated at $2.6 billion in 1975 dollars. (See p. 81.)

Defense believes the space shuttle will provide increased military capability and offer the potential for reduced space program costs. The program has not, however, progressed to the stage at which Defense can fully substantiate all these benefits. In fact, several Air Force cost-benefit studies have suggested it may be more costly than continued use of expendable vehicles. (See pp. 80 and 81.)

QUESTIONS FOR CONSIDERATION BY THE CONGRESS

In future deliberations on authorizing and appropriating funds for development, production, and operational phases of the Space Transportation System program, the Congress should consider the following:

--Should separate budget line items be established for space shuttle development, production, and operations to insure better program visibility? The completion date for the development program may need to be extended to encompass testing planned to verify the capabilities of the space shuttle. Should the cost of all development tests be included as a cost of the development program?

--Could or should the space shuttle alone fulfill all the Nation's space transportation needs? For instance, it is possible that two systems competing in both development and operations could (1) offer greater flexibility in the level of space exploration, (2) offer opportunities to maintain a broader industrial base to support the national space goals, and (3) maintain proven systems over a longer timespan. In addition, using the space shuttle as a research program to develop and demonstrate reusability technology while maintaining and improving competing expendable systems could offer the flexibility to accommodate unknown needs for space research or exploration in the 1980s.

--Should funding authority for orbiter production and western test range facilities be delayed until the benefits of a single space transportation system could be substantiated? Possible additional advantages for delayed funding which should be explored include:

1. Potential cost savings by eliminating concurrent development and production and providing an opportunity to demonstrate that the objectives of the shuttle will be attained before committing funds for full-scale operations. Past experience in major Government acquisitions has shown that NASA's development approach can lead to costly retrofit or redesign at a later date or to deploying systems that cannot adequately fulfill their intended role. Eliminating concurrent development and production would be consistent with the "fly before buy" concept used by Defense.

2. The opportunity before committing funds to better define space transportation requirements during the 1980s. The large increase in space science postulated by NASA, which is needed to justify expansion of the shuttle beyond the research and development stage, will undoubtedly have to compete for available scientific research funds.

3. The chance to answer key environmental questions and solve potential problems before commitment of additional funds. The two primary unresolved issues involve sonic booms over major U.S. land masses and ozone depletion in the upper atmosphere.

--When do NASA and Defense plan to decide and resolve the extent to which operational flights will require a range safety system and to determine what, if any, impact the range safety system will have on the shuttle's capabilities and cost per flight?

The following additional questions relate to matters identified but not fully developed during our review. The Congress may wish to pursue these matters further during future authorization and appropriation deliberations.

1. What is Defense's reason for delaying the decision to procure the two orbiters and why has it recommended NASA assume responsibility for procuring orbiters?

2. What is NASA's justification for continuing the planning and development of the space tug when few satellites are projected to be recovered from high-energy orbits and Defense selection of a solid propellant interim upper stage is expected to have a comparatively low operating cost?

3. How does NASA expect to meet the provisions of the United States Code (49 U.S.C. 1431), as implemented by the Federal Aviation Administration, prohibiting civil aircraft, including Government aircraft carrying commercial cargo, from creating sonic booms over the United States in the absence of a waiver by the Federal Aviation Administration? Should the present law be clarified or should new legislation be enacted before the first landing will occur?

4. Why has NASA not held public hearings on the potential environmental effects of

the space shuttle, particularly on the expected sonic booms, to judge their acceptability to the public?

5. Why has NASA not disclosed the increased costs resulting from Office of Management and Budget funding cuts to the Congress so that congressional budget committees could have more information to assess NASA budget requirements?

6. Why has NASA not provided Defense an official user charge estimate for the space shuttle?

7. What are the scope and results of the Air Force studies concerning the technical and economic feasibility of recovery, refurbishment, and reuse of Defense satellites?

AGENCY COMMENTS

A draft of this report was reviewed by NASA and Defense officials associated with managing the System. The agencies' views regarding differences of opinion on specific issues are appropriately reflected in the relevant sections of this report. Further, there are no residual differences in fact. There are differences related to the interpretation of some data and opinions expressed. These differences of opinion on specific issues or in the interpretation of data are reflected in the relevant sections of this report.

At NASA's request additional NASA comments are included at the end of chapters 2, 3, and 6. GAO carefully evaluated these comments and determined that they have already been adequately covered, as stated above, or that they are not directly pertinent to our findings, conclusions, and recommendations.

Letters received from NASA and the Office of Management and Budget commenting on the draft report are included as appendixes I and II, respectively.

CHAPTER 1

INTRODUCTION

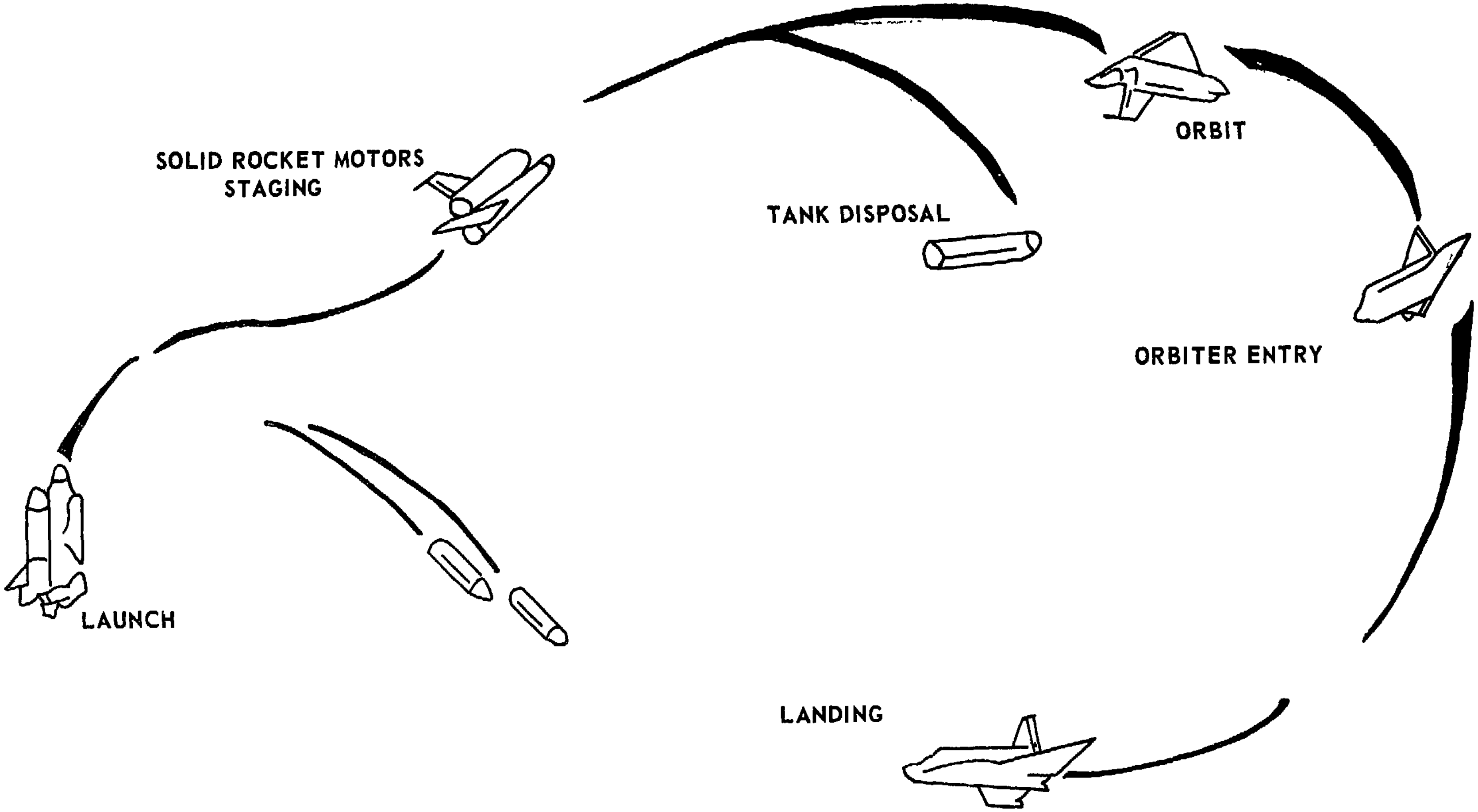
This is the fifth GAO study of the Space Transportation System under development by the National Aeronautics and Space Administration. This updates the program's status which was reported in our February 1975 study.

The primary objective of STS is to provide a new space transportation capability that will substantially reduce the cost of space operations and support a wide range of scientific, defense, and commercial uses. The STS will include the space shuttle, spacelab, space tug and the interim upper stage. The space shuttle will consist of a manned reusable orbiter, which looks like a delta-winged airplane; an expendable, liquid propellant tank; and two reusable solid rocket boosters.

It will be boosted into space through the simultaneous burn of the space shuttle main engines and the rocket boosters. At an altitude of about 25 miles the boosters will detach and descend into the ocean by parachute for recovery and reuse. The main engine burn will continue until the orbiter and external tank are near orbit velocity, at which time the tank will be disposed of in a predetermined remote ocean site.

After completing its space mission, the orbiter will reenter the earth's atmosphere and glide to an aircraft-like landing at one of two designated landing sites. A pictorial of a shuttle mission follows.

MISSION PROFILE



The space shuttle will be designed to place 65,000 pounds into a 150-nautical-mile due-east orbit and 32,000 pounds into a specified 100-nautical-mile near-polar orbit.

The space tug is a propulsive upper stage that extends the shuttle's capabilities to greater altitudes than those achievable by the orbiter alone. The tug is not expected to be operational before July 1985. During the 1980-85 period, an interim upper stage, in lieu of the tug, will be used but will have less capability than the space tug.

The spacelab is being developed under a cooperative program with the European Space Agency as a laboratory and observatory for in-orbit space research.

RESPONSIBILITIES

NASA has the primary responsibility for overall program management and integration of the space shuttle and space tug and will fund their development, including all facilities for development and operations at the Kennedy Space Center (KSC). Overall program direction is the responsibility of the Program Director in Washington. The authority to manage the shuttle and tug program on a day-to-day basis had been delegated to the Johnson Space Center (JSC) and Marshall Space Flight Center (MSFC), respectively, as the lead centers.

A new management directive was recently adopted for the space shuttle which states that all requirements changes exceeding $500,000 in any fiscal year must now be approved by the Space Shuttle Program Director. NASA said the reasons for the management change were due to funding constraints resulting from Office of Management and Budget reductions and the desire for closer program control.

Project managers have been designated for the orbiter, solid rocket boosters, main engine, external tank, and the launch and landing systems. These managers are responsible for the design and development of their projects and report directly to the Space Shuttle Program Manager at JSC.

The Department of Defense has named the U.S. Air Force as the organization responsible for assuring that DOD's interests are considered and for making provisions for the DOD STS program. Since DOD missions require an upper stage prior to the availability of NASA's full capability space tug, DOD has agreed to develop an interim upper stage by June 1980. The Air Force has named the Space and Missile Systems Organization (SAMSO) as the implementing agency for matters pertaining to DOD utilization of STS.

The responsibility for development, production, and operational support for the space shuttle is divided among four prime contractors and numerous subcontractors. Rockwell International's Space Division will develop and plans to fabricate five orbiter vehicles. It is also responsible for supporting JSC as lead center for overall shuttle integration.

The remaining contractors are (1) Rockwell International's Rocketdyne Division--main engine, (2) Martin Marietta Corporation, Denver Division--external tank, and (3) Thiokol Chemical

Corporation--solid rocket motor portion of the booster. MSFC will continue to design the booster during the initial phase of the program. Details concerning the contracts are in appendix III. A contractor has not been selected for either the tug or the interim upper stage. DOD plans to award the interim upper stage contract in September 1976; NASA is uncertain as to when the space tug contract will be let. (See pp. 62 and 87.)

PROGRESS IN RESOLVING ACCESS TO RECORDS PROBLEMS

Attempts with NASA to resolve access to records issues encountered during our previous STS reviews have resulted in significant improvements. We are continuing to work with NASA officials in an attempt to totally resolve this issue.

ESTIMATED STS PROGRAM COSTS

In March 1972 when the Congress approved the program, NASA presented to the Congress the results of an analysis of the development and operations of STS from 1972 through 1990 on the basis of a mission model of 581 flights. The purpose of the analysis was to compare the economics of the STS program with alternate programs of existing and/or new expendable launch systems. The following table presents the 1971 dollar cost estimates from this analysis together with the current estimates, including provisions for inflation (real year dollars). The inflated estimates are internal NASA and DOD estimates and do not represent official agency positions.

Estimated Space Transportation System Costs Through 1990

Elements		Original estimate in 1971 dollars	Current estimate in real year dollars(a)
		(billions)	
Nonrecurring costs:			
Space shuttle development costs (DDT&E)		$5.150	$ 6.932
Orbiter inventory (refurbishment of the two development orbiters and production of three orbiters)		1.000	2.234
Facilities (including two launch sites):			
NASA	$ .300		
DOD	.500	.800	1.449
Modifications and requirements for expendable stage (note b) (interim upper stage)		.290	.241
Reusable space tugs:			
DDT&E	$ .638		
Production	.171	.809	1.303
Total nonrecurring costs		8.049	12.159
Recurring costs during operations		8.050	(c)
Total		$16.099	(c)

[a] These estimates are internal NASA and DOD estimates and do not represent official agency positions.

[b] Original and current estimates are for different configurations of the expendable stage.

[c] Estimates not available.

The $16.1 billion estimate (1971 dollars) does not include inflation over the life of the program, spacelab, all Government salaries, and travel and certain related costs to be funded through NASA's research and development appropriation. During fiscal year 1975 testimony before the Senate Committee on Appropriations, NASA estimated about $2.3 billion would be required for these last two categories. A complete cost estimate for development and operation of STS has not been provided to the Congress.

NASA made indepth reviews of cost estimates for three STS elements to establish cost estimates which can be used for tracking NASA's progress. These estimates in 1971 dollars are (1) $5.15 billion for the space shuttle DDT&E, (2) $300 million for NASA's space shuttle facilities, and (3) $1 billion for refurbishment of two development orbiters and production of three orbiters. Apart from the March 1972 analysis, NASA estimated $10.45 million in 1971 dollars as the average cost per flight for the recurring cost of operating the shuttle.

NASA's internal cost estimates consider an inflation factor through the life of the program. For this reason, cost estimates in this study are based on real year dollars unless otherwise stated. NASA states that these inflated estimates are preliminary and should not be construed as official NASA estimates.

We have used cost estimates prepared by project offices (field centers) during NASA's budget process as the basis for analyzing the status and expected outcome of the shuttle development program. NASA does not believe that such an approach will produce valid conclusions because Headquarters continually assesses the validity of field center resource estimates. According to NASA, these assessments bring to bear the collective experience and judgment of various levels of NASA management over all field center resource requirements. This frequently results in increases, decreases and consolidations over the original field center estimates. NASA believes that field center identified resource requirements should not be considered hard facts until they have been approved by higher NASA management.

We recognize that field center estimates do not represent NASA's official position. However, we do not believe either Headquarters' or field center's estimates include costs for all development work necessary to complete the program. This is because of NASA's management to cost techniques used to prevent estimates from exceeding funding limitations. Since field center estimates are more complete than Headquarters' estimates and are made by personnel charged with the program's day-to-day management, they should be more representative of the expected outcome of the program.

CHAPTER 2

1973 MISSION MODEL

The 1973 mission model represents a compilation of the number and types of payloads which NASA believes could be flown under certain assumptions. With certain exceptions in DOD, the model does not reflect firm or tangible payload requirements during the space shuttle era (1980-91). The model clearly demonstrates that sufficient payloads can be developed to fully use the STS, assuming that NASA will have a stable budget level ($3.3 billion in 1972 dollars). This assumption may not be valid since NASA and other Government agencies request approval of program activities (including payloads) on a year-by-year basis; thus the space shuttle's flight profile is, and will likely remain, uncertain.

BACKGROUND

NASA used a number of traffic and mission models, ranging from 445 to 779 flights, for STS planning and justification. The 1971 mission model, containing 581 flights, was used to seek congressional approval of the STS. Later, NASA developed the 1973 mission model to provide a long-term projection of candidate shuttle payloads to compare the revised STS program's cost effectiveness with expendable launch systems. This 1973 model, which NASA presented to the Congress in October 1973, consisted of 986 payloads to be flown on 725 flights from 1980 through 1991. The model required the acquisition of seven orbiters while NASA's planned STS program presented to the Congress only provided for five orbiters.

To assist it in developing the NASA payloads, NASA sponsored several workshops for scientists to express their views on how the STS could best be used. In order not to inhibit the study groups, NASA instructed them to ignore funding constraints and program priorities.

NASA recently announced that a new 572-flight traffic model would be used to assess the technical and procurement requirements for the STS program. Specific payloads have not been applied to the new model. No evidence has been provided to us to suggest that this new model of 572 flights will not also be affected by the uncertainties identified and discussed below.

VALIDITY OF COST-BENEFIT ASSUMPTIONS

NASA's cost-benefit analysis of the 1973 model showed a dominant STS economic advantage. NASA claimed a $14.1 billion savings (1972 dollars) for the STS over expendable vehicles. The savings were due primarily to reductions in payload costs, not to transportation costs. This was because the higher initial investment required for the STS more than offset a $4.4 billion savings projected for recurring transportation costs. During fiscal year 1976 hearings, NASA reiterated its belief that the economic benefits in this study are one of the primary justifications of the STS.

We did not validate these projected savings, because the cost estimating techniques and analogies NASA used were similar to those in NASA's 1971 cost-benefit study which we previously analyzed and reported on (B-173677, June 1, 1973). At the time our report was issued, we did not place too much confidence in NASA's projected cost savings due to the uncertainty of its cost estimates. In addition, we were not convinced that the choice of a launch system should be based principally on cost comparisons.

Our later reviews have generally substantiated our previous findings. For example:

--Significant costs have been excluded from the analysis. For instance, about $2.3 billion of NASA in-house costs for shuttle development and an undetermined amount of the same costs for STS facilities and tug development were not considered in the analysis. The costs should have been included. NASA stated that similar in-house expenditures for other program elements would be required to accomplish an equivalent science and application program using expendable vehicles. Therefore, NASA believes that including in-house costs in the analysis would not have changed the conclusions. Because NASA did not compute all in-house costs for either alternative, we could not determine that these costs would have been the same. We believe that the in-house costs should have been computed for both alternatives and included in the analysis.

--Changes in the shuttle's development plan have reduced the probability of meeting cost and performance goals.

--The innovative design and refurbishment techniques, which account for much of the projected payload savings, are controversial issues. (See pp. 15 through 17.)

In addition, an Air Force cost-benefits analysis completed in November 1975 shows that the STS will not reduce the total cost of the DOD space program through 1991 unless payloads are recovered and refurbished. DOD plans to refurbish payloads if economically and technically feasible. It is studying this concept, but has not yet made a decision. (See p. 16.)

Effects of reduced launch rates

The STS economic benefits, as shown in the 1973 mission model, will vary with the number of flights projected for the shuttle era. Generally, the more flights, the greater the shuttle's advantage; the less flights, the more attractive the expendable systems become from a cost viewpoint because the STS's development and investment cost would be prorated over fewer flights. Based on its analysis, NASA concluded that the STS will be cost effective at 25 flights a year. The analysis, however, did not include costs such as in-house effort required for STS development. If these amounts had been considered, the conclusions may have been different.

Reducing flights by using multiple payloads could increase shuttle efficiency. The 1973 model assumed that 29 percent of the flights would carry multiple payloads.

From a practical viewpoint, a number of obstacles to combining payloads exist; for example, payload weights, dimensions, and orbital requirements must be compatible. Several payloads must be developed and be available for the same shuttle flight. A schedule slippage on one payload could increase cost to the other(s), potentially invalidating the expected savings of the multiple-payload flight. Therefore, developing launch schedules will require careful planning and close coordination between NASA and DOD, other Government agencies, foreign governments, and commercial users. Both DOD and NASA are currently studying the potential for combining payloads. According to NASA, the space shuttle will provide a much more flexible launch schedule than present space transportation.

VALIDITY OF LAUNCH RATE ASSUMPTIONS

The 1973 model projects an average of 60 launches a year compared with the 38 launches planned during 1975 using expendable vehicles. Thus, the model reflects a 58-percent increase in launches over the 1975 plan and a 50-percent increase in launches over the preceeding 10 year average of 40. However, potential shuttle users are not committed to a specific number of flights and, with minor exceptions in DOD, funds have not been committed to develop specific payloads. These launch rates depend on the validity of NASA's assumptions that it will receive a constant funding level and meet all STS cost and performance goals. Because of the uncertainties of these assumptions, there is some question whether the projected launch rates will be possible.

We agree with NASA that the probability of flying specific payloads in the model is low because the Nation's space program is too dynamic to permit precise projections over an 18-year period. For procurement planning, NASA has adopted a lower flight model.

Unpredictable funding level

Neither the Congress nor the Office of Management and Budget is committed to giving NASA a $3.3 billion (1972 dollars) constant level budget. Whether they will provide this level budget through 1991 is unpredictable. NASA's fiscal year 1976 budget gives some indication of what could happen. NASA's purchasing power has declined up to $500 million, or 15 percent, after adjusting for inflation. This has reduced NASA's ability to fund all new payloads, including those for the shuttle. For example, NASA's fiscal year 1976 budget did not provide any funds for new payload starts. Although this was consistent with the President's policy, the 1973 model assumed $154 million (1972 dollars) would be available for new starts.

The 1973 model projects that over 50 percent of the $3.3 billion (1972 dollars) annual budget would be available after 1982 for payload development and launch operations assuming

--a 58-percent reduction in basic research and development and operational support[1] and

--no new major development programs, other than payloads, during the shuttle era.

It seems unlikely that either condition will occur. For example, in the 1973 model, NASA assumed an 11-percent decline in the Office of Aeronautical and Space Technology's operational base. The House Committee on Science and Technology

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[1] According to NASA, the 58-percent reduction results primarily from completion of shuttle development.

recently urged NASA to resume and continue a modest growth rate in this area. NASA also has several new development programs under study (including a follow-on fully reusable shuttle), each of which, if approved, will compete with payloads for available funds.

Optimistic cost goals

According to NASA, reducing recurring transportation and payload costs will encourage greater use of space. This theory accounts for much of the model's increased flight activity. Thus, failure to achieve these cost reductions could invalidate NASA's projected launch rates.

Ability to achieve cost reductions

Payload savings, which account for most of the cost reductions, are made possible by the shuttle's capability to retrieve payloads for refurbishment and reuse and to deliver heavier, bulkier payloads. Checking out payloads in orbit and retrieving malfunctioning payloads permit acceptance of less reliable payloads and greatly reduced ground testing. Removing weight and volume constraints allows cost savings techniques, such as modular design, less sophisticated componentry, and more rugged hardware.

Payload refurbishment and reuse account for 75 percent of the payload savings in the model, but several sources outside NASA have stated that the amount of these savings is uncertain. Several contractors, for example, told us that unforeseen factors in handling the payloads might result in the actual savings being higher or lower because payloads have never been returned for refurbishment. According to one scientific study group, payload recovery and in-orbit servicing would be of value for the large expensive systems such as orbiting observatories, but the advantages are unclear for the less expensive payloads. The model projects a 61-percent savings in unit production cost by refurbishing the lower cost payloads and a 68-percent savings for the high cost payloads.

Several experts testifying before the Senate Committee on Aeronautical and Space Sciences in 1973 concluded that payload recovery and reuse is probably invalid for most NASA and non-NASA payloads[1]. The experts concluded, partly on the basis of scientific and technological obsolescence that occurs during the several year lifetimes of those payloads, that reuse may only be plausible for routine DOD surveillance satellites.

DOD has not yet decided whether it is economically and technically feasible to reuse payloads. According to the Air Force its studies show that refurbishment might be feasible for one or two of their satellite programs and one program is tentatively planning reuse. The Director of Defense Research and Engineering believes that in-orbit maintenance and servicing of payloads will not be attractive until the latter part of the 1980s. Thus, the expected savings will not begin until several years later than projected in the model.

NASA concluded that low cost design techniques could be applied to 60 percent of the payloads in the model with cost

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[1] Other experts in testimony to the same committee concluded that reuse is a valid approach to reducing space flight costs.

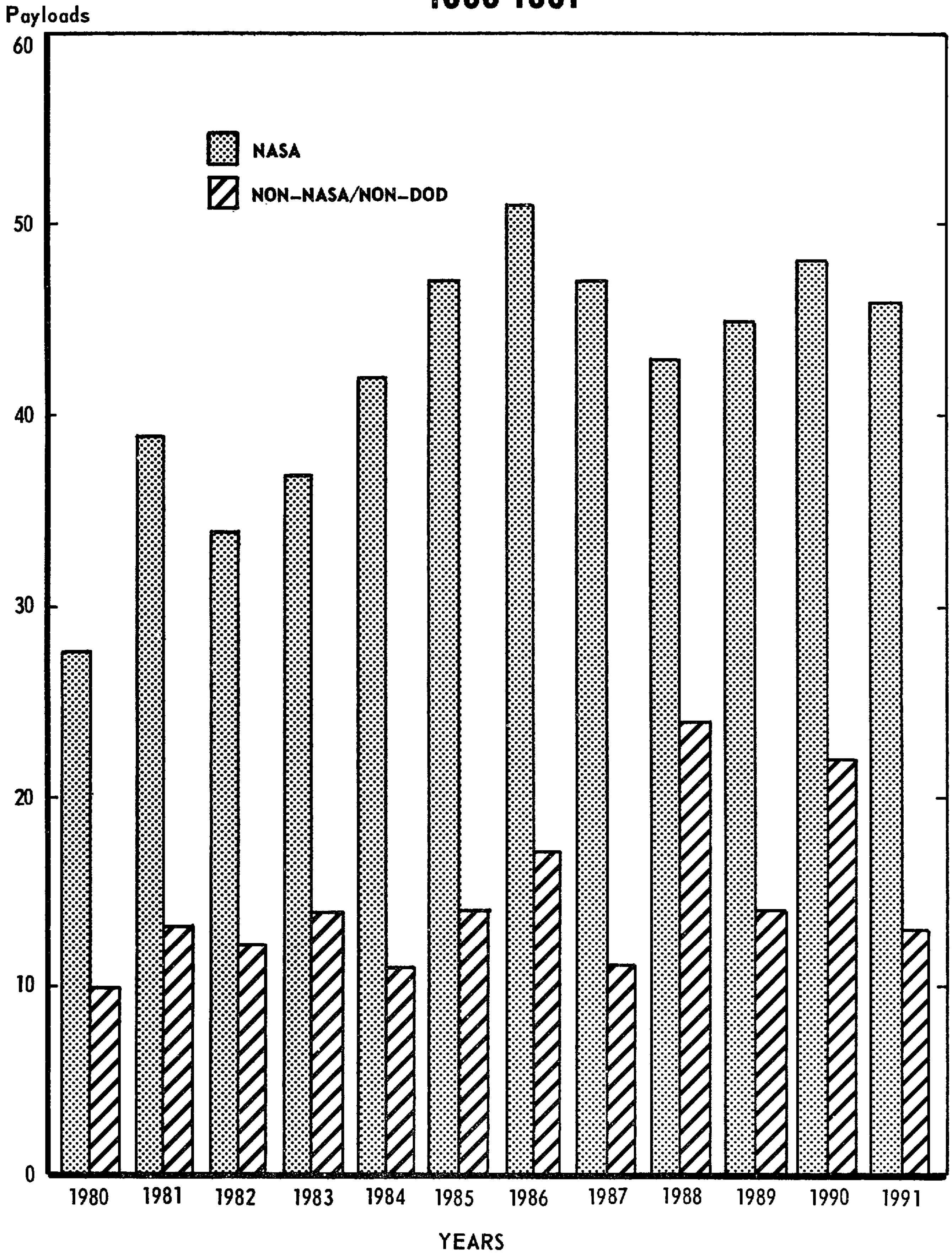
savings of 21 to 50 percent. The Federation of American Scientists stated that, while some savings were undoubtedly possible with such techniques, low-cost design was inconsistent with the trend in the American aerospace industry; that is, emphasis on high reliability, microminiaturization, and ruggedness.

With regard to reliability, a July 1975 NASA study of 57 Goddard Space Flight Center spacecraft shows that a sevenfold increase in failures during the first 30 days in space would have occurred if system-level environmental tests had not been conducted on the spacecraft. The study discusses low-cost design concepts during the shuttle era and concludes that "No change * * * in test philosophy or practice is recommended until test and space performance show the additional risk is cost effective." NASA advised us that this recommendation is consistent with its plans.

Cost to individual users

Although NASA's cost-benefit analysis shows that the STS will lower the cost of space operations, this may not be true for individual users. Not all payloads will benefit from low-cost design techniques and refurbishment. In the 1973 mission model, 40 percent of the payloads do not benefit from low-cost design and 46 percent are not refurbished. DOD, which has 31 percent of the payloads, is committed to use the shuttle, but has no firm plans to refurbish payloads. Therefore, since NASA payloads make up 51 percent of the model, NASA should benefit the most from payload refurbishment. (See p. 18.)

NASA AND NON-NASA/NON-DOD PAYLOADS 1980-1991



SOURCE: 1973 MISSION MODEL

An absolute comparison of the transportation costs for the space shuttle and expendable systems will not be possible until NASA completes its study of the cost to be charged shuttle users. However, the shuttle may not always reduce the user's transportation cost. For example, the projected flight cost for the Thor Delta is $9.3 million less than the preliminary shuttle flight cost[1] NASA gave DOD. Thus, for payloads weighing up to 5,000 pounds, Delta's delivery capability, users might prefer the expendable vehicle if given a choice. Payloads would have to be combined on a single flight before the shuttle would be cost competitive.

For heavier payloads, and particularly high energy-payload flights which are 43 percent of the model, the Atlas/Centaur may be cost competitive for payloads flown singularly. Considering the estimated recurring cost of the interim upper stage[2], use of the shuttle would cost about $24.9 million to place a high-energy payload in orbit, or about $5.5 million more than the Atlas/Centaur.

NASA believes the direct cost comparisons made above would occur only when the shuttle was used far below its capability. Its position is that only in the case of an overriding priority would these light payloads be flown singularly and that under normal circumstances the carrying of several payloads on each flight would result in the cost comparison strongly favoring the shuttle.

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[1] Based on an average flight cost of the first 5 years of shuttle operations.

[2] Based on Air Force estimates of $5.5 million for each interim upper stage flight. We were subsequently advised that the cost was reduced to $4.3 million.

Uncertain performance goals

Effective STS use largely depends on NASA's ability to achieve the performance goals established for the system. Under NASA's management to cost philosophy (see ch. 3), many of these goals may not be achieved when scheduled because of trade offs made by NASA to minimize costs. Although the STS operational capability is yet to be determined, the following examples illustrate the optimism inherent in the model.

Buildup rates

The model assumed that STS development and production would progress sufficiently to support 85 flights during the first 3 years of the program (1980-82). Development and production have not progressed as planned. In October 1974 NASA considerably realined buildup rates. The new rate contains 44 fewer flights, or almost 48 percent less during this period. The shuttle development program is currently proceeding under a relatively higher schedule risk (see ch. 3) than originally planned. Major schedule delays could further reduce buildup rates and invalidate the current flight model.

Payload carrying capability

Decreases in the space shuttle's payload weight carrying capability could affect the number of flights in the model. As the space shuttle's development has progressed, at least two factors have been identified which could reduce the system's capability.

--Shuttle payload carrying capability could be reduced by 2,000 to 7,000 pounds if alternative solid rocket propellants must be adopted to overcome environmental problems. (See p. 70.)

--Payload delivery capability could be reduced if the shuttle vehicle's weight increases. According to a team of aeronautical and space engineers that NASA contracted to evaluate the program, the orbiter and external tank weight could exceed design goals by as much as 5 percent, or about 11,000 pounds.

An 11,000 pound decrease in payload carrying capability could impact 30 percent of the model's 501 projected nonmilitary flights. Although such flight losses could be minimized by changing other model assumptions, such as the manner in which payloads are grouped, large reductions in the shuttle's expected capability would affect the utility of the STS program.

Availability of full performance tug

The 1973 model assumed that the space tug with payload retrieval capability would be available late in 1983. Due to funding constraints, however, the tug may not be available until at least 2 years later. About 19 high-energy payloads (orbital requirements above shuttle capability) were planned for retrieval during this period. Unless these payloads can effectively be retrieved and reused during later years, the total number of flights projected through 1991 will be reduced. According to NASA the availability or loss of the space tug with payload retrieval capability would have a relatively small effect on the total calculated shuttle benefits.

In addition, the basic interim upper stage being developed by SAMSO will not have the capability to place in orbit seven NASA payloads in the model. (See p. 87 for further details.) Alternative approaches will have to be considered for these payloads.

ADDITIONAL NASA COMMENTS

NASA states:

"Obviously, in 1973 there were no commitments in the space program for the 1980s and the 1990s. It was therefore necessary to base our planning for the use of the Shuttle on our best projection of the opportunities which space affords within what were considered to be reasonable budget assumptions. The 1973 Mission Model, which defined the program on which the analysis was based, was the result of planning studies by the National Academy of Sciences; ten separate working groups within the science and applications disciplines with members from both within and outside of NASA; an input from the European Space Research Organization (now the European Space Agency) and the Deparment of Defense.

"The thinking and planning of these individual groups was combined into the overall model, with an assumed level NASA budget (level in 1972 dollars). Although our budget has decreased somewhat, and our detailed thinking about individual missions has changed, we see no reason to revise the model as a statement of the type of program which is reasonable to plan toward for the 80's and early 90's.

"One of the most fundamental objectives motivating the development of the Shuttle is the opportunity which it provides for innovative approaches to space system design and operations. Many of the system characteristics: the large volume and weight capability, the presence of man to provide assistance on orbit, and the return to earth capability, all provide such opportunities. The capability of the shuttle into low earth orbit is 13 times that of the Thor Delta, and the combination of the shuttle and the interim upper stage is somewhat greater than 3 times the capability of the Atlas Centaur. The principal justification of the Spacelab itself is principally to allow new approaches to space observations and experimental activity. NASA did not establish this objective casually, but after considerable study determined that it was fundamental to effective development of the opportunities which space affords.

"As we are proceeding with design and development of Spacelab payloads and multi-mission spacecraft and the definition of large facilities such as the Space Telescope, it is becoming increasingly apparent that our decision was correct and that, in fact, spacecraft developers who do not take advantage of these systems characteristics will not remain competitive with those who do.

"In performing an economic analysis as comprehensive as the 1973 Mission Model, it is necessary to establish certain baseline assumptions. We considered it realistic that the nation would continue to pursue dynamic science, applications and manned programs in space and therefore, realistic to project that NASA's budget would continue level at $3.3 billion (1972 $). One of the big questions at the time was would NASA's budget need to be increased to fully utilize the operational Shuttle's capability. The analysis demonstrated clearly that no budget increase would be required. In fact, at the $3.3 billion level, the Shuttle sustained a dominant economic advantage ($14 billion) over the conventional mode of space flight with expendable launch vehicles.

"Uncertainties do exist in forecasting funding levels for government agencies, but the overwhelming cost-effectiveness of the Shuttle diminshes the sensitivity of these uncertainties. Consistent with accepted systems analysis procedures NASA has tested the assumptions in the 1973 analysis and has established that much lower Shuttle flight rates (lower than the 60 per year average in the 1973 Mission Model) would still result in cost savings. Specifically, as we have previously reported, our analysis has indicated that the Shuttle would be cost-effective if flown only on the average of 25 times per year.

"NASA must continue to provide the nation with the capability to meet national space goals and, therefore, must be supported with adequate funding to exploit the new Shuttle mode of operation thru new science and applications in space. The level of this funding will determine the effectiveness of our use of the Shuttle, but will not modify our previous conclusions on its cost benefit to space flight.

"NASA has never made any claim that the specific payloads represented by the Mission Model will be flown. The Space Program is much too dynamic to permit precise projection over 18 years, and we have specifically pointed this out a number of times. However, as the Administrator has repeatedly pointed out, the agency believes the model is quite indicative of the Shuttle traffic and payload activity in the 1980-1991 period. As we have seen, the Mission Model estimates have been increasing from the early days of the program, (445 to 581 to 725), which is due to our finding better ways to use the Shuttle. The present planning is for an average launch rate of 48 per year and a sustained rate of 60 per year. Although no payload model has been developed for this flight rate, it is quite logical that the unique capabilities of the Space Shuttle would be utilized by an increase in space customers.

"Although the 1973 analysis consisted of 725 flights, we are pursuing a more conservative management approach by using a 572 flight traffic model for planning the staffing and procurement requirements for the STS Program. We do not consider the 572 flight model to represent a total mission plan. We did, however, determine that even at that flight rate, the Shuttle afforded a cost benefit of approximately

$12 billion when compared with the continued use of expendable vehicles.

"As we continue to examine the contribution which space can make to solving some of the pressing problems which face the people of the country and the world, it is our belief that we have intended to underestimate the level of space activity and that the opportunity which the Shuttle will afford to exploit the use of space will bring yet unidentified benefits during the next several decades."

CHAPTER 3

STATUS OF THE SPACE SHUTTLE DEVELOPMENT PROGRAM

Late in 1974 NASA completed an extensive shuttle requirements review (SRR), which was intended to

- --accurately determine program cost requirements and establish adequate reserves for fiscal years 1976-79 and
- --identify program changes to reduce funding requirements while keeping a realistic probability of making the first manned orbital flight in March 1979.

In fiscal year 1976 congressional testimony, NASA officials said changes made as a result of the SRR did not increase the risk of cost growth or jeopardize safety and performance. Schedule and technical risks, they stated, were increased but the increase was considered minor. Overall, they reiterated their confidence in their ability to develop the space shuttle successfully--with expected performance, on schedule, and within target costs.

NASA's SRR findings, in part, were intended to correct problems reported in our February 1975 report. The risk of cost growth identified in the report had increased because development work was being deleted, deferred, or reprogramed to aline development work within funding ceilings. We noted that project estimates were not well defined and did not include all development work necessary to complete the program. The report also quoted the space shuttle program manager's concern that no funds were available for growth or design changes during fiscal years 1975 through 1977. SRR dealt with these issues but was completed too late for us to make an indepth review before issuing the 1975 report. We evaluated the effectiveness of SRR during this year's review.

OVERVIEW

NASA's original plan for buildup of the development effort was not achieved, because planned funding never reached expected levels. According to NASA, the Office of Management and Budget did not allow NASA's congressional budget request to keep pace with inflation, resulting in a funding shortfall. This, in turn, caused the space shuttle and other NASA programs to be realined. Some were discontinued, others were reduced in scope, and new starts were kept to a minimum. The adjustments to each program, however, have been the prerogative of NASA management because the Office of Management and Budget's reduction was applied to the total budget rather than individual projects.

The space shuttle program has generally taken its proportionate share of the reductions. Work planned for the early development years has been delayed and the program completion date has been extended 16 months[1] to stay within

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[1] In February 1976, NASA informed us that the July 1980 initial operational capability date has changed to May 1980.

the annual funding limitations. The rephasing of work, however, has caused inefficiency in development and increased costs. To cope with increased costs, development and testing were reduced and a $50-million cost increase was announced. The $50 million is not the total cost growth, but NASA has used various techniques to absorb additional cost increases. These included (1) using reserves to absorb increases, (2) reducing development, and (3) transferring work tasks to other budgets and other phases of the STS program.

The techniques used to keep the space shuttle from exceeding annual funding and the total development estimate are part of NASA's management-to-cost philosophy. Because NASA has used these techniques the space shuttle development plan has changed. Program adjustments over the past 3 years have had a cummulative effect on the space shuttle development effort. Changes in cost, schedules, and program content suggest that the shuttle is now a higher risk program. Much of the reserves have been allocated early in the program, and schedules are tighter than would normally be expected in a highly technical program. In the order of priority, cost has become one of the most important management concerns. With this priority, program content may be deleted in favor of cost when other factors are not an overriding concern. In prior NASA programs, other management factors, including mission accomplishment, generally had priority over cost.

NASA's changed approach has raised two major questions. First, can success be expected in accordance with goals initially established for the shuttle? Generally, major space programs have not been developed using this approach and NASA's testing programs will be carried out without the same degree and intensity of testing as in past programs. NASA stated this approach is being followed to take advantage of past test experience. Second, how much development can be eliminated and still keep a viable program? For 3 consecutive years NASA has maintained that all feasible modifications have been made without major cost growth. Yet, in each of these 3 years NASA has continued to delete and defer development work, and modifications are continuing.

NASA believes program adjustments have been reasonable and have not resulted in unacceptable risks. Although the shuttle's outcome cannot be precisely predicted, our previous reviews of NASA acquisitions have shown its cost and schedule estimates have frequently been optimistic; for example, Need for Improving Reporting and Cost Estimating on Major Unmanned Satellite Projects, PSAD-75-90, July 25, 1975. In addition, past experience with major civil and defense acquisitions has shown that NASA's development approach can lead to costly retrofit or redesign at a later date or to deploying systems that cannot adequately fulfill their intended role.

COST GROWTH POTENTIAL

The cost to complete individual shuttle projects has been consistently understated, because project managers are given predetermined ceilings which they are instructed not to exceed. NASA's top management believes providing cost goals causes project managers to search for and identify excessive or unneeded requirements. We believe it also understates project requirements and inhibits meaningful analysis of remaining reserves.

Project estimates

SRR, a programwide effort to quantify the total cost of all known requirements, resulted in a $390 million net increase in project estimates. Project estimates were increased by $538 million for known requirements, and were decreased by $148 million by deleting work or deferring work to a later period. Appendix IV shows the changes comprising the $148 million. Of this $390 million net increase ($538 minus $148), $300.2 million was an allowance to cover errors in estimates and changes expected by NASA top management for remaining program years. The allowance was not considered a contingency reserve; additional funds over and above project estimates were available for reserves. (See pp. 37 and 38.)

Within 8 months after the SRR, revised project estimates had eliminated the $300.2 million allowance and further increased project estimates by $110.3 million , excluding project reserves, as follows:

Cost Increases Since SRR

Project	Increase or decrease
	(millions)
Orbiter	$ 147.7
Main engines	147.0
External tank	56.5
Solid rocket boosters	20.0
MSFC systems management	53.2
Launch and landing	-13.5
Other	- .4
Total	$ 410.5 (a)

The revised cost estimates were higher because (1) some SRR adjustments were unattainable, (2) SRR estimates were refined, (3) expected changes materialized and (4) new requirements were identified. Some of the more important changes are discussed below.

Orbiter

The orbiter project estimate has increased by $147.7 million since the SRR. A portion of this change resulted from completion of orbiter prime contract negotiations. The increased resulted because (1) adjustments made during the

[a] NASA Headquarters subsequently reduced the project estimates by $199.6 million as part of the recurring semi-annual budget cycle. NASA believes Headquarters cost estimates should be used rather than project estimates. (See pp. 7 and 8.) We do not concur. For example, $15.8 million of approved requirement changes and an additional $15.6 million of known requirements were excluded from the orbiter estimate by Headquarters. NASA's position is that requirements excluded from Headquarters estimates are provided for in the reserves. We believe this procedure understates project requirements and inhibits meaningful analysis of reserves.

SRR were unattainable ($43.4 million), (2) all known requirements were not included ($34.7 million), and (3) cost estimates were refined with additional requirements identified ($69.6 million).

Approximately $43.4 million, or 29 percent of the $148 million total savings projected from SRR adjustments were not attainable on the orbiter project. Of this amount, $14 million could not be saved because the orbiter contract had to be extended 4 months to achieve cost benefits projected from the other SRR adjustments.

The remainder of the $43.4 million resulted from reinstatement of two deleted items ($20.2 million), the addition of a test article ($1.1 million), and alternate thermal vacuum-vibroacoustic testing ($8.1 million). The contractor estimated alternative thermal vacuum-vibroacoustics testing at $101 million or about $16 million more than the ground tests NASA deleted. The cost was reduced to $8.1 million by NASA accepting a greatly reduced level of in-flight testing during the orbital flight test program.

Requirements known to NASA but not included in the SRR estimate totaled $34.7 million for approved contract changes, subcontractor work associated with the carrier aircraft modification program, and the compilation of certain orbiter maintenance documentation. The remainder of the $147.7 million increase--$69.6 million--came from identifying additional requirements and refining cost estimates.

The revised orbiter estimate may not yet include all costs. The prime contractor predicts its cost will be at least $70 million more than the NASA estimates because of anticipated contract changes. Additionally, the amount of inflation included in the negotiated orbiter contract was not agreed on and may be adjusted at a future date.

Space shuttle main engines

The SRR development estimate for the main engine project excluded the cost of a major test program and did not update prices for anticipated increases in engine test propellants. In addition, the estimate did not include certain in-house costs which directly support engine development. As a result of these and other changes, the project estimate has increased by $147 million.

An estimate for a test to demonstrate that the main engines can achieve specified duration goals before major refurbishment was included in the operations rather than the development estimate although NASA's procedures require inclusion of such costs in the development estimate. At the direction of the JSC program manager, $46.7 million was added to the project development estimate for this test.

At the time of SRR, project officials knew propellant prices would increase but were unable to accurately forecast prices because of a widely fluctuating market. The propellant estimate has subsequently been increased by $57.2 million.

The main engine project estimate was increased by $19.4 million, because (1) certain costs were shifted from NASA's institutional support budget[1] and (2) support requirements were better defined.

The contractor's estimated cost has increased by $14.8 million from the SRR estimate ($9.7 million for changes identified after the SRR and $5.1 million for further refinement of SRR estimates). The remaining $8.9 million increase was due to (1) adding 3 months of Government support as a result of the change in the Government's fiscal year, (2) accelerating the contractor's schedule for delivery of a prototype engine, and (3) refining estimates.

<u>External tank</u>

The external tank project has increased by $56.5 million since SRR. During SRR NASA Headquarters officials deleted $30 million that MSFC project officials thought was needed to correct deficiencies in the prime contractor's cost proposal. Since that time the project manager reinstated $21.5 million. Increases of an additional $25 million occurred when SRR estimates were refined and subsequent changes were made that resulted in cost increases.

About $10 million[2] has been shifted from other NASA budgets to the shuttle external tank estimate as a result of a recent review of planned in-house work. The review showed, for example, that civil service personnel would not be available to make structural test equipment as initially

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1 NASA Headquarters subsequently returned these costs to the institutional support budget.

2 NASA Headquarters subsequently returned a portion of these costs to the other NASA budgets.

planned. The MSFC officials planned to have a contractor build the equipment and to charge costs to the space shuttle budget.

Solid rocket boosters

Project estimates have increased by $20 million, of which $11 million[1] resulted from the transfer of work planned under another NASA budget. The other budget's funding level was not sufficient to support all shuttle requirements. NASA said that the majority of the remaining increase was caused by revisions of prior project estimates and identification of costs omitted during SRR. According to NASA, an additional $3 million requirement was subsequently offset by savings resulting from contract negotiations.

Systems management at MSFC

The cost of systems management at MSFC is now estimated at $71.2 million, an increase of $53.2 million over the $18 million SRR estimate. Of the $53.2 million increase, $32.3 million was a transfer of costs previously included in the orbiter estimate. The remaining $20.9 million resulted from (1) refining the estimate, (2) shifting costs for certain in-house support from the institutional support budget to the project estimate[2], and (3) including certain costs omitted from the SRR estimate. The current estimate, however, still does not include all known requirements. MSFC officials

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[1] NASA Headquarters subsequently reinstated these costs to the other NASA budget.

[2] NASA Headquarters subsequently reinstated these costs to the institutional support budget.

stated that at least $1.5 million[1] of valid requirements were excluded because of anticipated funding limitations.

Launch and landing

The launch and landing project estimate has decreased a net of $13.5 million since SRR. The decrease is primarily due to deleting $28.8 million for equipment-related requirements. KSC officials stated that these requirements were still valid but were deleted to stay within top management's budget ceilings.

Reserve estimates

The adequacy of remaining reserves cannot be reliably evaluated without knowing the estimated cost of valid requirements excluded from NASA estimates. Another factor limiting reserve evaluation is a lack of knowledge of NASA's original plan for reserve phasing. Although reserves cannot be reliably evaluated, a number of transactions have reduced reserves and have raised questions about the adequacy of remaining reserves.

The $390 million increase in requirements identified during SRR was absorbed by reserves planned for the later years of the program. In total, program reserves have declined by about 55 percent since NASA initiated the development program while only 30 percent[2] of the projected funding had been obligated as of October 31, 1975. Reductions of this magnitude are particularly important because many of the major test programs have been deleted or delayed to later program years. Thus,

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[1] NASA Headquarters subsequently provided funds for these costs.

[2] 33.2 percent of the projected funding had been obligated as of December 31, 1975.

fewer reserves and less time will remain to correct any technical problems identified during later tests.

NASA has not made a comprehensive analysis of the adequacy of remaining reserves. The technical and managerial development experience of NASA management is NASA's basis for determining the adequacy of reserves. In NASA's judgment, based on the development progress and schedule performance to date and the technical uncertainties NASA currently foresees for the next 3 1/2 years, the reserves available for the balance of development are adequate to support NASA's schedule and cost commitments to the Congress.

A limited study used by NASA during SRR indicated a need for about 52 percent more reserves than were available. According to the space shuttle program director, the need for more reserves above the $5.2 billion could not be supported during SRR because of the many unknowns and uncertainties in the later years of the program. A more recent study provided by NASA indicates a need for about 14 percent more reserves than are now available. Since SRR the actual reserve dollars have declined because reserves have been allocated for approved increases in project estimates. We used project estimates to compute reserve shortfalls. Using NASA Headquarters estimates, the recent study shows adequate reserves are available.

It will be 2 or 3 years, according to the program director, before the ultimate cost of the shuttle can be projected with absolute certainty. He believes it would be premature for NASA to acknowledge a change in program cost before then. The obvious effect of this approach is to report incomplete data to the Congress.

POTENTIAL SCHEDULE SLIPPAGE

The schedule initially chosen for the space shuttle was derived using historical analysis and engineering judgement. Because of funding constraints the development schedule, including testing, has been compressed and major test programs have been deleted or reduced in scope. The test program for shuttle now contains less testing than previous programs. As a result, schedules may ultimately have to be delayed because little or no time will be available to solve problems that may be identified.

Compressed schedules

Before SRR, program adjustments had been accompanied by a 15-month extension of the development program's completion dates. Some intermediate milestones necessary to meet projected completion dates were delayed longer than 15 months. This reduced the time available to correct technical problems which might occur before the first manned orbital flight. Adjustments made during SRR further compressed schedules because some intermediate milestones were delayed without corresponding extension of completion dates. The following example illustrates what may happen.

--NASA planned to make systems-level ground vibrations tests in January 1978 using a simulated orbiter mated with an external tank and solid rocket boosters. During SRR, the simulated orbiter was deleted. As a result, all tests will be made on the first development orbiter. To accommodate this change, the test initiation date for full scale testing was slipped

6 months to July 1978 when the first developmental orbiter was scheduled to be available, and the test schedule was compressed from 13 to 6 months. The revised schedule concerns test officials because (1) less time is available to analyze test data and make any required changes, (2) flexibility to test and correct problems through overtime and multiple shifts is reduced, and (3) there is no room for slips in the scheduled availability of the first development orbiter. A slip in the completion date for this test could also delay the first manned orbital flight scheduled 3 months after the mated test. According to NASA, some adjustments in milestones have subsequently been made to improve the test flow and it is continuing to look for ways to provide more schedule margin. NASA believes the present test program provides a significantly higher probability of schedule success.

In December 1974 NASA had a team of 35 recognized experts in the aeronautical and space industry make an independent analysis of the program's technical and schedule aspects. The team, headed by Mr. Willis Hawkins, Lockheed Aircraft Corporation, concluded that the space shuttle program was healthy, well conceived, and well managed. However, the Hawkins team noted that little or no schedule margins are available in the event that technical or other unforeseen problems are encountered. According to Mr. Hawkins, the likelihood of such problems is high due to the magnitude of the program and the difficult technical goals, and there is a substantial risk that the first orbital flight schedule will not be met.

An analysis by the JSC Space Shuttle Program Office in January 1976 supports Mr. Hawkins' point about little or no schedule margins to resolve new and unanticipated technical problems. The analysis showed that unless the schedules can be improved, the first manned orbital flight will slip beyond the current target date of March 1979. This could cause a corresponding slip in NASA's July 1980 initial operational capability milestone.

Another JSC Space Shuttle Program Office analysis indicated the orbiter is the element most likely to delay the space shuttle program. The second development orbiter will be used for the first manned orbital flight. The analysis identified a 3 to 6 month potential slip in the first manned orbital flight because (1) schedules for the second development orbiter are compressed with little margin to work around late component deliveries or technical problems, and (2) the current emphasis on the first orbiter has compressed the final assembly and systems installation time for the second development orbiter. The number of man-hours planned for final assembly of the second orbiter has not changed.

The analyses discussed above are part of NASA's continuing effort to assess the schedule status and are used to identify areas where management attention should be placed. It is NASA's position that because of the many subjective variables involved in any such analysis, it is very difficult to make valid quantitative projections. Although NASA agrees that compressions have occurred in post-test schedules, it believes adequate time is available to meet the first manned orbital flight. According to NASA, this is because major systems tests are not qualification tests but are primarily verification tests; that is, verifying data generated by other techniques such as math modeling or use of the 1/4 scale mated vibration tests. Major problems are not anticipated to be identified in the full scale testing so that large schedule pads would not be cost effective nor prudent management.

The Hawkins team concluded that the main engine schedule was highly compressed and recommended a schedule extension to allow more time for confirmation of the engine subsystems. Part of the concern, which was shared by the prime contractor, was the lack of sufficient backup test hardware--substitute engines and components--to prevent schedule delays if unexpected failures occur during engine testing. Mr. Hawkins believes a 6- to 12-month schedule extension will allow for such contingencies. Such an extension would most likely result in an extension of the shuttle development program. NASA rejected the recommendation as not being cost effective; it believed sufficient flexibility existed in the schedules. NASA pointed out that no major technical problems had been identified which required additional hardware or development time.

Deletion of testing

Some test programs and related hardware have been deleted or reduced to (1) remain within budget constraints and (2) relieve schedule pressures and improve the probability of meeting the first manned orbital flight. While the changes may improve the chances of meeting this milestone, some of them may have decreased chances of meeting another--the initial operational capability milestone of July 1980[1].

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1 The initial operational capability milestone was extended from March to July 1980 as a result of SRR adjustments. In February 1976 NASA informed us this milestone was changed to May 1976.

To illustrate this point, the vibroacoustics ground test program planned for the orbiter's forward portion was deleted during SRR. This test was to verify that crew station and internal payload-bay[1] noise levels met design criteria and determine the validity of acoustics fatigue testing[2] of structural panels. While the deletion will provide more time to meet the first manned orbital flight, the initial operational capability date may not be met if noise levels or structural panels are found to be unacceptable during the flight test program. The Hawkins team recommended reinstatement of this ground test, but NASA rejected this recommendation because it does not believe the tests would produce a sufficient increase in confidence to warrant the expenditure.

Shuttle program managers contend that past programs, such as Apollo, contained more tests than needed to attain reasonable technical assurance and they believe the revised test plan for the shuttle will be cost effective, even if major technical problems are encountered. The test verification program approach originally planned for the shuttle evolved from the experience gained in recent manned programs of similar complexity and size. NASA's position is that adjustments to this program have been made to accommodate funding limitations only when detailed technical assessment of the program criticality of each test modification verified that the integrity of the system would not be impacted.

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[1] A 15- by 60-foot area in the orbiter.

[2] Ability of orbiter structure to withstand noise.

No study has been made to show whether past programs contained unnecessary testing. However, a study of thermal vacuum tests for past programs showed that numerous anomolies were detected which required design, procedure, and process changes. Thermal vacuum tests for the orbiter were eliminated even though NASA officials believe the shuttle is no less complex than previous programs. Therefore, this testing approach assumes a higher degree of success than the Apollo program.

Shuttle program managers have not confirmed their belief that the current testing philosophy is cost effective. In fact, three NASA studies at Goddard Space Flight Center have questioned the validity of a reduced test philosophy.

The issue, we believe, is not whether reduced te .ing is cost effective. NASA's initial cost estimate included provisions for test programs and related funds to avoid taking these risks. When the test programs were deleted, the cost estimate and funding requirements were not reduced. Since current cost estimates do not include provisions for such tests (the tests were deleted to stay within funding constaints), cost and schedule goals may not be met if major technical problems are encountered.

TECHNICAL UNCERTAINTIES

As discussed above, the likelihood of not meeting cost and schedule goals largely depends on the technical problems encountered. There are presently no known technical problems, according to program officials, which could result in considerable schedule delays or cost increases. Most test programs designed to verify the adequacy of technical performance characteristics, however, have yet to be made. For example, the main engine is the most advanced development program but only 13 of the 964 tests required for final flight certification by 1980 had been completed as of September 5, 1975.

According to Mr. Hawkins, the magnitude and complexity of the space shuttle program make it likely that major technical problems will surface. He considers the space shuttle main engines as the highest risk element because they require the greatest advancement in technology. According to NASA, other areas in which technical problems may be encountered are (1) avionics, (2) reusability of various shuttle hardware, and (3) system's integration. One of the most important problems facing NASA is potential weight growth for the orbiter and external tank.

The Hawkins team concluded that the weight of the orbiter and external tank will undoubtedly follow a typical growth curve and may exceed design goals by up to 5 percent. Weight growth on the space shuttle will reduce payload carrying capability on a pound-per-pound basis unless engine thrusts exceed design specifications. This is a possibility with both the main engines and the solid rocket motors. After the Hawkins team review, NASA identified weight reserves over and above those disclosed to the review team. Mr. Hawkins still believes actual weight will exceed design goals but is uncertain whether it will be as great as 5 percent. Other technical problem areas NASA is currently addressing are

--thermal protection system reusability,

--external tank lightning protection,

--external tank thermal protection system,

--vibration effects of the boosters and main engines, and

--solid rocket booster water-impact damage.

POTENTIAL PERFORMANCE REDUCTIONS

The objectives of testing during development are to determine the degree to which risks are being progressively decreased and to physically demonstrate, before a system is committed to operation, that the system and its subsystems will perform as intended and will provide the capabilities needed to complete the mission involved. Experience has shown that delayed testing and performance verification may ultimately affect performance or increase costs, or both.

Changes already made by NASA will delay the verification of certain capabilities beyond the initial operational capability of the space shuttle. The shuttle will begin operations using a development vehicle rather than an operational vehicle. Tests will be continued on flights otherwise considered operational. For example, in-flight thermal vacuum and vibroacoustic tests may continue during operational flights because instrumentation and additional development flights necessary to make complete tests during the flight test program were determined too costly. With this change, the contractor was directed to treat the thermal design mission as a design goal rather than a contract requirement.

In addition to the preceding example, present hardware delivery schedules require verifying the following shuttle capabilities during the operational phase instead of during the development flight test program, as planned:

--Full closed circuit television capabilities.

--Full capabilities demonstration of the payload station.

--Spacelab atmospheric revitalization system.

--Payload radio frequency communications and command.

--Extravehicular activity operations external to the orbiter using the shuttle baseline extravehicular mobility unit.

--Operational sleep station.

--Department of Defense communications performance.

--Manned maneuvering unit.

--Passive and active radar--full demonstration.

--Docking system.

--Operations with dual remote manipulator subsystem arms.

In addition, payload carrying capability of 32,000 pounds, rather than the 65,000 pound design goal, will be demonstrated during development flights. This is because no candidate payloads of 65,000 pounds have been identified. NASA stated it is considering reinstating verification of several of the above listed hardware items to the development flight test program.

NASA believes that delaying flight verification of certain operational systems is a prudent utilization of resources. The items delayed, NASA stated, fall into three categories: (1) those for which no identified user requirement has emerged, (2) those for which a required payload interface will not be available, and (3) those which will be essentially verified in ground tests.

QUANTIFICATION OF POTENTIAL COST GROWTH

As stated earlier, NASA Headquarters' cost estimates cannot be used to quantify the cost growth which may occur because of the increased risks described in other sections of this chapter. However, costs can be expected to exceed by more than $1 billion NASA's original development cost estimate. This is because of (1) increases in inflation in excess of that originally projected, (2) delays in the timing of expenditures, and (3) tranfers of work tasks to other STS program elements and other NASA budgets.

NASA does not agree with the $1 billion cost growth primarily because it does not recognize inflation as cost growth. It points out that the original shuttle estimate was in 1971 dollars. However, our calculations were based on information presented by NASA to congressional committees and on data used to manage the program. We, therefore, believe the $1 billion is a conservative estimate of cost growth in real year dollars.

Cost estimates

NASA's management-to-cost techniques do not allow cost estimates to exceed the total commitment estimate until approved by NASA Headquarters. Reserves are not analyzed in detail to determine their adequacy but, instead, are used as a balancing figure between NASA Headquarters' estimate of project costs and the total $5.2 billion program target. Determination of the program's current status and projection of its outcome is not possible because (1) the baseline estimate, current estimates, and actual costs are not in sufficient detail and (2) adequate documentation, such as data sources, assumptions, exclusions, methods, and decisions basic to estimates, is not maintained.

Additionally, shuttle cost estimates publicized by NASA do not include all resources required to accomplish the development program. For example, KSC development budget estimates show the shuttle launch and landing project will cost $491.9 million. But KSC estimates show that an additional $508 million will be required for NASA personnel at KSC and contractor personnel which directly support the development work. Other budgets to which shuttle development effort is charged include (1) development, test and mission operations, (2) research and program management, and (3) research and development budgets of offices other than the Office of Space Flight[1]. In total, NASA estimates that about $2.3 billion of other budget's funds will be required in direct support of space shuttle development.

According to NASA officials there is no clear criteria for determining which costs should be included in the shuttle estimate. Because NASA has shifted costs between the shuttle estimate and other budgets, it is not possible to properly evaluate the program's cost status to determine where NASA stands in relation to meeting its cost goals. In addition, according to the NASA Comptroller the development, test, and mission operations budget was initially intended to support a variety of programs instead of principally the shuttle.

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[1] Formerly Office of Manned Space Flight.

Inflation and timing of expenditures

Although the development commitment was expressed in 1971 dollars, NASA manages and accumulates costs in real year dollars; that is, the actual cost with inflation from 1971 through completion of the development program. This is appropriate because changes in our nation's economy over the life span of a project can have an impact on total costs. In addition, the timing of expenditures has a major impact on both the total program's cost and the budgets required for each fiscal year when inflation is taken into consideration.

NASA projected a 5 percent annual inflation rate for the program in its first internal real year dollar projections. Therefore, NASA's commitment in real year dollars would have been $5.982 billion[1]. The difference between this estimate and the current estimate approved by NASA Headquarters is a cost growth of $950 million. Of this amount, $524 million is an increase in the projected rate of inflation from 5 to 7 percent and $426 million is cost growth directly attributable to NASA decisions to delay work tasks and related expenditures to later years of the program. According to NASA, the delays were made because of Office of Management and Budget funding constraints. The following chart shows how the $950 million was calculated:

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[1] This figure was derived by applying NASA's internal assumptions about expected inflation to its original plan for the timing of expenditures.

Expected Space Shuttle

Cost Growth

Design, Development, Test, and Evaluation

Change in inflation rate:		
Original estimate assuming 7 percent inflation (note a)	$6,506	
Original estimate assuming 5 percent inflation	5,982	
Cost Growth		$524
Timing of expenditures:		
Revised estimate at 7 percent inflation after rephasing of expenditures to later program years	6,932	
Original estimate at 7 percent inflation	6,506	
		b/426
Total		$950

a/Computation based on 7 percent inflation for all fiscal years subsequent to 1973 except fiscal years 1975 and 1976 when 8.3 and 9.3 percent were used respectively.

b/Includes $50 million increase in 1971 dollars.

Only $50 million of the $426 million of controllable cost growth attributable to management decisions and prerogatives is evident from the manner in which NASA reports cost estimates to the Congress. The $50 million is the cost growth in 1971 dollars resulting from inefficiencies in the development process.

NASA does not agree with the GAO identified cost growth of $950 million. It points out that the original commitment to the Congress was in 1971 dollars and NASA does not recognize inflation as cost growth. NASA states it did not project shuttle inflation at a 5-percent rate at the time of the commitment. However, in answers to questions in fiscal 1976 Senate appropriation hearings, NASA testified that over the last several years, its practice has been to use a 5-percent rate to estimate project costs in real year dollars. In addition, NASA's first internal estimates in real year dollars projected a 5-percent rate. A 7-percent rate is currently being used in NASA's internal projections.

<u>Transfers of development effort</u>

NASA has avoided cost growth in the development commitment by transferring work tasks originally planned to be charged to the shuttle budget. Some of the transfers were to other NASA budgets and to the production and operational phases of the STS program. We are unable to determine how much was transferred, but did identify net transfers of $195.1 million as follows:

	Amount transferred
	(millions)
Transfers to other budgets:	
Booster development activities	$ 78.1
Orbiter development	.4
Transfer to operations:	
Orbiter development	16.6
Transfers to production:	
Orbiter development	57.0
Launch and landing development	70.0

	Amount transferred
	(millions)
Other transfers:	
Remote manipulator arm	22.7
Phase B studies	12.4
Subtotal	$257.2
Less adjustments including transfers reinstated	62.1
Net	$195.1

NASA believes that net transfers out of the program amount to $111.7 million. (See app. VI.) It believes these transfers are consistent with NASA's budget structure and commitments to the Congress. NASA's records do not permit us to determine the total value of transfers with precision. Our major point is that cost growth is being absorbed by other budgets and other phases of the STS program.

RECOMMENDATIONS

--The Administrator, NASA, should estimate and total all costs, including those funded from other budgets. This would result in more complete and realistic estimates of the cost to develop the space shuttle.

--The Administrator, NASA, should present estimates to the Congress in real year dollars. These estimates should be compared to the real year dollar amounts anticipated at the time the 1971 estimate was prepared. This would allow a more meaningful analysis of the program's status and permit specific identification of reasons for cost changes.

ADDITIONAL NASA COMMENTS

NASA does not concur with our analysis of the program's status and potential outcome. It takes exception to criticisms levied against the development plan. NASA's position follows:

"The Space Shuttle development plan provides a balanced program with reasonable probability in meeting schedule, performance, and cost goals. Adjustments and rebalancing are a continuous process within the fixed boundaries of commitments to (1) a national space transportation capability, clearly defined in terms of performance, (2) a schedule for obtaining and demonstrating that capability, and (3) a cost commitment for the program.

"The following significant issues raised by the GAO report are discussed in more detail.

Performance goals versus cost

"NASA's design-to-cost philosophy must be considered in the context of NASA's additional philosophy, equally firm, of meeting Space Shuttle requirements and commitments to the Space Shuttle user community. No changes have ever been taken to reduce performance goals and system capabilities in favor of cost. Further, no adjustments have been made to test activities which threaten to compromise baseline system performance capabilities or payload support functions. NASA has consciously delayed flight verification of certain operational systems as a prudent utilization of resources.

Deferrals and deletions of planned work

"The adjustments to internal Space Shuttle plans which resulted in deferrals or deletions have not altered NASA's commitment to meet cost and performance goals. In fact, these adjustments were made to produce the best program balance in NASA's judgment, when all factors were considered, and were consistent with minimizing risk to schedule and costs. In addition, there is an adequate program reserve consistent with the $5.2 billion commitment. Adjustments have increased the probability of meeting program goals since funds were made available to solve new problems without recourse to schedule slippage or performance degradation.

Schedule changes and compressions

"NASA believes the schedule risk is in proper balance with the technical goals. Specifically, while NASA does not make schedule allowances for unforeseen catastrophic technical difficulties, as none are anticipated, the schedules are established on the basis of the best judgment as to time needed to solve identified or expected technical problems. There is, in NASA's judgment, sufficient schedule margin for these latter problems."

CHAPTER 4

STATUS OF OTHER STS PROGRAM ELEMENTS

The status of other program elements including production, cost per flight (operations), construction of facilities, upper stages, and the spacelab has changed since our February 1975 study. Many of the changes in these elements can be traced to changes in the development program. (See ch. 3). The revised status in each case presented below is NASA's current status, and we have not verified its information.

Budget limitations have caused reductions and delayed starts in the other program elements. Generally, changes have caused less efficient scheduling of work resulting in cost increases because of delayed spending. For example, a NASA study shows that certain actions considered during SRR to reduce early year funding by an estimated $476.1 million is expected to increase total STS cost by an estimated $793.9 million. While most of the actions were taken, some were implemented in a different manner than proposed. Principal factors contributing to the estimated increase include $219 million in orbiter production, $371 million in operations, and $170 million in the development, test, and missions operations budget.

NASA considers these costs to be misleading. It estimates the total cost impact of SRR actions for DDT&E and production were savings of $402 million (FY 75-78) and a program total increase of $107 million, assuming a uniform development, test, and missions operations budget base. The total cost impact of actions taken is not available.

PRODUCTION

Production requirements are uncertain. DOD has not decided how many, if any, orbiters it will purchase or when it will purchase them. Also, NASA's funding constraints are affecting decisions on production. NASA and the orbiter contractor jointly studied five options for production. The estimated cost of these options varies depending on the number of orbiters to be produced and the length of time needed to manufacture the vehicles. For budget purposes, NASA is concentrating on an option requiring production of three orbiters and refurbishment of two. NASA's estimated cost of this option, including reserves, is $2.2 billion.

Technical problems identified during the development program could increase the cost of production, because a concurrent development and production program is planned. The Hawkins team suggested that a delay in production schedules, if required by main engine delays, would overcome some development and production phasing problems. The team did not believe the schedule provided sufficient time to incorporate revised designs, as a result of systems tests, into the production orbiters and engines. Revised designs based on test results could reduce the spacecraft's weight, the team believed, and such a reduction may be necessary to fulfill some of the shuttle maximum payload missions. NASA did not modify production schedules as recommended. However, it is presently considering schedule delays to overcome funding problems.

COST PER FLIGHT

NASA is continuing work toward an agency cost per flight of $10.45 million in 1971 dollars. This estimate equals about $13.3 million in 1976 dollars. On the basis of a stated traffic model (439 flights) the estimate is the average recurring cost for operating the space shuttle only and is not the cost which will be charged space shuttle users. The cost-per-flight estimate is used internally to evaluate decisions and system trade offs between initial investment and recurring costs.

NASA's $10.45 million estimate usually shows a breakdown between internal budgets prepared by the program-project offices and an amount for reserves. The cost-per-flight reserve is a balancing figure between current project estimates and the $10.45 million agency estimate. The August 1974 project level estimate of $9.5 million increased 14 percent and eliminated a reserve of $0.95 million. NASA Headquarters, in conjunction with the JSC shuttle program office, evaluated project estimates and reduced them. This action provided a small working reserve of $0.38 million.

The following chart shows point-in-time estimates compiled by the program-project offices during the official NASA budget process. Also shown are the decreases resulting from the Headquarters-JSC refinements.

Cost-Per-Flight
Estimates in 1971 Dollars

Elements	Agency target	Program-Project 8/74	Program-Project 8/75	Increase or decrease	Hqtrs. and JSC 9/75	Adjustment by Hqtrs. and JSC
	(millions)					
External tank	$ 2.31	$ 1.75	$ 2.16	$ .41	$ 1.82	$-.34
Solid rocket booster	4.28	3.33	3.31	-.02	3.31	0
Ground operations	.27	.49	.39	-.10	.38	-.01
Spares	1.40	.91	.90	.01	.84	-.06
Main engines	.23	.23	.19	.04	.19	0
Fuels & propellants	.20	.31	.59	.28	.51	-.08
Program support	1.76	2.48	3.29	.81	3.02	-.27
	10.45	9.50	10.83	1.33	10.07	-.76
Program reserve	0	.95	0		.38	.38
Total	$10.45	$10.45	$10.83		$10.45	$-.38

CONSTRUCTION OF FACILITIES

NASA's estimate for construction of facilities was $300 million (1971 dollars). Through fiscal year 1976 and the transition quarter, a total of $277.4 million of appropriated funds will have been applied to NASA's shuttle facilities program. The $277.4 million includes $23.1 million of appropriated funds that are not part of NASA's construction of facilities appropriation. The $23.1 million was used to construct and modify facilities at Santa Susana, California, and Brigham City, Utah. DOD facility costs are discussed in chapter 7.

As of October 31, 1975, NASA estimates total facility costs at about $295 million in 1971 dollars as compared to its July 1974 estimate of $292.1 million to $302.1 million in 1971 dollars. The revised estimate is attributable to a better definition of requirements, resulting in both cost increases and decreases. A portion of the increase was attributable to the inclusion of all modification and rehabilitation projects under $500,000 in the fiscal year 1976 and subsequent year budgets. These projects would previously have been budgeted in nonshuttle facility programs.

Detailed requirements for the solid rocket booster production facilities area have yet to be determined and defined. The production contract for the solid rocket motor, component of the booster, has not yet been awarded so it is not known whether Government or corporate facilities will be used or at what location.

NASA's $295 million (1971 dollars) estimate equals $453 million in real year dollars. This represents a $43 million increase over NASA's original estimate of $410 million and a $24- to $41-million increase over its July 1974 estimate. These increases are due primarily to the rephasing of some projects to later budget years with corresponding increases in inflation costs.

Recognizing that inflation rates and the phasing of individual projects might change, NASA made its original commitment in 1971 dollars. The current estimate in 1971 dollars is $295 million or $5 million less than the $300 million commitment.

NASA now feels confident that space shuttle faciities will be completed within this original commitment.

SPACE TUG

The space tug is a reusable propulsion stage planned to extend the capabilities of STS to greater altitudes than can be achieved by the orbiter alone. Preliminary performance requirements for the tug are delivery of 6,000 to 8,000 pounds of payload to geosynchronous orbit[1] and retrieval of 3,000 to 4,000 pounds from this orbit.

The space tug program costs are now estimated at about $1.3 billion, a $528 million increase over the previous estimate. A comparison of the two estimates is shown below.

Space Tug Estimates

	October 1974 (1974 dollars)	October 1975 (Real year dollars)	Increase
	(millions)		
Development	$399.4	$ 727.9	$328.5
Procurement	209.2	328.0	118.8
Operations	166.0	246.7	80.7
Total	$774.6	1,302.6	$528.0

Neither of the above estimates contain tug facility costs, because MSFC, the lead center, has not estimated these costs.

The increase in cost estimates is attributed to inflation, schedule changes, and additions and deletions. Inflation accounts for about $336.2 million of the development and procurement estimate. Schedule changes account for about $104.1 million, while the net effect of additions and deletions was an increase of about $7 million. Program support originally

[1] Orbits in which satellites remain stationary in relation to a point on earth.

planned to be funded from other budgets was the primary addition. Deletions included estimates for tug flights from the western test range and estimates for kick stages (extra boosters). Although the estimates for western test range launch operations have been deleted, the final decision regarding this launch capability has not been made. The $80.7 million was the net result of adding inflation and decreasing the number of tug flights due to initial operational date change.

NASA has changed the tug operational date from December 1983 to no earlier than late 1985, a delay of at least 18 months. Under the revised schedule, phase B definition studies will not begin before fiscal year 1979 and full-scale development will not be started before 1981. The schedule changes resulted from funding limitations, and the extended tug development schedule would make more funds available for payload development.

After the IUS configuration has been determined (see ch. 7), NASA plans to study the cost effectiveness of continuing the tug program. Based on this study, NASA will make a decision on whether to delete the tug from the STS program.

MSFC officials told us that tug performance requirements discussed in our February 1975 study have not changed.

SPACELAB

The spacelab program is a cooperative venture between NASA and the European Space Agency. The major program objective is to provide versatile, low-cost laboratory and observatory facilities which will reduce the time and cost required for space experimentation and make direct space research possible for qualified scientists and engineers without astronaut training. MSFC is the lead center for spacelab.

MSFC currently estimates NASA involvement in the program will cost about $283.8 million (1976 dollars) or $30.8 million less than the June 1974 estimate of $314.6 million as shown below.

Space Lab Estimates
in 1976 Dollars

Cost element	June 1974	October 1975	Increase or decrease (-)
	-------------(millions)-------------		
Development	$141.7	$ 97.8	$-43.9
Procurement	161.8	178.9	17.1
Facilities	11.1	7.1	- 4.0
Total	(a) $314.6	$283.8	$-30.8

Spacelab project officials told us that the decrease in estimated costs resulted because requirements were better defined.

The spacelab program is on schedule, according to project officials, and no changes have been made to the program milestones or performance requirements discussed in our February 1975 study.

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[a] This estimate equals $354.7 million in real year dollars based on a 5 percent inflation rate.

CHAPTER 5

ENVIRONMENTAL EFFECTS

NASA's July 1972 "Environmental Statement for the Space Shuttle Program" concluded that the potential effects will be environmentally acceptable, localized, of short duration, and controllable. Continuing studies by NASA, however, show that the extent to which shuttle operations will affect the environment is uncertain. For example, sonic booms have been predicted to be more than double the level originally cited in the 1972 statement as acceptable. More recently sonic booms were estimated at the originally predicted level. Other uncertainties include

--the rate of ozone depletion in the stratosphere;

--the effects of ozone redistribution;

--the medical and ecological effects of ozone depletion such as increased skin cancer and decreased agricultural productivity due to increased ultraviolet radiation; and

--the potential hazards of shuttle exhaust emissions near the launch sites.

NASA knows of these uncertainties and is attempting to obtain a better understanding of how the shuttle will affect the environment. Some studies were delayed due to funding constraints and difficulties in coordinating research with other Government agencies. It is important, however, to resolve these uncertainties early, especially if some of the potential space shuttle environmental effects are considered unacceptable. Solutions to environmental problems could be expensive, reduce operational capabilities or performance, and/or delay or even terminate shuttle operations. NASA, however, considers its environmental effects program to be well defined at this time, to be on schedule with the development program, and to be producing results which show acceptable levels of environmental impact.

SONIC BOOMS

In its 1972 shuttle environmental statement, NASA predicted that sonic booms would be limited to 2 pounds per square foot (psf) within 100 nautical miles of the landing sites; i.e., KSC and Vandenberg Air Force Base. NASA gave the Congress the same data in its testimony during fiscal year 1976 authorization hearings. However, changes in the orbiter to improve flight characteristics resulted in more than doubling the projected sonic booms to a maximum range of 5.7 to 8.2 psf.

NASA is considering operational and design changes to reduce these sonic booms. These constraints will not, according to NASA, degrade overall performance or impact on safety. The extent to which sonic booms can be reduced will not be known before NASA's studies are completed and the operational and design changes under consideration are approved and implemented. In December 1975, preliminary calculations for the first orbital test flight showed maximum sonic booms of 2.355 psf. During recent discussions with NASA in February 1976 we were advised that new test data using the proposed modifications has resulted in a predicted peak sonic boom of 2 psf.

However, NASA said the proposed modifications require further evaluation and approval by NASA management.

An International Civil Aviation Organization report pointed out that such nonprimary structures as plaster, windows, and bric-a-brac were damaged at sonic booms from 1 to 3 psf for fighter aircraft. The report noted that most persons considered sonic booms, which occurred 10 to 15 times daily, as annoying when it reached 3 psf. It is not known whether the less frequent (approximately one a week), lower frequency, and longer duration orbiter sonic booms would be as annoying or as damaging as those studied in the report.

Except for a limited number of approaches at Vandenberg, there is no reasonable way to land the orbiter without creating sonic booms over populated land masses such as Orlando, Florida. According to the Environmental Effects Projects Office Manager at JSC, there are no criteria for acceptable sonic booms over the United States. At the present time, supersonic flight is not permitted over land except for some carefully controlled high altitude military flights.

The United States Code (49 U.S.C. 1431) as implemented by the Code of Federal Regulations (14 C.F.R. 91.55) prohibits civil aircraft, including operational Government aircraft carrying commercial cargo, from creating sonic booms over the United States. However, NASA states that under the

National Aeronautics and Space Administration Act (42 U.S.C. 2452) the space shuttle is not an aircraft because it operates in the Earth's atmosphere only in order to travel to and from outer space, and that, therefore, the regulations regarding aircraft noise and sonic booms would not apply to space shuttle operations.

Unless exempted by the Federal Aviation Administration we believe that the space shuttle may be considered a civil aircraft under the Code of Federal Regulations because when it is operational it will be used to carry commercial cargo and it will navigate in the Earth's atmosphere.

STRATOSPHERIC EFFECTS

Legislation has been introduced in the Congress to prohibit and control dangerous emissions which threaten to reduce ozone in the stratosphere. Ozone is vital in preserving life, because it prevents excessive ultraviolet radiation from reaching the earth's surface. It is feared that depletion of the ozone will increase ultraviolet radiation.

The space shuttle's solid rocket motors will produce hydrochloric acid which, when converted to chlorine, will destroy ozone. But unlike fluorocarbons and other depletents which are released at the earth's surface and take up to 10 years to reach the ozone layer, hydrochloric acid will be released directly into the stratosphere where its ability to destroy ozone is greatest. NASA predicts a 1 to 2 percent ozone depletion in the upper stratosphere, but feedback effects cause an increase in ozone at the lower altitudes leading to a predicted 0.15 percent reduction of the total ozone column averaged over the Northern Hemisphere after a twenty-year period at peak space shuttle flight rates. Because of uncertainties in this calculation, it could be as low as 0.03 or as high as 0.45 percent, and represents an equilibrium condition. In addition, depletion up to 0.3 percent (a range of 0.04 to 0.6 percent due to uncertainties in this calculation) might occur in a unique corridor across the United States. By comparison to the 0.15 percent prediction above, fluorocarbons released to date may have depleted average ozone concentrations by 0.5 to 2 percent, and may eventually cause a 3- to 15-percent depletion.

Uncertainty exists in NASA's ozone depletion rates because (1) a few key chemical reaction rates are unknown, (2) stratospheric measurements have not been completed, and (3) the interaction of shuttle emissions with other man-induced ozone depletents has not been determined. Although the long-term effects of ozone redistribution from the upper to the lower atmosphere are unknown, temperatures will be changed and some changes in the dynamics of the stratosphere and perhaps the troposphere could occur. The significance of these changes is undetermined at this time. The National Academy of Sciences, as well as NASA, believes more detailed studies are needed before definitive answers can be given.

Environmental study programs will try to evaluate shuttle exhaust effects and assess the medical and ecological effects of such stratospheric alterations. Another study program will identify and assess alternative solid rocket propellants in case shuttle exhaust products are judged unacceptable. This study has shown that alternative propellants could severely penalize the shuttle program by

--negating the fundamental basis for selecting the solid rocket booster, i.e., a low-risk, high confidence booster;

--increasing the cost of shuttle development by about $107 million to $119 million;

--requiring new propellant production facilities costing as much as $50 million to $100 million, and

--reducing the shuttle's payload carrying capability by 2,000 to 7,000 pounds. (NASA believes the loss could be held to 2,000 pounds.)

An alternative propellant could not be available until about 2 1/2 years after shuttle operations are scheduled to begin since a 6-year development program is estimated.

NASA plans to have sufficient studies on the stratosphere to decide upon the need for continuing alternative propellant studies by May 1976. The penalties of adopting the alternative propellant will have to be weighed against the results of the environmental studies before a decision can be made. The information necessary to make the decision may not be available because all medical and ecological effects may not be identified and analyzed by May 1976. The Space Shuttle Environmental Effects Project Office Manager said this decision could be delayed since the ozone depletion will occur gradually due to the small number of launches during early shuttle operations and would be replaced within a few years after discontinuing use of present propellants. This is contrasted to the predicted stay time for the fluorocarbons on the order of a century.

Medical and ecological effects of ozone destruction or depletion are still to be determined. Potential effects identified to date include increased incidence of human skin cancer, "cancer eye" in cattle, reduced agricultural productivity, and detrimental disturbance of terrestrial and aquatic ecological systems. For example, the Federal Task Force on

Inadvertent Modification of the Stratosphere believes a 1-percent reduction in average ozone concentration may cause an additional 2,100 to 15,000 skin cancer cases in the United States each year. The task force, of which NASA was a member, recommended regulations restricting fluorocarbon use. NASA and all other agencies concerned believe considerable research will be necessary to properly define the biological significance of increased ultraviolet radiation. A recent study by the National Cancer Institute states that we now have physical data and not merely theoretical calculations which support the hypothesis that ultraviolet radiation has an effect on the risk of skin cancer. It further states that the results may be dependent on variables which could not be incorporated into elementary models.

Although theoretical studies show small decreases in ozone due to the shuttle, NASA believes this must be considered in relation to the total cummulative ozone depletion[1] and the potential complex responses of ecological systems. A shuttle biospheric effects program has been created to investigate the shuttle operations' potential hazards. The program will include an evaluation of ultraviolet effects. It is not known when the results of this program will be available but

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[1] A provision in the fiscal year 1976 Appropriations Act directs NASA to conduct a comprehensive program of research, technology, and monitoring of the phenomena of the upper atmosphere. The purpose of the Act is to provide for an understanding of and maintenance of the chemical and physical integrity of the earth's upper atmosphere.

funds were released in September 1975 to begin the program. The delays in initiating the program were due, in part, to funding constraints.

NASA believes that because the ozone-ultraviolet radiation problem contains multiple causes for ozone depletion and numerous Governmental agencies are involved, a multiagency approach with tight coordination should be undertaken. Some of the other organizations studying atmospheric effects are Department of Transportation, Energy Research and Development Administration, Environmental Protection Agency, National Oceanic and Atmospheric Administration, and National Science Foundation.

GROUND CLOUDS

Rain, fog, and other adverse weather conditions could cause emissions from the shuttle's solid rocket motors to form ground clouds that could create hazardous conditions near the launch sites. The principal concern is the diffusion of aluminum oxide and hydrochloric acid in sufficient concentrations to adversely affect the environment.

Two possible solutions for this problem are delaying launches under unfavorable conditions and a ground cloud neutralization program. Launches would be deferred if weather conditions were such that predicted exhaust cloud concentrations could affect the surrounding environment.

The ground cloud neutralization program would minimize launch constraints due to ground cloud. This program would remove the toxic hazards by drenching the ground cloud with a neutralizing substance. The launch constraints and neutralization program are still under study.

CHAPTER 6

RANGE SAFETY

The basic purpose of range safety is to protect life and property from a missile or space vehicle malfunction during launch or flight. To achieve this objective, the vehicle must be equipped with a suitable flight termination system. Until December 4, 1975, NASA believed that the system being developed for the space shuttle satisfied the basic purpose of range safety, but the Air Force National Range Commanders, which are responsible for range safety at the two shuttle launch sites, advised NASA that the system did not meet minimum range safety requirements.

The commanders strongly urged NASA to change its system design for shuttle development flights and advised that a command destruct system may be required for some operational flights. NASA established a committee to study shuttle safety requirements and assess the potential hazards associated with development and operational flights. Before the committee completed the study, NASA advised us that it intended to adopt a system for its development flights acceptable to the Air Force. No decision or agreement has been reached regarding operational flights.

BACKGROUND

The Commander, Air Force Eastern Test Range, is responsible for flight safety and for approving the design of range safety systems for NASA vehicles even when they are launched from

NASA-owned facilities at KSC. The Commander, Space and Missile Test Center, has the same responsibilities at the Air Force Western Test Range, the other shuttle launch site. Because of the inherent dangers involved in the launch and flight of missiles and space vehicles, the commanders of these two national ranges have established minimum safety requirements, including flight termination systems, that have to be incorporated into the design of a missile or a space vehicle to minimize risks to life, health, and property.

On August 6, 1974, NASA selected a flight termination system which did not meet established minimum Air Force safety requirements. The system provided for placing explosive charges, controlled by the ground safety officer, on each of the shuttle's solid rocket boosters. The system design provided that if the shuttle went out of control before the boosters separate, the charges on the boosters would adequately disperse the highly explosive liquid propellants contained in the external tank. Since the external tank could not be destroyed after the boosters separate, the shuttle crew would be responsible for terminating main engine thrust and jettisoning the tank away from land masses. It is assumed that the crew would not be incapacitated by the malfunction and that they would have sufficient control to maneuver the orbiter.

NASA planned to use the booster destruct system only during development flights. NASA believed that a range safety system would not be needed on the operational shuttle because adequate safety would be attained through system design reliability and redundancy. This concept required the flight crew to deal with any emergency abort situation that might be encountered.

Before selecting the booster system, the shuttle program manager considered several alternative systems. Two of these systems probably would have satisfied the minimum range safety requirements established by the range commanders because explosive charges would also have been installed on the external tank to assure propellant dispersion. The program manager told us that he was aware the booster system did not meet all Air Force safety requirements but that he selected the system because it was less costly and, in his opinion, provided adequate safety without the additional features of the other systems.

MSFC officials had reservations about the capabilities of the booster destruct system because there was no way to guarantee that the liquid propellants in the external tank would be dispersed before booster separation and no capability existed to disperse the propellants after such separation. The Director of Marshall's Systems Analysis and Integration Laboratory, therefore, recommended against continued development of the system. However, in February 1975, the program manager directed that the development and implementation of the booster system be continued.

An October 1975 NASA estimate showed that development of the booster system would cost $4.7 million as compared to $6.6 million for one of the alternative systems, or a difference of less than $2 million. The booster system estimate, however, did not include the cost of full scale testing which might have been required to demonstrate that the system would work. MSFC officials, responsible for developing the system, estimated that these tests might cost as much as $10 million.

RANGE COMMANDERS' POSITION

In March 1975 NASA advised the eastern test range commander that the booster destruct system had been selected for development and requested tentative approval of the system. The commander denied the request primarily because the proposed system was inadequate and would not permit him to discharge his responsibilities after booster separation. In addition, he p nted out that the system would not satisfy range safety requirements for operational flights with missions having unacceptable flight safety risks.

Although NASA's request for tentative approval was denied, development continued and studies were initiated to resolve the range commander's concerns about the system's capabilities. NASA also began gathering data to show that during development flights the external tank could not hit land intact after booster staging and began assessing operational flights for possible hazards to land masses. NASA identified 84 operational flights for which a range safety system might be required.

In August 1975 the commander advised NASA that the above actions would still not satisfy his minimum range safety requirements because the booster destruct system:

--Will not provide the capability to shut down the orbiter main engines or destroy an erratic vehicle once the boosters are separated or the astronauts or astronaut systems are incapacitated, thereby increasing the probability of external tank impact upon down range land masses, such as Europe and Africa.

--Eliminates the safety officer's flexibility to permit an erratic, but safe, vehicle to proceed beyond booster burnout if the vehicle deviates from the intended flight direction.

--Does not allow any safety control during an aborted mission's return to the landing site.

NASA's response to the range commander's objections was to propose a joint ad hoc committee to make a detailed study of shuttle flights and the hazards involved. In October 1975 the commander advised NASA that establishing a committee would not alter the fact that the booster system does not provide the required safety capabilities during development flights or provide an adequate destruct system for operational flights posing safety hazards.

NASA POSITION

NASA established a Range Safety Committee to study this issue. The committee consists of engineers from headquarters and various field centers. NASA intended to evaluate the recommendations of the committee before initiating any change and perceived its options to be (1) continuing the effort to gain approval of the booster system, (2) changing to a system acceptable to the Air Force, or (3) referring the issue to higher authority.

We were advised later that the second option was adopted before the committee's finding because it was believed the study results would show a need to change the system. The capability of the new range safety system has yet to be defined by NASA and approved by the Air Force.

No decision has been made or agreements reached on the extent to which operational flights will require a range safety system. If operational flights require such a system, the space shuttle's weight and cost per flight will be increased. Increased weight could have an impact on payloads.

ADDITIONAL NASA COMMENTS

NASA states:

"The Space Shuttle baseline booster destruct system was changed to a system acceptable to the Air Force on December 4, 1975. There were three basic reasons for this decision. First, a preliminary assessment of the public and crew risk factors by the NASA Ad Hoc Range Safety Committee indicated that the probability of launching without a complete two-stage system during the development flights was small. Second, the cost impact of a change from the booster system could be significant if the decision to change were delayed and subsequently had to be made by cancelling the efforts to demonstrate the capabilities of the baseline booster system.

"While some operational flights will carry the new two-stage range safety system, it is not anticipated that the weight of this system will cause a change in the baseline mission payload weights. Rather, it is likely that the operational flexibility inherent in Shuttle cargo weight/space optimization will accommodate such added weight without increasing overall mission costs or changing the mission profile. There is an additional cost per flight for the on-board range safety hardware when it is required. However, this cost is minimized since the components on the booster are being designed for re-use.

"In order to expedite agreements on criteria for the employment of a full or partial flight termination system in the operational phase, DOD has officially joined NASA in the Range Safety Ad Hoc Committee. This Committee will also address the range safety considerations and constraints involved in deletion of the ground controlled system for operational flights. This joint effort should assure that subsequent decisions are consistent with national test range public risk/benefit policies."

CHAPTER 7

DOD-NASA INTERFACE

DOD is committed to using the space shuttle after 1980 as its primary launch vehicle. The scope and schedule of DOD's participation was contingent upon a number of factors including:

--NASA's ability to successfully accomplish program milestones leading to an initial operation capability of mid-1980 for the space shuttle.

--The number and cost of orbiters, if any, to be procured by DOD.

--The amount and nature of user charges.

--Availability of funds.

Accordingly, the total cost of DOD's participation is subject to change as the program and DOD's requirements become better defined.

DOD believes the space shuttle will increase military capabilities. The shuttle will provide routine access to space and is expected to improved payload reliability and delivery. DOD officials told us the shuttle also provides the opportunity to achieve reduced launch costs; phase-out the costly complement of current expendable launch vehicles with their numerous launch complexes; and gain an increased payload delivery capability. The program has not, however, progressed to the stage where all of these benefits can be substantiated. From a cost-benefit view, several studies show total costs of acquisition and recurring operations to be more than the costs of continued use of expendable vehicles for the 1980-91 period.

The DOD also believes the STS will offer opportunities for cost savings through eventual recovery and reuse, or repair of satellites. We were advised that DOD plans to use this concept where economically and technically feasible. DOD is tentatively planning to implement recovery and reuse on one satellite program. However, no commitments have been made to recover and reuse satellites. Recoverable satellites, we were advised, probably will not be a reality until the mid to late 1980s.

A phased developmental approach that will meet the DOD commitment of using the space shuttle as its primary launch vehicle has been adopted. This approach was taken (1) to minimize risks to military space programs which could occur through delays in space shuttle development and (2) to phase costs and optimize the transitioning of payloads from expendable launch vehicles to the space shuttle.

CURRENT PROGRAM STATUS

SAMSO's acquisition cost estimate late in 1975 for the DOD portion of the STS program, excluding orbiters, totaled about $1.8 billion (1975 dollars). If current costs for two orbiters are considered the DOD estimate would be $2.6 billion. SAMSO officials advised us that every attempt was made to include all potential costs. However, the program is still in the validation phase so the estimates can be expected to undergo continuing revision and refinement.

Acquisition costs

The initial acquisition estimate, presented to the NASA-USAF Space Transportation Committee in March 1974, totaled $1.5 billion in 1974 dollars. The following table compares the 1974 estimate, restated in constant 1975 dollars, to the November 1975 estimate, also stated in 1975 dollars. The $959 million increase is primarily the result of the addition of two program elements for which costs had not previously been estimated, changes in IUS requirements and inflation.

DOD Acquisition Cost Estimates

Program elements	1974 dollars: March 1974 estimate	March 1974 estimate escalated to 1975 dollars	1975 dollars: Nov. 1975 estimate	1975 dollars: Cost increase
	(millions)			
Two production orbiters[a]	$ 559	$ 620	$ 835[b]	$215
Vandenberg Air Force Base facilities[c]	640	710	710	0
Interim upper stage	100	108	191[d]	83
Mission operations	123	135	119	-16
Payload transition	98	106	309	203
System engineering test and evaluation and payload and program integration	-	-	155	155
Backup expendable launch vehicles and modifications	-	-	319	319
Total initial acquisition cost and increases	$1,520	$1,679	$2,638	$959

[a] DOD did not include an amount for orbiters in its November 1975 estimate. DOD and NASA have agreed to study and resolve the issue of funding of additional orbiters by the fiscal year 1978 budget cycle. DOD is not currently funding for orbiter procurement.

[b] $125 million (1975 dollars) cost for orbiter operational spares was not included. This is consistent with DOD reporting policy. To relate current cost of production estimates with NASA's original estimate of $500 million, all spares must be considered.

[c] Amounts shown are for a two launch pad configuration. DOD now plans to acquire one launch pad, and a second pad, if required by traffic rates and mission requirements.

[d] Amount includes development of a basic IUS stage including increased avionics reliability ($138 million), a third motor configuration, and costs of KSC related activities such as mission planning and the USAF portion of IUS/orbiter integration.

Considering inflation the November 1975 estimate increases $1.1 billion to about $3.8 billion in real year dollars.

Orbiters

Air Force Headquarters and SAMSO officials said that DOD guidance directed the exclusion of funding for orbiters from SAMSO's budget submission. A Headquarter's official said the 1977 Air Force budget submission would also reflect this decision. We noted that a September 30, 1975, letter from DOD to NASA suggested that NASA assume responsibility for procurement of any additional orbiters. In January 1976 DOD and NASA agreed to study and resolve the issue of funding for the two additional orbiters for the fiscal year 1978 budget cycle. Any delays in the decision to fund the two additional orbiters will likely result in additional program costs. Last year NASA estimated that an 18 month delay in procurement would cost about $350 million.

SAMSO officials advised us that according to NASA information the cost growth of $215 million (1975 dollars) from the March 1974 estimate to the current estimate of $835 million (1975 dollars) was attributable to:

--Inclusion of spares amounting to about $41 million (1975 dollars) in the current estimate, which were excluded from the March 1974 estimate.

--Inclusion of orbiter and crew related Government furnished equipment of about $37 million (1975 dollars) in the current estimate.

--Delays in the procurement of orbiters and better definition of efforts (about $137 million in 1975 dollars). When the March 1974 estimate was made, a continuous production run of five orbiters was envisioned.

Current NASA planning, however, contemplates a gap in production between the first three orbiters and the last two orbiters.

If inflation is considered the $835 million estimate (1975 dollars) amounts to a real year estimate of about $1.2 billion.

Facilities at Vandenberg Air Force Base

A SAMSO official said that the facilities project is on schedule although the military construction program had been compressed 1 year. The schedule was originally planned for 4 years for the first launch pad; it is now compressed to 3 years. This offical does not believe the schedule can be compressed further if the pad is to be operational by late 1982. The availability of the second launch pad has also been delayed from late 1982 to late 1986 to give DOD more time to determine

--if the planned rate of 20 shuttle launches a year is realistic and

--whether the second launch pad is a valid requirement.

The current cost estimate for a two pad Vandenberg facility is unchanged from the March 1974 estimate of $710 million in 1975 dollars. Analysis of available data, however, shows an $84 million decrease (1975 dollars) and a $29 million increase (1975 dollars) in the 1974 estimate due to changes in the program. The current facility estimate was not reduced because the net $55 million in 1975 dollars ($84 million minus 29 million) was retained as provision for contingencies.

The estimated reduction of $84 million (1975 dollars) involved scaling down some facilities, using some existing buildings, and eliminating a marine facility on the basis of NASA's contention that air ferry of external tanks was feasible. The marine facility has now been reinstated at a cost of $29 million in 1975 dollars since NASA no longer considers the air ferry of tanks as a viable option.

The facilities cost estimate of $710 million would increase by $286 million if real year dollars were used in the calculation.

Interim upper stage

A propulsive upper stage is an essential part of STS because about 35 percent of the projected DOD and NASA missions require an orbit capability which exceeds that achievable wit the basic space shuttle. Since early DOD use of the STS requires an upper stage, before NASA's full capability space tug would be available, the Air Force agreed to develop an interim upper stage by June 1980. However, the Air Force has the option to delay the availability of the interim upper stage if the space shuttle encounters schedule delays.

In October 1974 the Air Force awarded five study contracts to evaluate modifications to existing upper stages for use as candidates for the interim upper stage. In August 1975, when the study contracts were completed and evaluated DOD selected an interim upper stage concept to be developed with essentially available technology. This concept was selected to minimize developmental risks, reduce life cycle costs and increase reliability. The DOD is attempting to minimize upper stage program commitments until major NASA shuttle milestones are accomplished.

The interim upper stage design DOD selected was an expendable, solid propellant vehicle. The basic DOD design has not yet been determined but may consist of two or three stages. The three stage configuration may be capable of placing in orbit all but seven of NASA's projected payloads. In a possible four stage configuration, the interim upper stage could be capable of placing in orbit all except three payloads, including two inter-planetary payloads. DOD plans to award the interim upper stage contract in September 1976.

The Air Force estimate indicates the basic interim upper stage development and associated KSC activities will be $83 million (1975 dollars) more than the March 1974 estimate of $108 million (1975 dollars). The $83 million increase was attributable to changes in interim upper stage requirements, better definition of integration efforts, increased requirements for reliability, and planning, training and ground support equipment. The estimate would be about $241 million based on real year dollars.

Mission operations

The cost decrease of $16 million (1975 dollars) from the March 1974 estimate to the estimate of $119 million (1975 dollars) is due to refinement of the cost estimates. The SAMSO officials responsible for developing these cost estimates said they represented the costs which would be incurred to prepare the Vandenberg facilities for operations. Any costs incurred after the start of operations would be included under recurring operations' costs. If inflation was considered the estimate would be $179 million based on real year dollars.

Payload transition

The cost increase of $203 million for payload transition was due to better definition of requirements. The March 1974 estimate included estimates for payloads studies and design and testing, whereas the November 1975 estimate also includes (1) production and integration related to payload transition and (2) the costs of the transition from the interim upper stage to the space tug. The estimate does not include transitioning costs for DOD support missions. The estimate based on real year dollars would be $444 million if inflation were considered.

COST BENEFITS ANALYSIS

In the November 1975 SAMSO draft program memorandum, as revised, a system cost analysis (see app. V) of four options using STS for the period 1980-91 indicated that in all cases, except where payload recovery and reuse was contemplated, total costs to DOD through 1991 for initial acquisition and recurring operations of the STS will be more costly than continued use of expendable launch vehicles. While the DOD plans to recover and reuse payloads, no commitment has yet been made. Further, the analysis shows that if only recurring operations' costs are considered, STS will in all cases be cost beneficial. These recurring costs were based on revision 4 of the DOD mission model which contained a total of 295 satellites although current indications are that a revised DOD mission model will contain between 236 and 249 satellites. Additionally, the analysis did not include $835 million for procurement of two orbiters.

If these factors are considered, and the decision is made that DOD fund the procurement of the two orbiters, STS may not be less costly in total even when payloads are refurbished.

DOD MISSION MODEL

Although DOD is committed to using the shuttle, the exact number of DOD payloads to be flown on the shuttle has not been decided. The current DOD mission model contains a total of 239 satellites to be flown on the shuttle through 1991. However, it is being revised and indications are that the new total of DOD missions to be flown on the shuttle through 1991 will be between 184 and 193 satellites, an approximate 23- to 19-percent reduction.

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

Office of the Administrator

B-173677 MAR 3 1976

Honorable Elmer B. Staats
Comptroller General of the
United States
General Accounting Office
Washington, DC 20548

Dear Mr. Staats:

We appreciate the opportunity afforded NASA to comment during the drafting of the GAO Space Transportation System Report and we recognize that as a result, changes were made and that our comments are reflected throughout the body of the report.

In my opinion, however, the report is seriously misleading in two major respects. By implication, the report states: (1) that NASA has altered its management philosophy and subjected the Shuttle program to unwarranted risks, and (2) that there is a $1.0 billion cost growth. Since neither of these is a correct interpretation, I request that my views as expressed in this letter be included in your report.

A principal thrust of the report is that NASA's economy measures and cost avoidance actions have subjected the Shuttle program to increased schedule, cost, and technical risks, and that the probable outcome will be increased costs and reduced performance. This conclusion is not warranted by the available facts or the past excellent NASA record for on-time, within cost program accomplishment on major manned programs. NASA has, and will continue, to evolve the Shuttle development plan consciously and conscientiously in the direction of <u>increasing</u> the assurance we will meet our performance and schedule goals within cost. I find no analytical basis in the report supporting any concerns about our eventual technical performance. Even the Office of Management and Budget has observed that it is ironic that the GAO is concerned that the Administration and NASA may be placing too much emphasis on managing the costs of the Space Shuttle program.

The report states that the development program will experience more than $1.0 billion in cost growth, with the implication that this is an overrun due to poor management. This is incorrect. The original commitment for the development of the Shuttle was $5.15 billion in 1971 dollars independent of inflation. The current estimate is $5.22 billion independent of inflation: a total increase to date of $70 million, all of which is a direct result of consciously made changes to NASA's original estimate as part of the Administration's budget decisions. What is described as $1.0 billion of cost growth in the report, in fact, is essentially all inflation. Inflation is beyond the control of the agency. It was specifically recognized at the time the original estimate was made that inflation would be additive to the 1971 baseline estimate. The only fair standard against which to measure program management efficiency is the clear basis of the original estimate provided the Administration and the Congress. By this measure, NASA's management of this program has been excellent. In summary, I believe the program is being managed within prudent risks with virtually no cost growth over NASA's original commitment to the Congress.

I am also concerned about the report's suggestion that the Shuttle program be restructured to delay its full operational deployment. Even a cursory analysis of such a concept would show enormous cost increases to the taxpayer and deferral or denial of the very benefits the Shuttle program is designed to provide. I believe it is inappropriate to include such considerations in a formal report without a full and fair assessment of all the severe national implications inherent therein.

Sincerely,

James C. Fletcher
Administrator

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF MANAGEMENT AND BUDGET
WASHINGTON, D.C. 20503

Mr. Richard W. Gutmann
Director,
Procurement and Systems
Acquisition Division
U.S. General Accounting Office
Washington, D. C. 20548

FEB 17 1976

Dear Mr. Gutmann:

We appreciate the opportunity to review and provide comments on your staff's draft report on the NASA Space Transportation System, forwarded with your letter of January 12, 1976. In your letter you requested our specific comments on those portions of the report that make reference to OMB's involvement in the formulation of the NASA budget which has affected the funding and schedule for the Space Shuttle program. Specifically, the GAO report makes reference to: a) funding constraints imposed by OMB during 1973 through 1976 which required NASA to extend the completion date of the shuttle by 15-16 months, resulted in significant changes in the "management philosphy" for the program, and caused cost estimates to increase by $50 million (in 1971 dollars); b) an OMB "commitment" to maintain a $3.3 billion (1972 dollars) constant level budget for NASA; and c) a failure by OMB to allow NASA's congressional budget request to keep pace with inflation in the program. We will address these specific items in this letter, but we will not attempt to address the many other substantive matters raised in the report, which should more properly be addressed by NASA as the agency charged with the management responsibility for the Space Shuttle program.

With regard to prior year budget reductions for the shuttle, your report is accurate in stating that the funding requested by the Administration and provided by the Congress for the Space Shuttle was below the levels initially planned by NASA for the program. Budget actions affecting the Space Shuttle program have occurred in every budget year since the initiation of the program in FY 1973. We do not consider this unusual considering the size of the Space Shuttle undertaking and the continuing need for the Administration to constrain the overall NASA budget as part of the fiscal constraints imposed throughout the Government. We would point out, however, that budget reductions in the Space Shuttle program have been taken only after careful consideration of the alternatives available for constraining total NASA expenditures and only after consultation with senior NASA officials concerning the consequences of such actions. As a general matter, OMB has been quite aware of the possibility that constraining the funding for the Space Shuttle program, once the program was underway, could lead to large increases in the out-year costs for the program. Such considerations were an important factor in the President's decision in the FY 1977 budget to seek to maintain the basic development schedule for the shuttle despite the overall need for fiscal constraint in the President's budget.

While budget constraints have clearly required some adjustments in the schedule and work planned for the shuttle, we are not aware that NASA's general "management philosphy" for the program has changed. Also, we are not aware that significant future cost growth, above NASA's current baseline estimates for the program, has now become inevitable (as implied in the GAO report); although we have certainly recognized that increased technical risk in the program could result from program adjustments required by the need for budgetary constraint--particularly those related to the adjustments undertaken in the FY 1976 budget. How much technical risk to accept in a complex development program and how to trade-off those risks against the need for budgetary restraint are difficult management judgments--judgments which we believe must ultimately rest with the agency managers who are responsible for the conduct of the program. OMB has been repeatedly reassured by NASA senior management that although the program has been tightly managed and constrained, the original NASA estimate of $5.2 billion (in 1971 dollars) appears to be sufficient to meet current shuttle commitment dates, provided the shuttle does not encounter major technical problems during its development.

Based on the evidence we have seen so far, it appears that NASA and its contractors have performed well in managing the program, in meeting major milestones, and in controlling program costs. In our view, NASA's focus on cost management need not take away from the agency's emphasis on the shuttle's performance and schedule--on the contrary, it provides a kind of discipline in the program which could enhance program success. We would also note that NASA has an excellent reputation for technical management of its programs and that the agency has strong incentives to complete the program at minimum cost in order to obtain acceptance of the shuttle as a new capability by various shuttle users and also so that funding can be made available within NASA's overall budget for payloads and missions to be flown with the shuttle.

With respect to your second point on the uncertainties concerning an OMB "commitment" to future funding levels for NASA programs (the report refers to a constant budget level at $3.3 billion in 1972 dollars), we are sure that you understand that OMB cannot provide any firm assurances about future budget levels for any agency. The allocation of budgetary resources must inevitably be subjected to an ongoing, annual review by OMB and the President in order to allow the President an opportunity to assess on a continuing basis the changing needs and priorities of the Nation. As a working assumption for long-range planning purposes, the notion of a constant budget for NASA is not a bad assumption--provided it is recognized as an assumption.

Concerning the third point, the report makes reference to OMB not allowing for inflation for the Space Shuttle in budget requests to the Congress. It has been OMB's policy to make allowance, to the extent possible, for price increases in NASA's major development projects in budget requests to the Congress. In addition, for the past several years, OMB specifically agreed with NASA on future year runouts for shuttle expenditures required to meet major program milestones (assuming no major technical problems) with the explicit understanding that no firm guarantees could be made for future year budgets. The purpose for making explicit OMB funding plans for the Space Shuttle is to recognize the multi-year character of the shuttle development requirements, and to avoid the inherent inefficiencies that would result from constantly adjusting the Space Shuttle program schedule in order to meet short-term funding problems.

As a final comment, we find some irony in the GAO staff concerns that the Administration and NASA may be placing too much emphasis on managing the costs of the Space Shuttle program.

Again, we appreciate very much having this opportunity to comment on the GAO draft report. When completed, the report should be useful to the Congress, as well as the Administration, in helping to bring into focus significant issues related to the development and operation of the Space Transportation System.

Sincerely,

James L. Mitchell
Associate Director

SPACE SHUTTLE CONTRACT DATA AS OF OCTOBER 1975

Contractor	Item	Type of Contract	Target Cost	Base Fee	Target Price	Potential Award Fee
			(millions)			
Rockwell International Corporation:						
Space Division	orbiter shuttle integration:					
	increment I	cost plus	$ 933.0	$ 42.5	$ 975.4	$34.9
	increment II	award fee	1,817.3	91.5	1,908.8	60.1
	Total		$2,750.3	$134.0	[a]$2,884.2	$95.0
Rocketdyne Division	main engine:					
	phase A	cost plus	$ 272.8	$ 9.6	$ 282.4	$11.5
	phase B	award fee	227.8	9.7	237.5	12.2
	Total		$ 500.6	$ 19.3	$ 519.9	$23.7
Martin-Marietta Corporation	external tank	cost plus award fee	$ 147.6	$ 5.0	$ 152.6	$ 6.0
Thiokol Chemical Corporation	solid rocket motor	cost plus award fee	$ 136.5	$ 4.0	$ 140.5	$ 6.2

[a]Space shuttle requirements of $245.2 million are excluded from the negotiated target price and will be negotiated at a later date. The exclusion consists of $115.9 million for spares, $72.3 million for launch operations at Kennedy Space Center, $10 million for carrier aircraft functional support during ground and flight tests, and $47 million for authorized changes. In addition to these excluded costs, the contractor estimates anticipated changes to be $100.6 million with fee. Accordingly, the contract target price may be understated by as much as $345.8 million considering the above exclusions and anticipated changes.

MAJOR CHANGES TO SPACE SHUTTLE REQUIREMENTS IDENTIFIED BY NASA DURING SHUTTLE REQUIREMENTS REVIEW DECEMBER 1974

Item Changes	Cost changes (real year dollars)	
	----(millions)----	
Item changes expected to result in reduced spending		
Delete vibroacoustic test-defer forward fuselage	$ 67.7	
Defer extravehicular mobility unit	5.1	
Manipulator arm (Canadian development)	22.7	
Reduce systems integration	16.0	
Defer/reduce payload bay television	5.7	
Defer manned unit	4.1	
Defer/delete additional flight Government-furnished equipment	7.2	
Reduce ground vibration tests	3.2	
Delete thermal vacuum test	16.9	
Simplify/defer secure communication and data	4.5	
Delete solid rocket booster tow test cases	2.5	
Delete solid rocket booster first development firing	2.4	
Defer/reduce solid rocket booster recovery testing	1.0	
Reduce main propulsion test setups	.7	
Eliminate one intertank structural test article	.4	
Defer/reduce training and simulators	5.2	
Subtotal		$ 165.3
Item changes expected to result in additional spending		
Defer second-line ground-support equipment	$ 9.2	
Defer orbiter spares	.8	
Defer payload orbiter communications	2.0	
Defer docking module	2.2	
Defer external tank rate tooling	.8	
Defer crew module structural test	.8	
Defer structural test article	2.0	
Subtotal		17.8
Expected reduced spending		$ 147.5

DOD SPACE PROGRAM LIFE-CYCLE COSTS
(MILLIONS-FY 75 DOLLARS)

COST ELEMENT	OPTION				
	CURRENT ELV	BASELINE STS	DOD P/L MULT	DOD/NASA P/L MULT	DOD P/L REFURB
INITIAL ACQUISITION	(141)	(1803)	(1814)	(1847)	(1830)
Program integration		37	37	37	37
Systems engineering		68	68	68	68
Test and evaluation		17	17	17	17
Ground operations		710	710	710	710
Mission operations		119	119	119	119
IUS		191	191	191	191
Payload integration		33	33	33	33
Payload transition	66	309	320	353	336
ELV modification	75	35	35	35	35
Back-Up ELV hardware	--	284	284	284	284
RECURRING OPERATIONS	(8189)	(6739)	(6713)	(6610)	(5981)
Mission operations	--	73	73	73	73
STS launch vehicles	--	2466	2442	2343	2623
ELV launch vehicles		536	536	536	536
ELV annual support	851	201	201	201	201
ELV range support	88	26	26	26	26
Back-up ELV annual support	--	108	108	108	108
Back-up ELV range support	--	15	15	15	15
Payloads	2988	3110	3110	3110	2189
Payload recurring integration	75	54	54	52	59
Reliability	520	150	148	146	151
GRAND TOTAL	8330	8542	8527	8457	7811
DISCOUNTED DOLLARS	3468	3999	3990	3957	3805
ESCALATED DOLLARS	15299	14629	14609	14492	12949

Note: ( ) Reflects subtotals
Source: Space and Missile Systems Organization
GAO Note: ELV--expendable launch vehicle
DOD P/L MULT--multiple payloads
DOD P/L REFURB--payload refurbishment

APPENDIX V

NASA ANALYSIS OF SPACE SHUTTLE DEVELOPMENT TRANSFERS

	Amount transferred (millions)
Transfers to other budgets:	
Booster development activities	$ 58.0
Transfers to production:	
Orbiter development	118.0
Launch and landing development	70.0
Other transfers:	
Remote manipulator arm	22.7
Subtotal	$268.7
Less transfers to development	157.0
Net	$111.7

PRINCIPAL OFFICIALS

RESPONSIBLE FOR ACTIVITIES

DISCUSSED IN THIS REPORT

	Tenure of office	
	From	To
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION		
ADMINISTRATOR:		
James C. Fletcher	Apr. 1971	Present
George M. Low (acting)	Sept. 1970	Apr. 1971
Thomas O. Paine	Apr. 1969	Sept. 1970
DEPARTMENT OF DEFENSE		
SECRETARY OF DEFENSE:		
Donald H. Rumsfeld	Nov. 1975	Present
James R. Schlesinger	June 1973	Nov. 1975
William P. Clements (acting)	May 1973	June 1973
Elliot L. Richardson	Jan. 1973	Apr. 1973
Melvin R. Laird	Jan. 1969	Jan. 1973
DEPARTMENT OF THE AIR FORCE		
SECRETARY OF THE AIR FORCE:		
Thomas C. Reed	Jan. 1976	Present
James W. Plummer (acting)	Nov. 1975	Dec. 1975
John L. McLucas	July 1973	Nov. 1975
John L. McLucas (acting)	May 1973	July 1973
Dr. Robert C. Seamans, Jr.	Feb. 1969	May 1973

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