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U. S. GENERAL ACCOUNTING OFFICE

STAFF STUDY

SPACE TRANSPORTATION SYSTEM

NATIONAL AERONAUTICS AND SPACE

ADMINISTRATION

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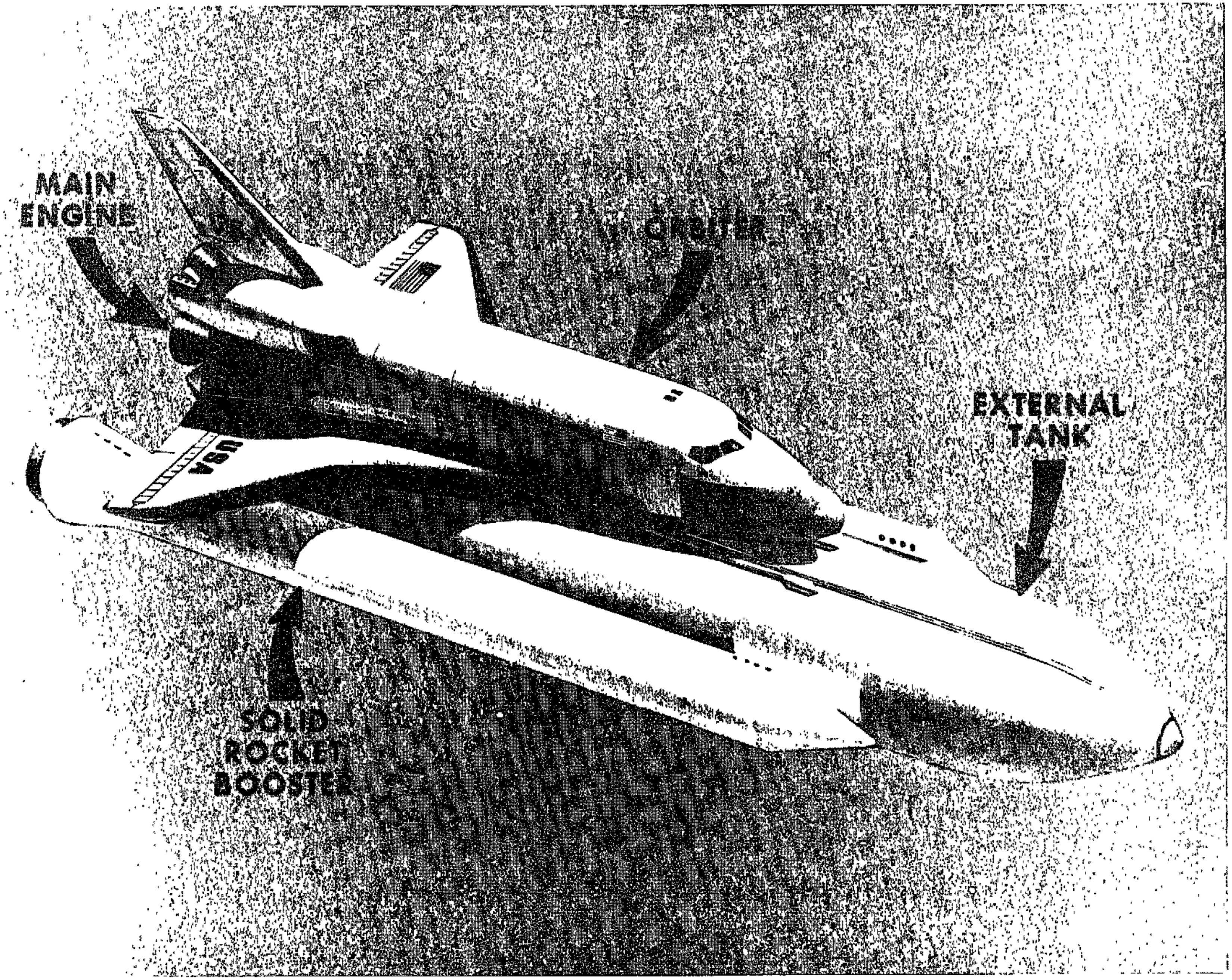
SPACE SHUTTLE SYSTEM



C O N T E N T S

ABBREVIATIONS

C of F	-	Construction of Facilities
DOD	-	Department of Defense
DTMO	-	Development, Test, and Mission Operations
ET	-	External Tank
GAO	-	General Accounting Office
JSC	-	Lyndon B. Johnson Space Center
KSC	-	John F. Kennedy Space Center
MSFC	-	George C. Marshall Space Flight Center
NASA	-	National Aeronautics and Space Administration
OAST	-	Office of Aeronautics and Space Technology
OMSF	-	Office of Manned Space Flight
OOS	-	Orbit to Orbit Stage
R&D	-	Research and Development
RDT&E	-	Research, Development, Test and Evaluation
R&PM	-	Research and Program Management
SRB	-	Solid Rocket Booster
SSME	-	Space Shuttle Main Engines
STS	-	Space Transportation System
USAF	-	United States Air Force

SUMMARY

This is the first of a series of annual staff studies which will provide data on the cost, schedule, and technical performance of the Space Transportation System (STS). This effort was undertaken as part of the General Accounting Office (GAO) review of the progress of major acquisition programs.

SYSTEM DESCRIPTION AND STATUS

The STS will include the space shuttle and space tug. The primary objective of the 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 space shuttle is currently planned to be operational in 1980. It will consist of a manned reusable orbiter; an external, expendable, liquid propellant tank; and two recoverable and reusable solid propellant rocket boosters. It will be boosted into space through the simultaneous burn of the space shuttle main engines (SSME) and the solid rocket boosters (SRB).

The shuttle is expected to place satellites in orbit; retrieve satellites from orbit; permit in-orbit repair and servicing of satellites; deliver space tugs and their payloads to low-earth orbit; and conduct short duration, low-earth orbit, science and applications missions with self-contained experiments. The shuttle effort is currently progressing under a combined design and development phase.

The space tug is a propulsive or upper stage that is expected to extend the capabilities of the shuttle to greater altitudes than those achievable by the orbiter alone. It is expected to be operational by late 1983. An orbit to orbit stage (OOS), with limited capabilities, will be used during the 1980-83 period. A tentative agreement has been reached between NASA and the United States Air Force (USAF) whereby the USAF will modify an existing upper stage to become the OOS and NASA will continue planning for development of the space tug.

COMING EVENTS

Major milestones of the program include the following:

--External Tank Preliminary Design Review	October 1974
--SRB Preliminary Design Review	November 1974
--Orbiter Preliminary Design Review for First Manned Orbital Flight	February 1975
--Shuttle System Preliminary Design Review for First Manned Orbital Flight	March 1975
--Space Shuttle Preliminary Design Review for First Manned Orbital Flight	May 1975
--First SSME Integrated Subsystem Test	July 1975
--External Tank Critical Design Review	November 1975

RESTRICTIONS ON REVIEW

Numerous restrictions and delays by NASA on access to information limited the depth of our review. Our attempts with NASA to resolve access issues have not yet been completed. We anticipate that pending changes will improve matters and allow future reviews to be conducted more effectively. NASA is currently preparing a management instruction for its various activities to follow in their relations with GAO.

RESPONSIBILITY FOR SPACE SHUTTLE

NASA has the primary responsibility for overall program management and integration of the Space Shuttle Program. Rockwell International's Space Division is NASA's principal contractor with overall integration responsibility of the system's major components: orbiter, SSME, external tank (ET), and SRB. It is also charged with the development and planned production of five orbiter vehicles.

The remaining contractors are (1) Rockwell International's Rocketdyne Division - SSME, (2) Martin Marietta Corporation, Denver Division - ET, and (3) Thiokol Chemical Corporation - solid rocket motor portion of the SRB. The selection of Thiokol as the solid rocket motor's (SRM) prime contractor is under award protest by Lockheed Propulsion Company and the outcome has not yet been determined. The Marshall Space Flight Center (MSFC) will perform SRB design and integration during the initial phases of the program.

NEED TO ESTABLISH BASELINES

Cost, schedule, and technical performance baselines serve as a starting point in our reviews of major acquisitions to measure the status of a program and as a basis for tracking its progress through the acquisition cycle.

One of our review objectives was to identify the baselines which had been established for the STS. Baselines play an important role in the management of a program. They permit management to measure, control, and evaluate the progress of a program. Established baselines provide a benchmark against which subsequent estimates may be compared.

Also, the comparsion of baseline cost estimates and current estimates aids the Congress in making decisions on whether a program should continue, be modified, or terminated. Without baseline and current cost estimates, the Congress may not be afforded an opportunity to effectively monitor the program with confidence that it is achieving its goals.

ESTIMATED COST OF THE SPACE TRANSPORTATION SYSTEM

NASA has not developed a cost estimate for the total cost of the development and operation of the STS but has established baseline cost estimates for four STS elements.

NASA stated that baseline cost estimates should be identified with definitive program content and/or specific system configurations. We believe that baseline estimates should be prepared early in program definition and that, if necessary, a range of costs may be provided to bracket the various system configurations under consideration.

When the present shuttle configuration was approved in March 1972, NASA presented to the Congress the results of an analysis of the development and operations of the STS from 1972 through 1990 based on a mission model of 581[1] flights. The purpose of the analysis was to compare the economics of the projected space effort for NASA, DOD, and others, using the STS and alternate programs of existing and/or new expendable launch systems.

The analysis included a $16.1 billion cost estimate, including DOD costs and STS operating costs from 1979 through 1990. Certain costs such as Government institutional costs paid through NASA's Research and Program Management (R&PM) Appropriation and Research and Development(R&D) technology costs were excluded from the economic analysis because they were considered applicable to all competing transportation systems. NASA has characterized the mission model used for the economic analysis as a representative set of candidate space missions rather than an approved program plan. Also, the $16.1 billion estimate was in 1971 dollars; therefore it did not consider inflation over the life of the program.

NASA officials stated that they have confidence in the estimates for defined program elements identified as baselines, whereas, the other estimates are considered preliminary or planning estimates which are likely to change when the final configurations have been established.

STS elements which have been baselined

NASA made in-depth reviews of the cost estimates for three STS elements included in the analysis and considers them to be baseline cost estimates.

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[1] NASA has updated its mission model throughout the program. Therefore, matters presented in the staff study involve 439, 581, or 782 flight mission models.

These estimates are (1) $5.150 billion for RDT&E of the space shuttle (2) $300 million for NASA's space shuttle facilities, and (3) $1.0 billion for refurbishment of the two development orbiters and production of three additional orbiters. Apart from the March 1972 analysis, NASA established a baseline estimate of $10.45 million as the average cost per flight for the shuttle based on a 439 flight mission model.

STS elements which have not been baselined

The following are STS elements which do not have baseline cost estimates. The cost estimates shown are in some instances contractor estimates and have not been subjected to in-depth reviews by NASA.

	Cost Estimate March 1972 (millions)
Elements considered in the March 1972 STS analysis:	
Modifications and requirements for expendable upper stages	$ 290
Development and investment for reusable space tugs	$ 809
DOD facilities	$ 500
Recurring STS operating costs exclusive of the space shuttle operating cost	See below
Elements excluded from the March 1972 STS analysis:	
R&PM costs	See below
R&D costs not defined as development cost chargeable against the STS	See below
Inflation	See below

Operating costs

The March 1972 economic analysis included STS operating costs of $8.050 billion from 1979 through 1990. A baseline estimate has been established only for cost per flight of the space shuttle. Operating costs not baselined include such items as the cost per flight for (1) expendable upper stages which NASA estimated to range from $1 million to $10 million (1973 dollars) and (2) the space tug which NASA estimated to be about $1 million (1973 dollars).

R&PM and R&D costs

NASA has projected that the Civil Service manpower level during peak year shuttle development (costs paid with R&PM funds) will be about 5,000 people. Also certain R&D costs related to the space shuttle development are not being charged against the space shuttle. These costs are for R&D effort which is funded by NASA organizations or activities outside the Space Shuttle Program. We identified $116.6 million of R&D obligations through November 1973 which appeared to be related to shuttle development, but were not charged against the shuttle RDT&E baseline estimate. In May 1974, NASA officials provided GAO with results of an analysis presented to the Congress which indicated that the total in-house costs which could be related or pro-rated to design, development, test, and evaluation of the space shuttle has been estimated at about $2.049 billion (1973 dollars) through fiscal year 1981.

Inflation

NASA used a 5 percent inflation factor to update its space shuttle development estimate from 1971 dollars to 1972 dollars. Based on this factor we projected inflation of about $1.5 billion on NASA's December 1973 estimate of $5.150 billion for development of the space shuttle.

STATUS OF BASELINED STS ELEMENTS

As of December 31, 1973, NASA expected to complete the RDT&E portion of the Space Shuttle Program within the $5.150 billion baseline estimate. However, on February 4, 1974, NASA announced a potential $50 million cost increase due to a program delay caused by funding constraints on the fiscal year 1975 budget.

Some facility and facility related costs are not included in NASA's shuttle facilities estimate but, according to NASA, will be charged against the RDT&E baseline estimate. These costs are for (1) unforeseen facilities requirements, (2) off-installation facilities, (3) locally-funded projects, and (4) non-collateral equipment. Costs for all of these shuttle-related facilities are charged against the RDT&E estimate when they are uniquely and directly required for the space shuttle.

During our review, we noted that NASA has identified potential cost growth or additional program requirements for three facilities projects: orbiter landing facilities, mobile launchers, and SSME test facilities. NASA expects,however,to complete its facilities program within the $300 million estimate because of off-setting changes which might occur in other facility requirements.

NASA has a current working estimate of $9.06 million for the average cost per flight of the space shuttle but considers the difference between this estimate and its baseline estimate of $10.45 million a program reserve.

SCHEDULE

NASA has established schedule baselines for certain critical milestones for the STS. Changes for these baselines are shown below:

NASA's Milestone Commitments to Congress

Milestone	Baseline (March 1972)	Fiscal Year 1974 Budget Request (February 1973)	Slippage (Months)	Fiscal Year 1975 Budget Request (February 1974)[a]	Slippage (Months)	Total Slippage (Months)
First Horizontal Flight[b]	Mid 76	1st QTR 1977	7-9	2nd QTR 1977[b]	1-3	10-12
First Manned Orbital Flight	1st QTR 1978	By end of 1978	9	2nd QTR 1979	4-6	13-15
Operational Capability	1st QTR 1979	By end of 1979	9	2nd QTR 1980	4-6	13-15

[a]Data provided by NASA and not verified.

[b]First Horizontal Flight replaced by Approach and Landing Test.

The initial 7- to 9- month slippage, according to NASA, was caused by reduced funding which forced it to proceed at a slower pace and delay contractor manpower buildup. However, NASA officials testified in fiscal year 1974 congressional hearings that further cost reductions or delays will start causing major increases in the program's cost.

Schedule changes may have a significant impact on both the cost and potential benefits to be derived from the STS. Target dates for delivery of orbiters four and five were extended by 24 and 26 months, respectively. These changes are related to the USAF's 1982 operational date for the Vandenberg Air Force Base launch site which is 2 years later than the date assumed by NASA in its economic justification analysis in March 1972.

Since the original production schedule was established to produce the most efficient flow consistent with anticipated annual funding, NASA stated that the production stretch-out may increase STS costs because of inflation and a less efficient production schedule. The increase would occur in the production phase of the program, rather than in the development phase where the NASA Administrator has made a commitment to the Congress to develop the shuttle within the $5.150 billion baseline estimate.

PERFORMANCE

NASA has established performance requirements which serve as guidelines for the design and development of the Space Shuttle Program.

Numerous changes have been made to performance requirements at all levels but, according to NASA personnel, have not significantly altered overall program objectives and cost projections.

NASA's performance management system requires that major shuttle contractors track and report periodically on selected performance characteristics. The status of three characteristics being tracked by NASA and Rockwell International's Space Division, is discussed below.

Payload-to-Orbit - This refers to the weight the shuttle system is expected to be able to place in orbit. The deployment of 32,000 pounds into a specified near polar orbit was one of the major factors used to establish the vehicle's size because this is the most demanding of the shuttle's missions. As of December 1973 the projected capability was 32,108 pounds.

Orbiter Weight - In August 1972, when Space Division received authority to proceed with the contract, the orbiter was designed to have a "dry weight" limitation (weight without payloads, fuel, etc.) of 170,000 pounds. In December 1972 this was reduced by NASA to 150,000 pounds primarily to reduce the cost per flight and to maintain control of the total vehicle size.

Reduction of the orbiter weight eliminated a 15,000 pound growth margin for contingencies and requirement changes. A vigorous weight reduction program was initiated which subsequently provided a weight margin of about 13,000 pounds. However, by December 1973, this margin had been reduced to about 1,900 pounds. This provides only about a 1.3 percent margin in contingencies and requirement changes. Space Division had originally planned to have a 10 percent margin at Preliminary Design Review scheduled for February 1974 because historical data on spacecraft indicated a 10.6 percent weight growth from that point through the life of the programs. NASA officials stated that the planned growth margin at Preliminary Design Review was reduced to 6 percent for the 150,000 pound orbiter. Studies are in progress to increase the orbiter weight-growth margin and according to NASA several potential weight reduction changes have been identified.

Thermal Protection System - The thermal protection system protects the primary airframe structure of the orbiter vehicle from the effects of aerodynamic heating during ascent and entry. The thermal protection system is considered by NASA to be the highest risk area of the program because methods of applying basic technology have not been fully demonstrated. Two areas of concern are (1) the amount of heat which could enter through gaps between tiles making up part of the thermal protection system and (2) whether the desired degree of reusability can be achieved.

UPPER STAGES

The space tug and the OOS will extend the capabilities of the shuttle to greater altitudes than those achievable by the orbiter alone.

Based on the 1973 mission model, upper stages such as the tug and OOS would be required for 65 percent of 555 automated payloads to be deployed by the space shuttle from 1980 through 1991. Some additional payloads beyond the payload delivery capability of the shuttle alone called for (1) expendable solid kick stages after deployment by the shuttle in low-earth orbit and (2) the use of expendable launch systems.

Current tentative plans call for an estimated development cost of up to $100 million (1973 dollars) for the OOS and $400 million (1973 dollars) for the space tug rather than about $770 million (1971 dollars) as estimated in March 1972 for development of upper stages. Upper stage capabilities under these plans, however, are less than those considered in March 1972. For example, the round trip payload capability of the tug between low earth orbit and geosynchronous orbit has been reduced from 3,000 pounds to 2,400 pounds. The reduction in cost resulted primarily from deleting the requirement for developing a new engine which was no longer needed because of the above reduction in payload capability.

MATTERS FOR CONSIDERATION

The following areas warrant special attention:

1. The absence of baseline cost estimates for some elements of the STS limits visibility and reduces management's capability to monitor and control the total STS effort. In addition, congressional decisions concerning the initial approval of large programs and subsequent funding levels can best be made when all related costs are known and baseline cost estimates are provided. Consequently, the Congress may wish to require NASA to provide cost estimates for all elements of the STS including those elements of the $16.1 billion estimate included in the economic analysis which have not been previously baselined and related elements excluded from this estimate such as R&PM, other research and development effort, and inflation. For those elements such as the space tug where a number of alternatives are still being considered and it is not feasible to establish a single baseline estimate, a range could be used as the baseline cost estimate.

2. Two high risk areas identified by NASA are the space shuttle's thermal protection system and the orbiter weight.

The Congress may wish to have NASA apprise them periodically on the development progress in these areas and other high risk areas which may arise.

3. Projected upper stage capabilities are now less than the capabilities assumed in March 1972. Moreover, projected economic benefits may occur later than planned because the planned operational date for the Vandenberg Air Force Base launch site is 2 years later than assumed by NASA in March 1972. Therefore, the Congress may wish to have NASA explain the impact the change in planned tug capabilities and the extension of operational dates for the Vandenberg Air Force Base launch sites will have on the program.

AGENCY REVIEW

A draft of this staff study was reviewed by NASA officials associated with the management of this program and comments are incorporated as appropriate. As far as we know, there are no residual differences in fact.

CHAPTER 1

INTRODUCTION

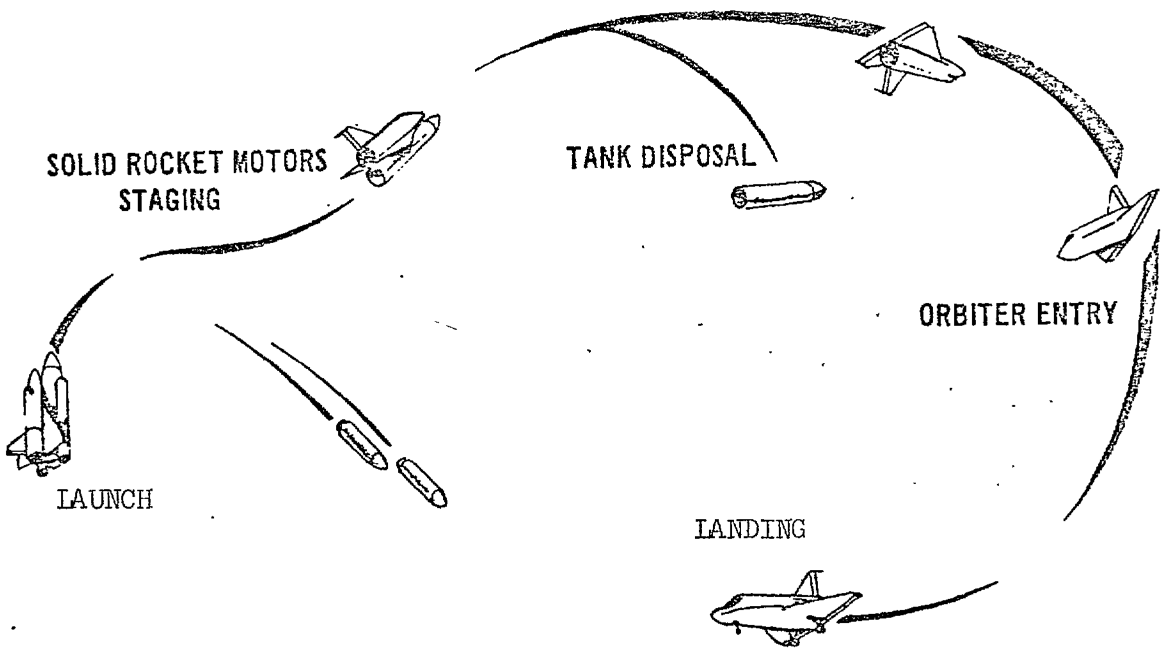
This is the first of a series of annual staff studies which will provide data on the status of cost, schedule, and technical performance for the Space Transportation System (STS) development by the National Aeronautics and Space Administration (NASA). The STS will include the space shuttle and the space tug. The review was undertaken in response to congressional requests that the General Accounting Office (GAO) report on the progress of major acquisition programs and covers the period from approval of the present shuttle configuration in March 1972 through December 1973.

The primary objective of the 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. In March 1972 NASA estimated that economic benefits from using the STS instead of expendable launch systems would be $5.6 billion through 1990. By October 1973, the number of projected space shuttle flights had increased from 581 to 725. NASA estimated that this increase and other program changes would increase the STS's economic benefits over expendable launch vehicles to $14.1 billion. Unless otherwise stated, all cost estimates cited this report will be in 1971 dollars.

The space shuttle is intended to place satellites in orbit; retrieve satellites from orbit; permit in-orbit repair and servicing of satellites; deliver space tugs and their payloads to low-earth orbit; and conduct short duration, low-earth orbit, science and applications missions with self-contained experiments.

DESCRIPTION

The space shuttle will consist of a manned reusable orbiter, which looks like a delta-winged airplane with length and wingspand comparable to a DC-9 airliner but with a wider body; an external, expendable, liquid propellant tank; and two recoverable and reusable solid rocket boosters (SRB). It will be boosted into space through the simultaneous burn of the space shuttle main engine (SSME) and the SRB which will detach at an altitude of about 25 miles and descend into the ocean by parachute to be recovered for reuse. The SSME burn will continue until the orbiter and external tank (ET) are near orbit velocity. The ET will then be detached and will land at a predetermined remote ocean site. Using its orbital maneuvering subsystem, the orbiter will continue into low-earth orbit. A pictorial profile of a shuttle mission is shown below.



The space shuttle will be able to place 65,000 pounds in a 150 nautical mile due-east orbit and 32,000 pounds into a specified 100 nautical mile near-polar orbit. The shuttle will be able to deliver lower payload weights to higher orbits.

The space tug is a propulsive or upper stage that extends the capabilities of the shuttle to greater altitudes than those achievable by the orbiter alone and is expected to be operational by late 1983. During the 1980-83 period, an orbit to orbit stage (OOS), which is to be a modification to an upper stage currently being used with expendable launch systems, will be used but will have limited capabilities. The space tug and the OOS are presented in Chapter 7.

HISTORY

After the first decade in space operations, the national space program was confronted by (1) a mix of promising and important space mission opportunities for the mid-1970s and beyond, and (2) a high cost of then current flight hardware and ground support operations for recurring orbital transportation operations.

Based on NASA's experience in space systems development and the large number of space flights anticipated, consideration was given to a reusable manned space shuttle which would operate between earth and low-earth orbit. NASA has projected economies in launch system costs and in payload development and procurement costs through the use of a space shuttle. NASA has stated, however, that the justification for the shuttle is not based on economics alone. Another fundamental reason is the necessity to have a means for routine quick reaction to space and return to earth in order to achieve the benefits of the scientific, civil, and military uses of space.

The United States Air Force (USAF) has been designated by the Department of Defense (DOD) as the organization responsible for making certain that DOD's interests are considered in the design and development of the shuttle.

Initially, NASA studied a two-stage fully recoverable shuttle configuration consisting of an orbiter and a booster, each of which would be operated by a two-man crew. Both stages were to use high-pressure oxygen/hydrogen engines and were to have internal tankage for both fuel and oxidizer. The shuttle was to take off vertically, and the booster rocket engines were to carry the orbiter to the fringe of the atmosphere. The booster would then separate from the orbiter and fly back to earth for an airplane-like landing using conventional air-breathing jet engines.

The orbiter would proceed under its own rocket power to orbit, perform its mission, and return to earth, landing horizontally like an airplane. The orbiter and the booster would maneuver in the earth's atmosphere using conventional air-breathing jet engines, and would be designed to be reusable for 100 or more flights.

During the fiscal year 1973 budget hearings, NASA testified that this fully reusable system would have maximum payload flexibility and would provide the least costly operational space transportation. However the annual funding and peak-year funding required during research and development were relatively high, so NASA extended its studies to cover new configurations which could be developed within anticipated funding constraints.

Subsequent alternatives considered before the present configuration (described on page 16) included the use of expendable hydrogen tanks and the use of liquid pump-fed or pressure-fed boosters.

When operational, the space shuttle is to accomplish most launches of NASA, DOD, and others. Shuttle launches and landings will be at the Kennedy Space Center (KSC) (to be operated by NASA) and a launch site at the Vandenberg Air Force Base (to be operated by the USAF).

NASA is to fund development of the space shuttle and construction of almost all facility requirements except those at Vandenberg Air Force Base. The USAF will fund facility costs at Vandenberg and plans to purchase two production orbiters and associated flight and ground support equipment.

STATUS

The shuttle effort is currently progressing under combined design and development phases of NASA's four-phase developmental approach--(1) Preliminary Analysis, (2) Definition,(3) Design,and (4) Development and Operations.

SPACE SHUTTLE RESPONSIBILITY

NASA has the primary responsibility for overall program management and integration. NASA also takes the lead in inline functions of softwear development, SRB integration, and operational planning.

The responsibility for development, production, and operational support for the space shuttle will be divided among four prime contractors and numerous subcontractors. Rockwell International's Space Division, is charged with the development and planned production of five orbiter vehicles. It is also charged with overall integration responsibility of the system's major components: orbiter, SSME, ET, and SRB.

The remaining contractors are (1) Rockwell International's Rocketdyne Division - SSME, (2) Martin Marietta Corporation, Denver Division - ET, and (3) Thiokol Chemical Corporation - Solid rocket motor portion of the SRB. The selection of Thiokol as the solid rocket motor (SRM) prime contractor is under award protest by Lockheed Propulsion Company and the outcome has not yet been determined. The Marshall Space Flight Center (MSFC) will perform SRB design and integration during the initial phases of the program. Details concerning the contracts are shown in Appendix I.

The contracts have been let in increments and the value of each successive increment will be subject to negotiations. The amounts of the initial increments of the major contracts are (1) $459.6 million for Rockwell International's Space Division, (2) $442.4 million for Rockwell International's Rocketdyne Division, and (3) $107.2 million for Martin Marietta, Denver Division.

RESTRICTIONS ON REVIEW

Numerous restrictions and delays by NASA on access to information limited the depth of our review. Our attempts with NASA to resolve access issues have not yet been completed. We anticipate changes which could improve matters and allow future reviews to be conducted more effectively. NASA is currently preparing a management instruction for its various activities to follow in their relations with GAO.

Restrictions on access to information stemmed from application and interpretation of preliminary guidelines concerning the GAO review which were prepared by NASA and issued by the Johnson Space Center (JSC) to other space centers and contractors. NASA Headquarters never officially approved the guidelines, but they nevertheless governed the release of information to GAO.

Limitations were placed on access to support for fiscal year 1975 and prior years' budgets, run-out cost estimates on individual contracts, and "planned actions, proposed dates, and future milestones." Application of the guidelines delayed receipt of essential information as long as three months. On occasion, requested supporting documentation such as contractor estimates on impact of delay in production, key issues and problem areas for facility projects, and detailed cost estimates used for internal management of the program was not released to the GAO.

CHAPTER 2

SPACE TRANSPORTATION SYSTEM COST

Cost, schedule, and technical performance baselines serve as a starting point in our reviews of major acquisitions to measure the status of a program and as a basis for tracking its progress through the acquisition cycle.

One of our review objectives was to identify the baselines which had been established for the STS. Baselines play an important role in the management of a program. They permit management to measure, control, and evaluate the progress of a program. Established baselines provide a bench-mark against which subsequent estimates may be compared.

Also, the comparison of baseline cost estimates and current estimates aids the Congress in making decisions on whether a program should continue, be modified, or terminated. Without baseline and current cost estimates, the Congress may not be afforded an opportunity to effectively monitor the program with confidence that it is achieving its goals.

ESTIMATED COST OF THE SPACE TRANSPORTATION SYSTEM

NASA has not developed a cost estimate for the total cost of development and operation of the STS, but has established baseline cost estimates for four STS elements.

NASA stated that baseline cost estimates should be identified with definitive program content and/or specific system configurations. We believe that baseline estimates should be prepared early in program definition and that, if necessary, a range of costs may be provided to bracket the various system configurations under consideration.

When the present shuttle configuration was approved in March 1972, NASA presented to the Congress the results of an analysis of the development and operations of the STS from 1972 through 1990 based on a mission model of 581[1] flights. The purpose of the analysis was to compare the economics of the projected space effort for NASA, DOD, and others, using the STS and alternate programs of existing and/or new expendable launch systems.

NASA informed the Congress of other categories of cost required for the STS but did not provide cost estimates for future years for some of these categories.

The following table presents the cost estimate from the STS/alternate programs analysis as presented to the Congress in March 1972. It includes DOD costs and STS operating costs from 1979 through 1990.

NASA officials stated that they have confidence in the estimates for defined program elements identified as baselines, whereas, the other estimates are considered preliminary or planning estimates which are likely to change when the final configurations have been established.

[1]NASA has updated its mission model throughout the program. Therefore, matters presented in the staff study involve 439, 581, or 782 flight mission models.

TABLE 1

Estimated Space Transportation System Costs Through 1990 (1971 Dollars in Billions)

Elements		Cost Estimate
Non-recurring Costs:		
Developmental Costs--Research, Development, Test and Evaluation (RDT&E)		$ 5.150[a]
Orbiter Inventory (Refurbishment of the two development orbiters and production of three orbiters)		1.000[a]
Modifications and Requirements for Expendable Upper Stages		.290
Facilities (Including two launch sites):		
NASA	$ .300[a]	
DOD	.500	.800
Reusable Space Tugs:		
RDT&E	$ .638	
Investment	.171	.809
Total		$ 8.049
Recurring Costs During Operations		8.050[b]
TOTAL		$16.099

[a]Baseline estimate.

[b]A baseline estimate has been established for the average cost per flight of the space shuttle based on a 439 flight mission model rather than the 581 flight mission model used in this analysis.

STS ELEMENTS WHICH HAVE BEEN BASELINED

NASA made in-depth reviews of the cost estimates for three STS elements included in the analysis and considers them to be baseline cost estimates. These estimates are (1) $5.150 billion for RDT&E[1] of the space shuttle, (2) $300 million for NASA's space shuttle facilities, and (3) $1.0 billion for refurbishment of two development orbiters and production of three orbiters. Apart from the March 1972 analysis, NASA established a baseline estimate of $10.45 million as the average cost per flight[2] for the shuttle based on a 439 flight mission model.

In addition to shuttle facilities to be funded within NASA's $300 million baseline estimate, some facility and facility related costs are chargeable against the $5.150 billion RDT&E baseline estimate. These costs are for:

Unforseen facilities requirements - When facilities requirements of $25,000 or less are not forseen at budget submission or are forseen but not validated, authority provided by recent authorization acts is utilized by NASA to fund them from its Research and Development (R&D) Appropriation if they cannot be deferred to the next budget cycle. This same authority can be used if the facilities have been made urgent by changed circumstances after preparation of the annual budget. According to NASA, the funds spent for all such projects are periodically reported to the Congress and have totaled less than $1 million to date.

[1]Also referred to by NASA as Design, Development, Test, and Evaluation

[2]The $10.45 million per flight estimate was based on a 439 flight mission model rather than the 581 flight mission model considered in developing the $16.1 billion STS cost estimate.

Off-installation facilities - Authority provided in authorization acts allows NASA to use R&D funds for facility items, other than land, at locations other than installations of the NASA Administrator when they are used in the performance of R&D contracts. By exercising this authority, NASA has obligated and charged to the RDT&E estimate $18.4 million for SSME test and assembly facilities at Conoga Park and Santa Susana, California.

Locally funded projects - New construction and additions to existing facilities up to $10,000 and rehabilitation and modifications up to $25,000 are not charged against the $300 million estimate. These projects are charged against the RDT&E estimate when the facilities uniquely support shuttle requirements. We did not determine the funds spent on such projects, if any.

Non-collateral equipment - Non-collateral equipment is defined by NASA as equipment that "...can be severed and removed after erection or installation without substantial loss of value or damage thereto or to the premises where installed." By definition non-collateral equipment are not facility items and are therefore not charged against the $300 million estimate. Examples of this type equipment include office furnishings and laboratory equipment. According to NASA personnel, shuttle related non-collateral equipment is charged to shuttle RDT&E and, to the extent possible, is disclosed to the Congress in annual construction of facility budgets and other documents. Non-collateral equipment costing about $31.5 to $35.5 million will be required for projects included in NASA's fiscal year 1974 budget estimates.

STS ELEMENTS WHICH HAVE NOT BEEN BASELINED

NASA purposely excluded certain costs from the analysis because they were considered equally applicable to all programs under analysis. These costs included shuttle related costs paid through NASA's Research and Program Management (R&PM) Appropriation and certain costs not defined by NASA as shuttle RDT&E costs. Also, the $16.1 billion estimate was in 1971 dollars and therefore, did not consider inflation over the life of the program.

The following are STS elements which do not have baseline cost estimates. The cost estimates shown are in some instances contractor estimates and have not been subjected to in-depth reviews by NASA.

	Cost Estimate March 1972 (millions)
Elements considered in the March 1972 STS analysis:	
Modifications and requirements for expendable upper stages	$ 290
Development and investment for reusable space tugs	$ 809
DOD facilities	$ 500
Recurring STS operating costs exclusive of the space shuttle operating cost	See below
Elements excluded from the March 1972 STS analysis:	
R&PM costs	See below
R&D costs not defined as development cost chargeable against the STS	See below
Inflation	See below

Operating costs

The March 1972 economic analysis included STS operating costs of $8.050 billion from 1979 through 1990. A baseline estimate has been established only for cost per flight of the space shuttle, however, it was based on a 439 flight mission model rather than the 581 flight mission model that was used in formulating the $16.1 billion estimate. Operating costs not baselined included such items as the cost per flight for (1) expendable upper stages which NASA estimated to range from $1 million to $10 million (1973 dollars) and (2) the space tug which NASA estimated to be about $1 million (1973 dollars).

Shuttle Related R&D Costs

Funds expended from the OMSF's space shuttle budget line item of NASA's R&D Appropriation are the only charges made against the development baseline estimate of $5.150 billion. These charges do not include some additional R&D effort related to shuttle development. NASA officials stated that a definite dividing line does not exist between R&D effort which should be charged against the space shuttle estimate and R&D effort which should not.

One member of the Senate Authorization Committee on Aeronautical and Space Sciences expressed concern about NASA's accounting practices. This Senator stated that:

> "My own feeling is that at the outset of a project such as this (space shuttle), where there is bound to be some controversy, I think that for the purposes of your credibility factor and ours, it would be best to have this (space shuttle appropriation) as a separate line item, and have everything in R&D included there ... Then nobody can accuse either you or the committee of having hidden costs."

The NASA Administrator said this could be done, but no action has been taken to include all R&D costs in the space shuttle line item.

We identified about $116.6 million of R&D obligations through November 1973 which appeared to be shuttle related and was not reported against the RDT&E estimate or as a cost of the Space Shuttle Program. If this amount were considered and added to the reported program obligations, total R&D obligations would be $583.2 million or 25 percent greater. The obligations we identified are discussed below.

Shuttle Technology and Shuttle Vehicle and Engine Definition

Shuttle Technology and Shuttle Vehicle and Engine Definition funds of $12.4 million from funds appropriated in 1970 are not considered by NASA as chargeable to their RDT&E estimate. These obligations were primarily incurred during early developmental phases and were excluded by an informal agreement reached between NASA and the Office of Management and Budget. According to NASA, they should not be charged against the baseline estimate because they were for feasibility studies rather than for development.

Supporting Research and Technology

By examining research and technology project definitions for NASA organizations, we identified about $93.0 million (Table 3) obligated by the OMSF and the Office of Aeronautics and Space Technology (OAST) for research and technology projects which appear to be in support of shuttle development.

TABLE 3

Shuttle Related Research Activity
Obligations by Fiscal Years (In Millions)

Organization	Prior to 1970	1970	1971	1972	1973	1974 thru 11/30/73	Total
OAST	$1.2	$10.6	$30.1	$23.3	$6.8	$ .3	$72.1[a]
OMSF	0.0	4.4	5.6	8.4	2.3	.2	20.9
TOTALS	$1.2	$15.0	$35.7	$31.7	$9.1	$ .5	$93.0[a]

[a]Figures do not add due to rounding.

NASA officials said that there is no clear distinction between R&D efforts represented by these obligations and those efforts which are charged against the RDT&E estimate.

Concerning OAST effort, NASA stated in 1972 Congressional testimony that "The OAST Shuttle technology program will ... support the Office of Manned Space Flight Shuttle program activities as appropriate to help assure that the shuttle vehicle will be built on schedule and within the available funds."

NASA stated that non-shuttle funded supporting research generally concentrates on "state-of-the-art technology" with broad potential application in future programs while shuttle funded tasks concentrate on development of a particular approach consistent with the shuttle system configuration and other requirements.

This explanation did not appear to be consistently valid for the research projects we examined. For example, the justification for a 1973 OMSF research project entitled Space Shuttle--Aerothermodynamics, the funds for which are charged to the RDT&E estimate (about $876 thousand obligated through June 30, 1973), reads in part as follows:

> "This effort is designed to provide current state-of-the-art technology studies in support of the engineering design analysis on the space shuttle vehicles. It includes analytical studies and experimental testing as necessary to analyze vehicle aerothermodynamic characteristics and to accurately define performance capabilities...."

The justification for another 1973 OMSF project with the same title, the funds for which are not charged to the RDT&E estimate (about $319 thousand obligated through November 30, 1973), reads almost identically:

> "The objective of this... is to provide support for the aerodynamic and thermodynamic development of the Space Shuttle vehicle. The tasks listed are of analytical and experimental nature. They involve the development of criteria and methods in those areas where adequate knowledge or prediction tools exist for the definition of aerothermodynamic environments or design values. The following items listed below have been selected because of their critical impact on the shuttle design: (1) Aerodynamic Study of Space Shuttle Vehicle Concepts, (2) Shuttle Load Distributions, (3) Booster Staging Environment,..."

Development, Test, and Mission Operations

Shuttle related R&D costs are also paid from the OMSF Development, Test, and Mission Operations (DTMO) portion of NASA's R&D Appropriation. DTMO funds provide a variety of contractual general support costs for manned space flight activities. No estimate was made for the amount of these costs related to the STS, although NASA informed the Congress that some DTMO costs would be related to shuttle development. NASA officials stated that the shuttle RDT&E estimate was made under the assumption that DTMO funding would be maintained at an annual level of about $200 million (1971 dollars).

Some of the general support programs planned that will benefit the shuttle include materials testing at the White Sands Test Facility and electrical power instrumentation testing at JSC. Future decisions on whether developmental tasks will be accomplished by shuttle R&D contractors or by contractors providing NASA's institutional support will normally determine whether they are charged to the shuttle RDT&E estimate or to DTMO. Only the cost of those tasks performed by shuttle R&D contractors are charged to the RDT&E estimate.

As an example of DTMO funding, $11.2 million of DTMO costs were incurred at MSFC in direct support of the Space Shuttle Program from July 1972 through December 1973. This amount represents about 10.4 percent of the total DTMO funds allocated to MSFC for fiscal years 1973 and 1974.

Research and Program Management

Consistent with the NASA appropriation structure, civil service manpower costs and logistics, technical, and administrative support costs are funded by the R&PM appropriation. For fiscal years 1972 and 1973, NASA identified 1,234 and 2,300 positions, respectively, as direct effort on the Space Shuttle Program. This number was expected to increase to about 5,000 at the peak of the development program. Shuttle related costs of $84.6 million were funded by this appropriation from July 1969 through November 1973. R&PM costs are not charged against the shuttle's baseline estimate. Therefore, future decisions on whether tasks will be accomplished by NASA personnel or by shuttle contractors will determine whether the costs are charged against the baseline estimate.

Inflation

Inflation can constitute a major portion of a program's total cost and the total amount of inflation incurred can be influenced by management decisions affecting the rate and timing of expenditures. Consequently, we believe inflation should be considered in the decision-making process and included in estimates made by Federal agencies. Our position was presented to the Congress in a report entitled "Estimates of the Impact of Inflation on the Costs of proposed Programs Should Be Available to Committees of the Congress," dated December 14, 1972 (B-176873).

The potential inflationary impact of a recent decision on total shuttle program costs is presented below for illustration:

> During fiscal year 1974 Senate authorization hearings, NASA announced that the shuttle development program had been extended by 9 months in order to hold fiscal year 1974 spending to the targets set by the President. This extension will result in inflationary increases because more funds will be expended duing the later years of the program than previously planned. Projected inflationary increases due to this change are shown in the following table. An inflationary factor of 5 percent per year[1] was assumed in the calculation.

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[1]A 5 percent per year factor was selected by GAO because NASA had previously used this rate as the inflation factor for 1972.

TABLE 2

Estimated Inflationary Cost
Increases in RDT&E (In Billions)

	Estimate Before 9-Month Delay	Estimate After 9-Month Delay	Estimated Inflationary Increase
RDT&E Estimate Without Inflation	$5.150	$5.150	$ -0-
Inflationary Cost	1.406	1.482	.076
Total Estimate Including Inflation	$6.556	$6.632	$ .076

Additional inflationary cost increases can be anticipated from other management decisions. A delay of the first manned orbital flight by an additional 4 to 6 months as announced by the NASA Administrator in February 1974, and a 2-year delay in production of two orbiters should increase STS costs because of inflation. Additionally, changes made in the timing of funding for facilities should result in similar increases.

In view of the impact of inflation, NASA has undertaken discussions with the Office of Management and Budget to recognize the influence of inflation in projecting funding levels for its programs in the future.

CHAPTER 3

STATUS OF STS ELEMENTS WITH BASELINE COST ESTIMATES

The status of three[1] STS cost elements for which NASA has made baseline cost estimates--space shuttle RDT&E, NASA funded facilities, and cost per flight--is set forth below.

SPACE SHUTTLE RESEARCH, DEVELOPMENT, TEST AND EVALUATION

NASA's baseline estimate of $5.150 billion was for the cost to design, develop, test, and evaluate two orbiters (including the SSME) and the SRB and ET needed to fly six development missions. This estimate was evaluated in detail by NASA, and the NASA Administrator made a commitment to develop the space shuttle within the estimate. NASA has subdivided the estimate into ten major categories. This subdivision together with recorded obligations through November 30, 1973, is shown in the following table:

[1] The status of the baseline estimate for refurbishment of two development orbiters and production of three new orbiters is not discussed because the Space Shuttle Program is still in the design and development phase.

TABLE 4

RDT&E Estimates and Recorded Obligations
(In Millions)

Category	Original Estimate in 1971 dollars[a] (March 1972)	Current Estimate in Real Year Dollars[b] (December 1973)	Obligations November 1973
Vehicle and Engine Definition		$ 88.4	$ 99.9
Technology		21.1	21.8
Main Engine			135.9
Solid Rocket Booster		4,911.5[c]	.4
External Tank			2.6
Orbiter			211.9
Airbreathing Engines		21.9	0.0
Launch and Landing		482.0	.5
System Management		1,078.9	.5
Contract Administration		76.8	5.4
Subtotal	$5,150.0	$6,680.6	$ 479.0[d]
Less: $12.4 million excluded by NASA from RDT&E baseline		-	12.4
Total	$5,150.0	$6,680.6	$ 466.6

[a]Detailed estimates were not prepared by NASA.
[b]The estimate in real year dollars is the estimate in 1971 dollars increased by assumed inflation factors.
[c]Estimates for the orbiter, main engines, external tank, and solid rocket booster were combined at NASA's request so as not to hinder contract negotiations with space shuttle contractors.
[d]Figures do not add due to rounding.

The obligations shown above account for about 55 percent of the $853.5 million budgeted for the Space Shuttle Program for fiscal years 1971 through 1974. NASA officials stated that through April 1974, $761.6 million, or about 89 percent of the funds budgeted for the Space Shuttle Program, had been obligated.

As of December 31, 1973, NASA expected to complete the RDT&E portion of the program within the $5.150 billion estimate. On February 4, 1974, however, NASA announced a revised cost estimate of $5.2 billion and a revised development schedule due to a reduction in its fiscal year 1975 budget request from $889 million to $800 million. The $50 million increase was described as tentative since NASA had not had an opportunity to work out the details of the new schedule with its contractors. Projected RDT&E funding prior to this announcement is shown in the following table:

TABLE 5

Projected RDT&E Funding Requirements
(1972 dollars in Millions)

Fiscal years	Amount
1975	$ 850
1976	1,100
1977	990
1978	873
Balance to Complete (1979 & 1980)	728
Total	$4,541

CONSTRUCTION OF FACILITIES

NASA's $300 million baseline estimate for construction and modification of test, development, and launch and landing facilities represents 37.5 percent of the $800 million estimate for all facilities. DOD facilities comprise the remainder. Included in NASA's estimate are facilities planning and design, both preliminary and final; engineering services of about 10 percent; collateral equipment [1]; and a 10 to 15 percent contingency.

Although the facilities estimate comprises only a small portion of projected STS costs, facilities are critical to the program's success. Completion dates for some facilities are linked directly to and are necessary for the shuttle development effort. NASA stated that the shuttle program will be delayed if these projects are not completed on time. For example, a 1-year funding delay for the SSME sea level test facilities would result in a corresponding delay of the shuttle vehicle program. NASA personnel have testified that any further delays will cause major increases in the cost of the shuttle program.

Current Construction of Facilities Estimate

As of December 31, 1973, NASA's estimated facilities cost was $285 to $310 million, as shown in Table 6. The amounts shown depict anticipated costs through 1980 and are expressed in 1971 dollars.

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[1] Collateral equipment is defined as that equipment which, if removed, would impair the usefulness, safety, or environment of the facility. Examples include elevators and heating, ventilating, and air conditioning systems.

TABLE 6

Cost of Facilities Estimate
FY 1971 - 1980
(Millions of 1971 Dollars)

Facility category	Baseline Estimate March 15, 1972	Current Estimate December 31, 1973	Variance from Baseline
Technology	$ 8.0	$ 9.0 - $ 9.0	$ 1.0 - $ 1.0
Engine	20.1	16.6 - 16.6	(3.5)- (3.5)
Manufacturing and Final Assembly	12.0	26.4 - 28.4	14.4 - 16.4
SRB Production and Test	46.0	37.0 - 42.0	(9.0)- (4.0)
Ground Test	40.9	38.7 - 41.7	(2.2)- .8
Launch and Landing	150.0	135.7 - 148.7	(14.3)- (1.3)
Total Projects	$ 277.0	$ 263.4 - $286.4	$(13.6)- $ 9.4
Plus: Facilities Planning and Design	23.0	21.6 - 23.6	(1.4)- .6
Total	$ 300.0	$ 285.0 - $310.0	$(15.0)- $ 10.0

NASA's explanation for the above variances was not furnished in time for our evaluation but is included as Appendix II. Moreover, the specific projects for which cost growth is projected by NASA were not identified in the information furnished. However, we noted during our review that potential cost growths have been identified by NASA on at least three projects: orbiter landing facilities, mobile launchers, and SSME test facilities. Even if these cost growths materialize, however, NASA's goal is to complete the facilities program within the $300 million estimate because of offsetting changes which might occur in other facility requirements.

Orbiter landing facilities - NASA stated on December 14, 1973, that fiscal year 1974 funding for construction of orbiter landing facilities at KSC may increase from $28.2 million to $29.3 million. The anticipated increase reflects potential cost growth attributable to shortages of materials and supplies and to the energy crisis. However, we were subsequently advised by NASA that they were able to obtain fuel allocations for this construction and resolve other uncertainties related to material escalation. During March 1974, a fixed price contract was awarded for these facilities. Based on the contract award, the current estimated cost is within the budgeted amount; and therefore NASA does not anticipate a cost increase related to this facility.

Mobile launchers - KSC officials have identified a requirement for a third mobile launcher to support the projected launch rate of 40 vehicles per year. An estimated $10.1 million (1971 dollars) in C of F funds would be required if the third launcher is necessary and is approved by NASA headquarters.

SSME test facilities - In March 1974, NASA identified a potential cost growth of approximately $3.85 million for the SSME test facilities at Santa Susana, California. NASA has advised the appropriate congressional committees of this increase.

Costs Incurred Through November 1973

NASA reports that through fiscal year 1974, the Congress has appropriated $123.5 million for shuttle facilities, or approximately 30 percent of the baseline estimate as adjusted for inflation. Of the $123.5 million, about $47.4 million had been obligated through November 1973.

COST PER FLIGHT

NASA's baseline estimate of $10.45 million for the average cost per flight of the space shuttle was based on a traffic model of 439 flights rather than the 581 flight mission model used for the STS cost estimate in the March 1972 analysis. NASA has a current working estimate of $9.06 million but considers the difference between its baseline estimate and its working estimate a program reserve.

The cost per flight estimates are comprised of several major cost elements and several sub-elements. The net changes between the baseline estimate and the current working estimate as of December 1973 are set forth below.

TABLE 7

Estimated Average Cost Per Flight
(In 1971 Dollars)

Cost Elements	March 1972 Million dollars	December 1973 Million dollars	Program Reserve Million dollars	Program Reserve Percent of March 1972 Estimate
External Tank and Solid Rocket Booster[a]	$ 6.59	$ 5.34	$ 1.25	19
Ground Operational	.27	.52	(.25)	93
Spares	1.40	.70	.70	50
Main Engines	.23	.23	-0-	-0-
Fuel and Propellants	.20	.30	(.10)	50
Program Support	1.76	1.97	(.21)	12
TOTALS	$ 10.45	$ 9.06	$ 1.39	13

[a] These cost elements were combined because they are considered contractor sensitive information, which, if disclosed, could compromise NASA's contract negotiations.

Primary reasons for changes in the estimates are:

	(millions)
External tank	
Decrease resulting from incorporation of contractor proposal[1]	
Increase resulting from weight increase[1]	
Solid rocket boosters	
Decrease resulting from updated component/system estimates and the use of five boosters from RDT&E phase[1]	
Increase resulting from better definition of booster and an increase in attrition rate[1]	
Ground operations	
Increase due to additional manpower for two launch sites (original estimate assumed one launch site)	$.26
Decrease resulting from reduction in manpower rate	(.01)
Net increase	$.25
Spares	
Decrease resulting from deletion of abort solid rocket motors and exclusion of installation costs for thermal protection system	($.54)
Decrease from update of orbiter spare requirement	(.16)
Net decrease	($.70)
Fuels and propellants	
Increase resulting from resizing to larger tank and orbiter	$.03
Increase resulting from additional production facilities for two launch sites	.07
Net increase	$.10
Program support	
Increase resulting from additional manpower requirement for two launch sites	$.21

The change from one to two launch sites resulted in an estimated cost increase of $540 thousand per flight or a total increase of about $237 million.

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[1]Individual figures were excluded because they are considered to be contractor sensitive information by NASA.

CHAPTER 4

SCHEDULE

NASA has stated to the Congress that the space shuttle will be developed within certain timeframes. These timeframes were used to establish controlled milestones for NASA's three levels of Space Shuttle Program management. These levels, called Levels I, II and III, cover the RDT&E and production phases of the program. NASA's objective is to schedule all program phases in the most efficient and economical manner consistent with anticipated annual funding. All Level III milestones have not been officially approved, and consequently, were not included in the scope of this review.

NASA MILESTONES

During fiscal year 1973 congressional hearings, NASA established timeframes for the first horizontal flight, the first manned orbital flight, and operational capability of the space shuttle. These were considered the baselines but were later changed because of funding constraints for fiscal years 1974 and 1975. The original dates and changes as presented in the fiscal year 1974 and 1975 budget submissions to the Congress are as follows:

TABLE 8

NASA Milestones

Milestone	Baseline (March 1972)	Slippage (Months)	Fiscal Year 1974 Budget Submission	Slippage (Months)	Fiscal Year 1975 Budget Submission[a]	Total Slippage (Months)
First Horizontal Flight[b]	Mid 1976	7-9	1st QTR 1977	1-3	2nd QTR 1977	10-12
First Manned Orbital Flight	1st QTR 1978	9	By End of 1978	4-6	2nd QTR 1979	13-15
Operational Capability	1st QTR 1979	9	By End of 1978	4-6	2nd QTR 1980	13-15

[a]Data provided by NASA and not verified with supporting documentation.

[b]First Horizontal Flight replaced by Approach and Landing Test.

The initial 7- to 9-month program slippage, according to NASA, was caused by reduced funding which forced it to proceed at a slower pace and delay contractor manpower buildup. NASA said that this would not cause developmental costs to exceed the baseline RDT&E estimate. However, NASA officials testified in the fiscal year 1974 congressional hearings that further cost reductions or delays will start causing major increases in the program's cost.

On February 4, 1974, NASA announced an additional 4- to 6-month program slippage caused by funding constraints. Program adjustments resulting from this slippage will be covered during our next review.

LEVEL I MILESTONES

Level I baseline milestones were issued in April 1972 and were consistent with those made to Congress. Changes in target dates for these milestones are depicted in Table 9.

TABLE 9

Level I Milestones and Target Dates

Milestones	Baseline (April 1972)	Slippage (Months)	Fiscal Year 1975 Budget Submission	Slippage (Months)	Fiscal Year 1975 Budget Submission[a]	Total Slippage (Months)
First Horizontal Flight [b]	Mid 1976	6	Dec. 1976	1	Jan. 1977	7
First Manned Orbital Flight	Mar. 1978	6	Sept. 1978	2	Nov. 1978	8
Operational Capability	Mar. 1979	6	Sept. 1979	2	Nov. 1979	8

[a]Data provided by NASA and not verified with supporting documentation.

[b]First Horizontal Flight replaced by Approach and Landing Test.

The slips reflected above resulted for the same reasons as the slippage in NASA's commitment to Congress. The Level I slippage was not as great because the Program Director wished to provide a contingency for unforeseen problems.

In December 1973, the number of milestones was increased to encompass such program elements as the orbiter, SSME, SRB, testing and facilities. Changes are being made to the Level I controlled milestones to reflect the 4- to 6-month slippage caused by funding limitations on the fiscal year 1975 budget request.

LEVEL II MILESTONES

Level II milestones were officially established in June 1973. Several approved changes to Level II milestones may have a significant impact on both the cost and potential benefits to be derived from the STS. Level II target dates for delivery of orbiters four and five were extended by 24 and

26 months, respectively. NASA officials said the delay resulted because of their peak year funding problems and because the DOD's initial activation date for the Vandenberg Air Force Base launch site was 1982. NASA's initial Level II milestones had been established prior to the DOD decision and assumed a 1980 operational date for Vandenberg.

The original production schedule was established to provide the most efficient flow consistent with anticipated annual funding. NASA stated that production stretch-out may increase program costs because of inflation and less efficient production due to the schedule change.

CHAPTER 5

PERFORMANCE

To attain the objectives of the Space Shuttle Program, the Program Director has established design objectives. These goals, called program performance requirements, serve as guidelines for detailed design and development by the JSC program manager, project managers, and contractors.

Performance goals controlled by the Program Director are referred to as Level I program requirements. They cover a wide range of topics in broad terms. For example, one requirement is for the orbiter vehicle to be capable of (1) use for a minimum of 10 years, and (2) low cost refurbishment and maintenance for as many as 500 reuses. More detailed requirements for attainment of Level I design goals have been established by the JSC program office (Level II), and the project offices (Level III). Level III requirements have not been officially approved and, accordingly, were not included in our review. Numerous changes have been made to program requirements at all levels but, according to NASA personnel, have not significantly altered overall program objectives and cost projections.

LEVEL I REQUIREMENTS

Baseline Level I program requirements for the present shuttle configuration were issued on April 21, 1972. They were revised on May 4, 1973, and an interim supplement was issued on December 12, 1973. We were able to determine the estimated cost impact of only four of the Level I changes although numerous other revisions were made. These four changes resulted in an estimated cost reduction of more than $330 million and a weight reduction of over 106,000 pounds. Two substantive changes made to Level I baseline program requirements are enumerated below.

--The shuttle was initially designed to have off-the-pad abort capability through the use of abort solid rocket motors. NASA stated that this requirement was deleted primarily because studies revealed that the degree of safety provided by abort motors was equalled or exceeded by increased redundancy requirements. This change resulted in an estimated cost reduction of about $238 million; $20 million for RDT&E, $214 million for the total program cost per flight, and $4 million for production. A gross lift off weight reduction of 101,450 pounds was associated with this change.

--The safety requirement for SRB thrust termination was eliminated to realize an inert weight reduction of about 1,566 pounds and a simplification of SRB structural and avionics subsystems. NASA was able to make this change after system abort studies were completed that determined the system ascent mode should continue through SRB burnout for all abort models. According to NASA this eliminated any requirement for SRB thrust termination to effect early separation and resulted in a "safer" system configuration. A total program cost reduction of $34.8 million is anticipated to result from an $80,000 cost per flight decrease.

LEVEL II REQUIREMENTS

Level II baseline program requirements were issued on March 20, 1973. Thirteen change packages were approved and issued against the baseline document through January 7, 1974. We were able to determine the impact of only nine individual changes. These changes resulted in a 4,686 pound weight reduction. We were not able to determine the cost impact of one of these changes, but the remaining eight changes resulted in an estimated net program cost increase of at least $14 million. Examples of Level II changes include the addition of ejection seats in test orbiters and design changes to the thermal protection and thermal control systems.

CONTRACTOR SUPPORT OF PERFORMANCE CHARACTERISTICS

NASA's performance management system requires that major shuttle contractors track and report periodically on selected performance characteristics. The status of four requirements being tracked by NASA and Rockwell International's Space Division, is presented below.

Payload-to-Orbit - This refers to the weight the shuttle system is able to place in orbit. The deployment of 32,000 pounds into a near polar orbit (104° inclination) was used as one of the major factors to establish the vehicle's size because this is the most demanding of the shuttle's missions. As of December 1973 the projected capability was 32,108 pounds.

Orbiter Weight - In August 1972, when Space Division received authority to proceed with the contract, the orbiter was designed to have a "dry weight" (weight without payloads, fuel, etc.) of 170,000 pounds. In December 1972 this was changed by NASA to 150,000 pounds primarily in order to reduce the cost per flight and maintain control of the total vehicle size. Space Division's estimated cost per flight for the 170,000 pound orbiter was about $2 million more than NASA's $10.45 million baseline estimate. The cost per flight is lower with the lightweight orbiter because it requires smaller, less expensive, SRB and ET.

Reduction of the orbiter weight to 150,000 pounds also eliminated a 15,000 pound growth margin for contingencies and requirements changes. A vigorous weight reduction program was therefore initiated by Space Division which subsequently provided a weight margin of approximately 13,000 pounds. However, by December 1973, this margin had been reduced to about 1,900 pounds.

The 1,900 pound growth margin provides only about a 1.3 percent margin for contingencies and requirement changes. Space Division had originally planned to have a 10 percent margin at Preliminary Design Review, scheduled for February 1974, because historical data on spacecraft indicated a 10.6 percent weight-growth from that point through the life of the program. NASA officials stated that the planned growth margin at Preliminary Design Review was reduced to 6 percent for the 150,000 pound orbiter. Within certain limits, any dry weight over the 150,000 pound baseline would reduce the payload-to-orbit capability discussed above. Studies are in progress to increase the orbiter weight growth margin, and according to NASA, several potential weight reduction changes have been identified.

Thermal Protection System - The thermal protection system protects the primary airframe structure of the orbiter vehicle from the effects of aerodynamic heating during ascent and entry. Its function is to maintain the temperature of the structure below 350° Fahrenheit and it is to be capable of at least 100 reuses with only minor repairs and replacements.

The thermal protection system is the program's highest risk area because methods of applying the basic technology have not been fully demonstrated. Some of the characteristics Space Division officials are concerned about included:

--Gaps between the tiles: The thermal protection system tiles will be affixed to the orbiter structure in a manner similar to regular floor tiles. The amount of heat entering through the tile gaps could damage the orbiter if adequate tile gap insulation and close out design is not provided.

--Reusability: The material has to be reusable for over 100 missions, with 3 to 5 percent projected replacement after each launch. Reusability is critical to keep cost-per-flight within the estimate.

--Other potential problems: Maintaining system design weight of 19,985 pounds and compensating for design changes that affect orbiter weight.

Turnaround Time - This is the time required to refurbish the space shuttle and prepare it for launch after it has returned from a mission. The Level I baseline for turnaround time is 160 working hours over 14 days. As an operational goal, NASA does not expect to meet the 160 hours requirement during the early flights where the scheduled launch rate does not require a two week turnaround capability. Instead, an evolutionary approach will be taken whereby the turnaround time is gradually reduced as experience is gained. According to NASA's April 1974 estimate, the turnaround capability is 211.5 hours, but various studies are under way to reduce this time.

CHAPTER 6

PROGRAM MANAGEMENT

NASA's program management system for the space shuttle has not been fully implemented. Implementation of the management system will continue to evolve as the program progresses. A description of selected elements of NASA's planned system is provided below for informational purposes.

RESPONSIBILITIES AND AUTHORITIES

The overall program planning, direction, and evaluation is conducted by the Space Shuttle Program Director within the Office of Manned Space Flight (OMSF) at NASA Headquarters. He recommends the total program budget, allocates and controls research and development (R&D) resources within authorized levels, and defines and controls program requirements. Program requirements controlled by the Space Shuttle Program Director are known as Level I program requirements.

The authority to manage the shuttle program on a day-to-day basis has been delegated to JSC as the lead center. A JSC Space Shuttle Program Office (Level II) has been established to provide management and technical integration for the entire effort in cooperation with project managers (Level III).

Five Space Shuttle Project Managers have been designated: one at JSC, three at MSFC, and one at KSC. Each of these managers, except the KSC manager, is responsible for one of the shuttle's major components, i.e., the orbiter, SSME, ET, or SRB. They must design and develop their projects, manage applicable contracts, and establish Level III requirements.

In addition, an overall projects manager has been designated at MFSC and is responsible for all work assigned to that center. The KSC Manager's responsibility includes launch, landing, recovery, and refurbishment operations. He must also assure that all shuttle program activities assigned to KSC are carried out.

PERFORMANCE MANAGEMENT

An integrated performance management system is being implemented by NASA and contractor organizations. As one of the significant management features, this system is intended to provide for the integrated planning and scheduling of the Space Shuttle Program. In addition, the system provides the basic program performance parameters to be considered in the normal technical decision and design process. This includes the measurement of progress in achieving established performance parameters. Elements of the integrated performance management system are (1) performance planning and control, (2) performance change control, (3) performance measurement, and (4) program visibility techniques.

Performance Planning and Control

A work breakdown structure which establishes categories for all work elements will be used to identify, plan, budget, allocate, authorize, schedule, and report on program work and related resources. In conjunction with the work breakdown structure, a program logic diagram will be developed. The diagram will graphically depict the integration of system elements and their interrelationships.

Performance Change Control

The performance change control element of the system will be designed to preclude unauthorized changes to performance baselines. The techniques to be used will assess the cost and schedule impact of changes before approval.

Performance Measurement

An integrated cost/schedule/technical performance measurement system will be established for the orbiter, ET, SSME, and SRB. A performance measurement system is designed to measure progress toward achievement of identified cost, schedule, and technical parameters and to identify potential problems in sufficient time to permit corrective action without adverse effects on the project. The system is to be keyed to the work breakdown structure.

Program Visibility Techniques

Multiple techniques will be used to provide project management visibility. These will include Management Information Centers at NASA and contractor facilities and key issue and problem lists.

CHAPTER 7

UPPER STAGES

The space tug is a propulsive or upper stage that is expected to extend the capabilities of the shuttle to greater altitudes than those achievable by the orbiter alone. The space tug will have the capability to deliver and retrieve payloads to high altitude, particularly geosynchronous orbit, to inject payloads into planetary trajectories and to conduct in-orbit servicing of payloads. It is being designed to be recoverable and reusable. The introduction of the space tug as an operational element of the STS will be in late 1983. An orbit to orbit stage (OOS), with limited capabilities, will be used during the 1980-83 period. A tentative agreement has been reached between NASA and the USAF whereby the USAF will modify an existing upper stage to become the OOS and NASA will continue planning for development of the space tug.

Current tentative plans call for an estimated development cost of up to $100 million (1973 dollars) for the OOS and $400 million (1973 dollars) for the space tug rather than about $770 million (1971 dollars) which was used in NASA's March 1972 analysis. Capabilities under these plans are, however, less than those considered in March 1972.

The importance of the capability to launch high energy payloads (payloads targeted beyond the capability of the shuttle alone) is demonstrated by the fact that 43 percent of the 986 payloads in the 1973 Payload Model for 1980 through 1991 are high energy payloads. Moreover, 65 percent of the automated payloads to be launched by the shuttle were high energy payloads. The 1973 Mission Model concluded that 725 shuttle flights and 80 expendable launch vehicle flights were required. The distribution of the payloads for those flights is given below:

TABLE 10

Distribution of Payloads in the 1973 Mission Model

(1980 THROUGH 1991)

Launch System		Number of Payloads
Expendable launch vehicles		95
Shuttle/Spacelab flights		336
Shuttle/Automated payloads		
Not requiring an energy stage	190	
Requiring a solid kick stage[a]	8	
Requiring an upper stage	357	555
Total		986

[a] A kick stage which is a small expendable propulsive stage can be attached to the payload for missions with extremely high energy requirements.

HISTORY

NASA and the DOD have studied a variety of upper stage approaches including (1) expendable stages not having payload retrieval or in-orbit servicing capabilities and (2) recoverable space tugs with varying performance capabilities (payload delivery; payload delivery and retrieval; or payload delivery, retrieval, and in-orbit servicing).

NASA's March 1972 mission model analysis included expendable Centaur and Agena stages as interim upper stages from 1979 through 1984 and a space tug from 1985 on. This model consisted of 581 shuttle flights and called for 65 Agena and 65 Centaur flights and for 173 space tug flights. Eight Agena kick-stage flights were also called for from 1985 through 1990.

In view of peak year funding problems for development of the shuttle and budget constraints on space effort, a tentative agreement was reached between NASA and the USAF in October 1973 calling for a three-phased upper stage development. The first phase was the OOS, which would be a modified existing stage and would be developed by the USAF. Leading candidates for modification were the Agena, Centaur, and Transtage.

The decision on whether the OOS would be expendable or reusable has not been made. NASA and the USAF are currently looking into performance trade-offs, required mission capabilities, capture characteristics, funding trade-offs, development trade-offs, and safety considerations.

The second phase was an interim space tug which would be operational in 1985. This tug was to be capable of payload deployment, retrieval, and in-orbit servicing of payload based on existing technology through fiscal year 1976 and was to use an existing engine. The third phase was a full-performance space tug which was to be operational sufficiently beyond 1985 to justify the development of the interim tug. This tug would be more powerful than the interim tug and would be based on technology available beyond fiscal year 1975. It would require new engine development to accomplish its desired capabilities.

In December 1973, NASA and the USAF reaffirmed the tentative agreement concerning development of the OOS, but changed from the interim tug/full-performance tug approach to the development of a full-capability tug instead.

NASA stated that the change from the three-phased upper stage development to the current tentative plan was made possible by reducing the required roundtrip capability between low earth orbit and geosynchronous orbit from 3,000 pounds (full-performance tug) to 2,400 pounds (full-capability tug). The decrease reduced the technical challenge in tug development because it eliminated the need for development of a new engine. This factor and other projected hardware changes account for a reduction in the estimated development cost from $800 million (1973 dollars) for the full-performance tug to $400 million (1973 dollars) for the full-capability tug. NASA will be responsible for planning related to this tug, and officials of both agencies stated that NASA will probably be responsible for development.

COST

In the March 1972 analysis, NASA included about $132 million for development of expendable upper stages (modified Agena and Centaur stages), $638 million for development of the space tug, and $171 million for investment in space tugs. NASA officials testified in congressional hearings that the estimated cost per flight for the tug was $1 million and that the estimated cost per flight for the Centaur was $8 million.

According to NASA, the estimated costs relative to the previous three-phased development plan and the current plans are as follows:

TABLE 11

Estimated Cost (1973 dollars) of the Three-Phased Upper Stage Development Plan

	Development	Cost per Flight
	(million)	
Orbit to orbit stage	up to $100[a]	$ 2 to $ 10[a]
Interim tug	400	$ 1-$2
Full performance tug	800	$ 1-$2

[a]Depending on reusability. There is a tradeoff between development cost and cost per flight.

TABLE 12

Estimated Cost (1973 dollars) of the Current Upper Stage Development Plan

	Development	Cost per Flight
	(million)	
Orbit to orbit stage	up to $100[a]	$2 to $10[a]
Full capability tug	400	about $1

[a]Depending on reusability. There is a tradeoff between development cost and cost per flight.

SCHEDULE

As stated previously, NASA's March 1972 analysis called for use of modified Agena and Centaur stages from 1979 through 1984 and for a space tug beginning in 1985. The three-phased development plans called for operational dates of 1980 for the OOS and about 1985 for the interim tug. The operational date for the full-performance tug had not been determined.

The current tentative plans call for an OOS operational date of December 19[illegible], following a 3-year development period and an operational date of late 1983 for the full-capability tug following a 5-year development period. A preliminary analysis of the full-capability tug is planned for fiscal year 1975 so that interface data can be obtained for input to the space shuttle development.

PERFORMANCE

Orbit to orbit stage

NASA stated that the number of flights and cost for modifying an existing upper stage does not appear to justify the development of more than one OOS. Therefore, due to the differences in the size and power of the candidate stages (Agena, Centaur, and Transtage), the OOS will have certain limitations in comparison with the modified Agena and Centaur stages as assumed in March 1972. For example, selection of the Transtage would not allow some high energy missions to be flown without the use of multiple stages. Also, because of the longer length of the Centaur, some DOD missions involving long payloads could not be flown in the shuttle with a modified Centaur stage unless a "short version" were developed. Expendable launch systems will be used during the transition period to the shuttle and one possibility is that more missions will be flown on the expendable launch systems than would have been required under the assumptions in March 1972.

Full-capability tug

The space tug considered in March 1972 was to be operational in 1985 and was to be capable of transporting a 3,000 pound payload round trip between low earth orbit and geosynchronous orbit.

The interim space tug in the three-phased development plan was also to be operational in 1985, but was to have a similar round trip capability of 2,000 pounds. The full-performance space tug (operational date not determined) was to have a 3,000 pound round-trip capability as shown below:

TABLE 13

Upper Stage Capabilities Under the Three Phased Development Plan

Geosynchronous performance from low earth orbit

	Deploy	Retrieve	Round Trip
	(pounds)		
Orbit-to-orbit stage	100-10,000	-	-
Interim tug	6,500	2,400	2,000
Full performance tug	8,000	4,000	3,000

Current tentative plans call for a full-capability tug in late 1983 which will have a round trip capability from low-earth orbit to geosynchronous orbit of 2,400 pounds as shown below:

TABLE 14

Planned Capabilities of the Orbit-to-Orbit Stage and the Full Capability Tug

Geosynchronous Performance

	Deploy	Retrieve	Round Trip
	(pounds)		
Orbit to orbit stage	3,500(minimum)	a	a
Full-capability tug	8,000	4,000	2,400

[a] The OOS will not have payload retrieval or round trip capabilities, but payloads launched by the OOS may be recovered by the tug at a later date.

NASA stated that the use of expendable kick stages is being considered to increase payload capability and that the upper stage may be expended on some launches to allow a greater payload capability.

APPENDIX I

SPACE SHUTTLE CONTRACT DATA
(Dollars in Millions)

CONTRACTOR	ITEM	TYPE OF CONTRACT	TARGET COST	BASE FEE	TARGET PRICE	POTENTIAL AWARD FEE
Rockwell International Corporation:						
Space Division	Orbiter-Shuttle Integration Increment I[a]	Cost Plus Award Fee	$440	$ 19.6	$ 459.6	$ 17.8
Rocketdyne Division	Main Engine Phase A & B	Cost Plus Award Fee	$424.6	$ 17.8	$ 442.4	$ 23.1
Martin Marietta Corporation:						
Denver Division (Letter Contract)	External Tank Increment I	Cost Plus Award Fee	$103.6	$ 3.6	$ 107.2	$ 6.2
Thiokol Chemical Corporation	Solid Rocket Motor	-b-	-b-	-b-	-b-	-b-

[a] Increment I is currently under negotiation and when finalized will incorporate a longer timeframe and more effort than currently included. There will, therefore, be significantly larger contract values for this increment.

[b] Information not shown. Award now under bid protest.

NASA EXPLANATION FOR CHANGES IN

SHUTTLE FACILITY ESTIMATES AT

APRIL 15, 1972 AND DECEMBER 13, 1973

This is in response to the above referenced GAO inquiry requesting an explanation of the variances in the shuttle facility runout costs from those originally developed, dated April 15, 1972, and the current estimates dated December 13, 1973.

It is our intention and goal to accomplish space shuttle facility requirements within the $300 million (1971 dollars) commitment. Our latest estimates indicate clearly that we are still on target. Inevitably, however, we expected and experienced some internal variations between the major categories that make up the $300 million total. Broadly speaking, these variances are the result of some changes from the original assumptions, increased requirements in some areas, decreased requirements in other categories, and better definition and improved cost estimates of the facilities as we move from the conceptual stage to the design and construction phases.

Specifically, the thermal protection system (TPS) facilities have increased by approximately one million dollars (1971 dollars). This increase is primarily due to the need for an additional requirement at JSC to provide capability for verification and acceptance testing for the TPS material.

The engine test facilities, on the other hand, experienced a net reduction in the amount of $3.5 million. This was caused by two reasons: (a) Deletion of the requirement for altitude testing of the main engine, after the decision was made to select the "parallel burn" concept, wherein the engines ignite at launch (sea-level) and need not ignite in the altitude environment, (b) Increased requirements for the sea level testing at MTF to provide capability for engine throttling tests.

Concerning the manufacturing and final assembly facilities for the orbiter and external tank, a net increase of approximately $15 million was experienced. The major part of the increase is attributed to the facility requirements at Downey and Palmdale in support of the orbiter manufacturing and assembly. The selection of these plants for this function was predicated on the successful proposal by Rockwell in mid-1972. In our initial estimates, we assumed a different location and a different manufacturing plan for the orbiter assembly functions. Although the Michoud Assembly Facility was baselined for the external tanks, some increase was experienced for these facilities as well. The current figures are based on preliminary engineering effort that was accomplished in the fall of 1972, after Michoud was selected for the external tank activities. These costs have now been confirmed after the Martin Marietta Corporation was selected for the development effort.

For SRB production and test facilities, our original estimates were based on discussions with potential contractors, our present estimates are based on limited preliminary engineering effort which indicates possible savings. It is premature, however, to reach final conclusions concerning these requirements until after the final production phase and the related sites are later determined.

The ground test facilities category combines those facility categories previously identified in the April 1972 summary as vehicle development test, systems integration and crew training, mission control and horizontal flight testing. The total for this category is essentially the same now as in the original estimates; although some variations have occurred within the projects involved.

Regarding the launch and landing facilities, our current estimates indicate potential reductions in the amount of $8-10 million. This is based on completed preliminary engineering for several projects and the final design of only one project, the runway. Again, it is too soon to reach final conclusions in this area although we feel confident that the $150 million previously estimated for these facilities, would not be exceeded.

In summary, therefore, we have based our original estimates on certain assumptions as to locations, requirements, rates and other factors. As assumptions vary, there will be corresponding variances in the facility categories involved. We have expected such variances would occur, and some had in fact occured. We keep the Congressional Committees informed of significant changes as they occur. We anticipate further internal changes as assumptions change and as requirements are further definitized and as the facility program advances from the conceptual stage to the final design and construction phases. But based on final design and/or construction awards of approximately 30% of the total facilities program, our current assessment is that we will achieve our goal of completing the facilities within the $300 million commitment announced in early 1972.

In summary, therefore, we have based our original estimates on certain assumptions as to locations, requirements, rates and other factors. As assumptions vary, there will be corresponding variances in the facility categories involved. We have expected such variances would occur, and some had in fact occured. We keep the Congressional Committees informed of significant changes as they occur. We anticipate further internal changes as assumptions change and as requirements are further definitized and as the facility program advances from the conceptual stage to the final design and construction phase. But based on final design and/or construction awards of approximately 30% of the total facilities program, our current assessment is that we will achieve our goal of completing the facilities within the $300 million commitment announced in early 1972.

C23307

U. S. GENERAL ACCOUNTING OFFICE

STAFF STUDY

SPACE TRANSPORTATION SYSTEM

NATIONAL AERONAUTICS AND SPACE

ADMINISTRATION

JUNE 1974

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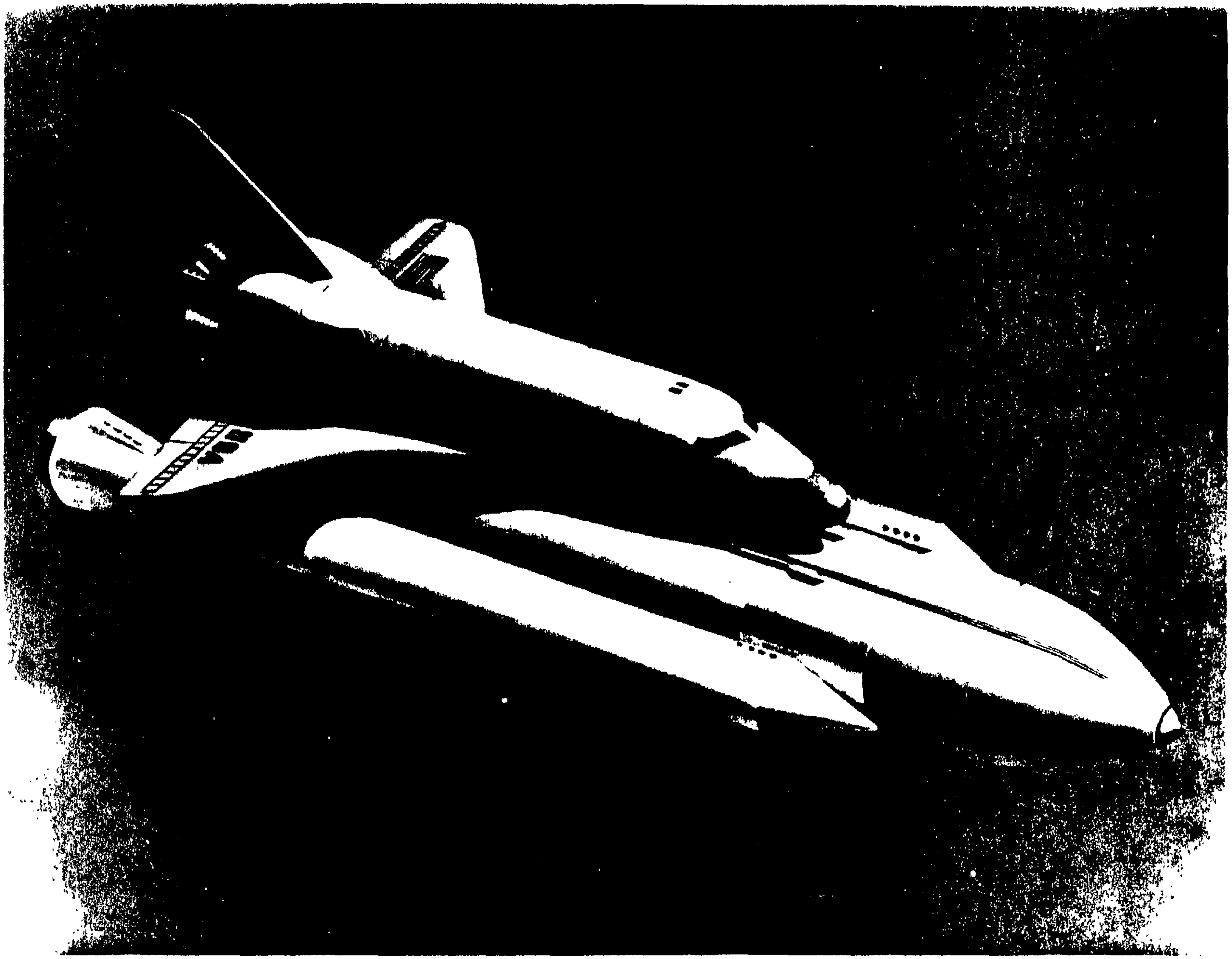
SPACE SHUTTLE SYSTEM



CONTENTS

ABBREVIATIONS

C of F	-	Construction of Facilities
DOD	-	Department of Defense
DTMO	-	Development, Test, and Mission Operations
ET	-	External Tank
GAO	-	General Accounting Office
JSC	-	Lyndon B. Johnson Space Center
KSC	-	John F. Kennedy Space Center
MSFC	-	George C. Marshall Space Flight Center
NASA	-	National Aeronautics and Space Administration
OAST	-	Office of Aeronautics and Space Technology
OMSF	-	Office of Manned Space Flight
OOS	-	Orbit to Orbit Stage
R&D	-	Research and Development
RDT&E	-	Research, Development, Test and Evaluation
R&PM	-	Research and Program Management
SRB	-	Solid Rocket Booster
SSME	-	Space Shuttle Main Engines
STS	-	Space Transportation System
USAF	-	United States Air Force

SUMMARY

This is the first of a series of annual staff studies which will provide data on the cost, schedule, and technical performance of the Space Transportation System (STS). This effort was undertaken as part of the General Accounting Office (GAO) review of the progress of major acquisition programs.

SYSTEM DESCRIPTION AND STATUS

The STS will include the space shuttle and space tug. The primary objective of the 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 space shuttle is currently planned to be operational in 1980. It will consist of a manned reusable orbiter; an external, expendable, liquid propellant tank; and two recoverable and reusable solid propellant rocket boosters. It will be boosted into space through the simultaneous burn of the space shuttle main engines (SSME) and the solid rocket boosters (SRB).

The shuttle is expected to place satellites in orbit; retrieve satellites from orbit; permit in-orbit repair and servicing of satellites; deliver space tugs and their payloads to low-earth orbit; and conduct short duration, low-earth orbit, science and applications missions with self-contained experiments. The shuttle effort is currently progressing under a combined design and development phase.

The space tug is a propulsive or upper stage that is expected to extend the capabilities of the shuttle to greater altitudes than those achievable by the orbiter alone. It is expected to be operational by late 1983. An orbit to orbit stage (OOS), with limited capabilities, will be used during the 1980-83 period. A tentative agreement has been reached between NASA and the United States Air Force (USAF) whereby the USAF will modify an existing upper stage to become the OOS and NASA will continue planning for development of the space tug.

COMING EVENTS

Major milestones of the program include the following:

--External Tank Preliminary Design Review	October 1974
--SRB Preliminary Design Review	November 1974
--Orbiter Preliminary Design Review for First Manned Orbital Flight	February 1975
--Shuttle System Preliminary Design Review for First Manned Orbital Flight	March 1975
--Space Shuttle Preliminary Design Review for First Manned Orbital Flight	May 1975
--First SSME Integrated Subsystem Test	July 1975
--External Tank Critical Design Review	November 1975

RESTRICTIONS ON REVIEW

Numerous restrictions and delays by NASA on access to information limited the depth of our review. Our attempts with NASA to resolve access issues have not yet been completed. We anticipate that pending changes will improve matters and allow future reviews to be conducted more effectively. NASA is currently preparing a management instruction for its various activities to follow in their relations with GAO.

RESPONSIBILITY FOR SPACE SHUTTLE

NASA has the primary responsibility for overall program management and integration of the Space Shuttle program. Rockwell International's Space Division is NASA's principal contractor with overall integration responsibility of the system's major components: orbiter, SSME, external tank (ET), and SRB. It is also charged with the development and planned production of five orbiter vehicles.

The remaining contractors are (1) Rockwell International's Rocketdyne Division - SSME, (2) Martin Marietta Corporation, Denver Division - ET, and (3) Thiokol Chemical Corporation - solid rocket motor portion of the SRB. The selection of Thiokol as the solid rocket motor's (SRM) prime contractor is under award protest by Lockheed Propulsion Company and the outcome has not yet been determined. The Marshall Space Flight Center (MSFC) will perform SRB design and integration during the initial phases of the program.

NEED TO ESTABLISH BASELINES

Cost, schedule, and technical performance baselines serve as a starting point in our reviews of major acquisitions to measure the status of a program and as a basis for tracking its progress through the acquisition cycle.

One of our review objectives was to identify the baselines which had been established for the STS. Baselines play an important role in the management of a program. They permit management to measure, control, and evaluate the progress of a program. Established baselines provide a benchmark against which subsequent estimates may be compared.

Also, the comparsion of baseline cost estimates and current estimates aids the Congress in making decisions on whether a program should continue, be modified, or terminated. Without baseline and current cost estimates, the Congress may not be afforded an opportunity to effectively monitor the program with confidence that it is achieving its goals.

ESTIMATED COST OF THE SPACE TRANSPORTATION SYSTEM

NASA has not developed a cost estimate for the total cost of the development and operation of the STS but has established baseline cost estimates for four STS elements.

NASA stated that baseline cost estimates should be identified with definitive program content and/or specific system configurations. We believe that baseline estimates should be prepared early in program definition and that, if necessary, a range of costs may be provided to bracket the various system configurations under consideration.

When the present shuttle configuration was approved in March 1972, NASA presented to the Congress the results of an analysis of the development and operations of the STS from 1972 through 1990 based on a mission model of 581[1] flights. The purpose of the analysis was to compare the economics of the projected space effort for NASA, DOD, and others, using the STS and alternate programs of existing and/or new expendable launch systems.

The analysis included a $16.1 billion cost estimate, including DOD costs and STS operating costs from 1979 through 1990. Certain costs such as Government institutional costs paid through NASA's Research and Program Management (R&PM) Appropriation and Research and Development(R&D) technology costs were excluded from the economic analysis because they were considered applicable to all competing transportation systems. NASA has characterized the mission model used for the economic analysis as a representative set of candidate space missions rather than an approved program plan. Also, the $16.1 billion estimate was in 1971 dollars; therefore it did not consider inflation over the life of the program.

NASA officials stated that they have confidence in the estimates for defined program elements identified as baselines, whereas, the other estimates are considered preliminary or planning estimates which are likely to change when the final configurations have been established.

STS elements which have been baselined

NASA made in-depth reviews of the cost estimates for three STS elements included in the analysis and considers them to be baseline cost estimates.

[1] NASA has updated its mission model throughout the program. Therefore, matters presented in the staff study involve 439, 581, or 782 flight mission models.

These estimates are (1) $5.150 billion for RDT&E of the space shuttle (2) $300 million for NASA's space shuttle facilities, and (3) $1.0 billion for refurbishment of the two development orbiters and production of three additional orbiters. Apart from the March 1972 analysis, NASA established a baseline estimate of $10.45 million as the average cost per flight for the shuttle based on a 439 flight mission model.

STS elements which have not been baselined

The following are STS elements which do not have baseline cost estimates. The cost estimates shown are in some instances contractor estimates and have not been subjected to in-depth reviews by NASA.

	Cost Estimate March 1972 (millions)
Elements considered in the March 1972 STS analysis:	
Modifications and requirements for expendable upper stages	$ 290
Development and investment for reusable space tugs	$ 809
DOD facilities	$ 500
Recurring STS operating costs exclusive of the space shuttle operating cost	See below
Elements excluded from the March 1972 STS analysis:	
R&PM costs	See below
R&D costs not defined as development cost chargeable against the STS	See below
Inflation	See below

Operating costs

The March 1972 economic analysis included STS operating costs of $8.050 billion from 1979 through 1990. A baseline estimate has been established only for cost per flight of the space shuttle. Operating costs not baselined include such items as the cost per flight for (1) expendable upper stages which NASA estimated to range from $1 million to $10 million (1973 dollars) and (2) the space tug which NASA estimated to be about $1 million (1973 dollars).

R&PM and R&D costs

NASA has projected that the Civil Service manpower level during peak year shuttle development (costs paid with R&PM funds) will be about 5,000 people. Also certain R&D costs related to the space shuttle development are not being charged against the space shuttle. These costs are for R&D effort which is funded by NASA organizations or activities outside the Space Shuttle Program. We identified $116.6 million of R&D obligations through November 1973 which appeared to be related to shuttle development, but were not charged against the shuttle RDT&E baseline estimate. In May 1974, NASA officials provided GAO with results of an analysis presented to the Congress which indicated that the total in-house costs which could be related or pro-rated to design, development, test, and evaluation of the space shuttle has been estimated at about $2.049 billion (1973 dollars) through fiscal year 1981.

Inflation

NASA used a 5 percent inflation factor to update its space shuttle development estimate from 1971 dollars to 1972 dollars. Based on this factor we projected inflation of about $1.5 billion on NASA's December 1973 estimate of $5.150 billion for development of the space shuttle.

STATUS OF BASELINED STS ELEMENTS

As of December 31, 1973, NASA expected to complete the RDT&E portion of the Space Shuttle Program within the $5.150 billion baseline estimate. However, on February 4, 1974, NASA announced a potential $50 million cost increase due to a program delay caused by funding constraints on the fiscal year 1975 budget.

Some facility and facility related costs are not included in NASA's shuttle facilities estimate but, according to NASA, will be charged against the RDT&E baseline estimate. These costs are for (1) unforeseen facilities requirements, (2) off-installation facilities, (3) locally-funded projects, and (4) non-collateral equipment. Costs for all of these shuttle-related facilities are charged against the RDT&E estimate when they are uniquely and directly required for the space shuttle.

During our review, we noted that NASA has identified potential cost growth or additional program requirements for three facilities projects: orbiter landing facilities, mobile launchers, and SSME test facilities. NASA expects, however, to complete its facilities program within the $300 million estimate because of off-setting changes which might occur in other facility requirements.

NASA has a current working estimate of $9.06 million for the average cost per flight of the space shuttle but considers the difference between this estimate and its baseline estimate of $10.45 million a program reserve.

SCHEDULE

NASA has established schedule baselines for certain critical milestones for the STS. Changes for these baselines are shown below:

NASA's Milestone Commitments to Congress

Milestone	Baseline (March 1972)	Fiscal Year 1974 Budget Request (February 1973)	Slippage (Months)	Fiscal Year 1975 Budget Request (February 1974)[a]	Slippage (Months)	Total Slippage (Months)
First Horizontal Flight[b]	Mid 76	1st QTR 1977	7-9	2nd QTR 1977[b]	1-3	10-12
First Manned Orbital Flight	1st QTR 1978	By end of 1978	9	2nd QTR 1979	4-6	13-15
Operational Capability	1st QTR 1979	By end of 1979	9	2nd QTR 1980	4-6	13-15

[a]Data provided by NASA and not verified.

[b]First Horizontal Flight replaced by Approach and Landing Test.

The initial 7- to 9- month slippage, according to NASA, was caused by reduced funding which forced it to proceed at a slower pace and delay contractor manpower buildup. However, NASA officials testified in fiscal year 1974 congressional hearings that further cost reductions or delays will start causing major increases in the program's cost.

Schedule changes may have a significant impact on both the cost and potential benefits to be derived from the STS. Target dates for delivery of orbiters four and five were extended by 24 and 26 months, respectively. These changes are related to the USAF's 1982 operational date for the Vandenberg Air Force Base launch site which is 2 years later than the date assumed by NASA in its economic justification analysis in March 1972.

Since the original production schedule was established to produce the most efficient flow consistent with anticipated annual funding, NASA stated that the production stretch-out may increase STS costs because of inflation and a less efficient production schedule. The increase would occur in the production phase of the program, rather than in the development phase where the NASA Administrator has made a commitment to the Congress to develop the shuttle within the $5.150 billion baseline estimate.

PERFORMANCE

NASA has established performance requirements which serve as guidelines for the design and development of the Space Shuttle Program.

Numerous changes have been made to performance requirements at all levels but, according to NASA personnel, have not significantly altered overall program objectives and cost projections.

NASA's performance management system requires that major shuttle contractors track and report periodically on selected performance characteristics. The status of three characteristics being tracked by NASA and Rockwell International's Space Division, is discussed below.

Payload-to-Orbit - This refers to the weight the shuttle system is expected to be able to place in orbit. The deployment of 32,000 pounds into a specified near polar orbit was one of the major factors used to establish the vehicle's size because this is the most demanding of the shuttle's missions. As of December 1973 the projected capability was 32,108 pounds.

Orbiter Weight - In August 1972, when Space Division received authority to proceed with the contract, the orbiter was designed to have a "dry weight" limitation (weight without payloads, fuel, etc.) of 170,000 pounds. In December 1972 this was reduced by NASA to 150,000 pounds primarily to reduce the cost per flight and to maintain control of the total vehicle size.

Reduction of the orbiter weight eliminated a 15,000 pound growth margin for contingencies and requirement changes. A vigorous weight reduction program was initiated which subsequently provided a weight margin of about 13,000 pounds. However, by December 1973, this margin had been reduced to about 1,900 pounds. This provides only about a 1.3 percent margin in contingencies and requirement changes. Space Division had originally planned to have a 10 percent margin at Preliminary Design Review scheduled for February 1974 because historical data on spacecraft indicated a 10.6 percent weight growth from that point through the life of the programs. NASA officials stated that the planned growth margin at Preliminary Design Review was reduced to 6 percent for the 150,000 pound orbiter. Studies are in progress to increase the orbiter weight-growth margin and according to NASA several potential weight reduction changes have been identified.

Thermal Protection System - The thermal protection system protects the primary airframe structure of the orbiter vehicle from the effects of aerodynamic heating during ascent and entry. The thermal protection system is considered by NASA to be the highest risk area of the program because methods of applying basic technology have not been fully demonstrated. Two areas of concern are (1) the amount of heat which could enter through gaps between tiles making up part of the thermal protection system and (2) whether the desired degree of reusability can be achieved.

UPPER STAGES

The space tug and the OOS will extend the capabilities of the shuttle to greater altitudes than those achievable by the orbiter alone.

Based on the 1973 mission model, upper stages such as the tug and OOS would be required for 65 percent of 555 automated payloads to be deployed by the space shuttle from 1980 through 1991. Some additional payloads beyond the payload delivery capability of the shuttle alone called for (1) expendable solid kick stages after deployment by the shuttle in low-earth orbit and (2) the use of expendable launch systems.

Current tentative plans call for an estimated development cost of up to $100 million (1973 dollars) for the OOS and $400 million (1973 dollars) for the space tug rather than about $770 million (1971 dollars) as estimated in March 1972 for development of upper stages. Upper stage capabilities under these plans, however, are less than those considered in March 1972. For example, the round trip payload capability of the tug between low earth orbit and geosynchronous orbit has been reduced from 3,000 pounds to 2,400 pounds. The reduction in cost resulted primarily from deleting the requirement for developing a new engine which was no longer needed because of the above reduction in payload capability.

MATTERS FOR CONSIDERATION

The following areas warrant special attention:

1. The absence of baseline cost estimates for some elements of the STS limits visibility and reduces management's capability to monitor and control the total STS effort. In addition, congressional decisions concerning the initial approval of large programs and subsequent funding levels can best be made when all related costs are known and baseline cost estimates are provided. Consequently, the Congress may wish to require NASA to provide cost estimates for all elements of the STS including those elements of the $16.1 billion estimate included in the economic analysis which have not been previously baselined and related elements excluded from this estimate such as R&PM, other research and development effort, and inflation. For those elements such as the space tug where a number of alternatives are still being considered and it is not feasible to establish a single baseline estimate, a range could be used as the baseline cost estimate.

2. Two high risk areas identified by NASA are the space shuttle's thermal protection system and the orbiter weight.

The Congress may wish to have NASA apprise them periodically on the development progress in these areas and other high risk areas which may arise.

3. Projected upper stage capabilities are now less than the capabilities assumed in March 1972. Moreover, projected economic benefits may occur later than planned because the planned operational date for the Vandenberg Air Force Base launch site is 2 years later than assumed by NASA in March 1972. Therefore, the Congress may wish to have NASA explain the impact the change in planned tug capabilities and the extension of operational dates for the Vandenberg Air Force Base launch sites will have on the program.

AGENCY REVIEW

A draft of this staff study was reviewed by NASA officials associated with the management of this program and comments are incorporated as appropriate. As far as we know, there are no residual differences in fact.

CHAPTER 1

INTRODUCTION

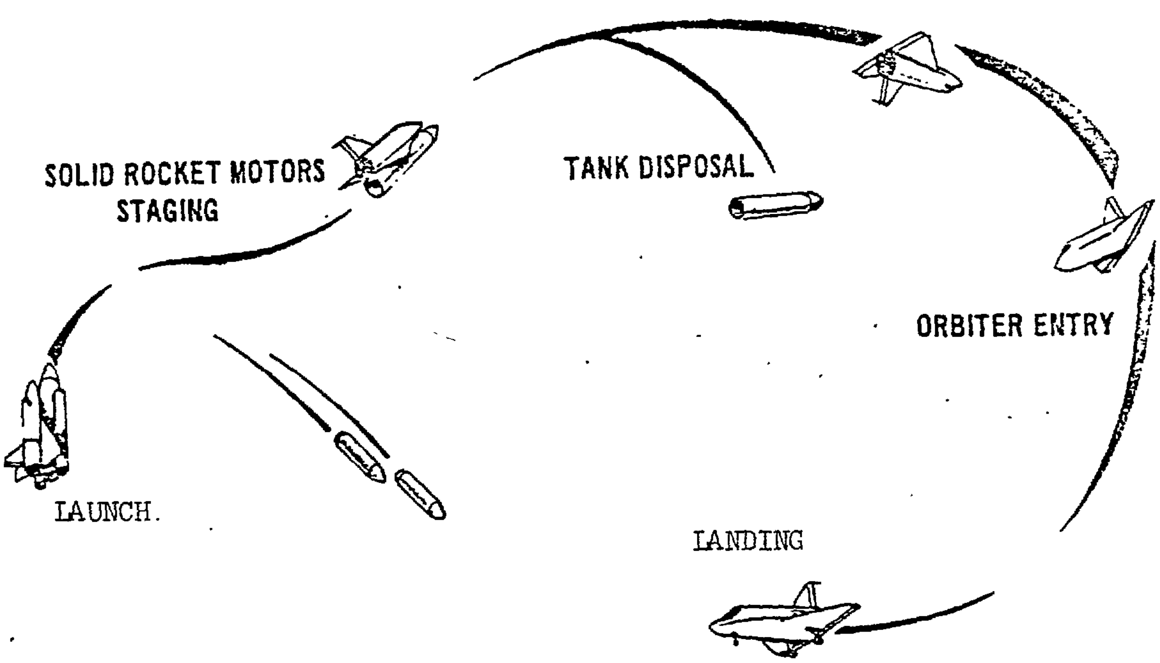
This is the first of a series of annual staff studies which will provide data on the status of cost, schedule, and technical performance for the Space Transportation System (STS) development by the National Aeronautics and Space Administration (NASA). The STS will include the space shuttle and the space tug. The review was undertaken in response to congressional requests that the General Accounting Office (GAO) report on the progress of major acquisition programs and covers the period from approval of the present shuttle configuration in March 1972 through December 1973.

The primary objective of the 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. In March 1972 NASA estimated that economic benefits from using the STS instead of expendable launch systems would be $5.6 billion through 1990. By October 1973, the number of projected space shuttle flights had increased from 581 to 725. NASA estimated that this increase and other program changes would increase the STS's economic benefits over expendable launch vehicles to $14.1 billion. Unless otherwise stated, all cost estimates cited this report will be in 1971 dollars.

The space shuttle is intended to place satellites in orbit; retrieve satellites from orbit; permit in-orbit repair and servicing of satellites; deliver space tugs and their payloads to low-earth orbit; and conduct short duration, low-earth orbit, science and applications missions with self-contained experiments.

DESCRIPTION

The space shuttle will consist of a manned reusable orbiter, which looks like a delta-winged airplane with length and wingspand comparable to a DC-9 airliner but with a wider body; an external, expendable, liquid propellant tank; and two recoverable and reusable solid rocket boosters (SRB). It will be boosted into space through the simultaneous burn of the space shuttle main engine (SSME) and the SRB which will detach at an altitude of about 25 miles and descend into the ocean by parachute to be recovered for reuse. The SSME burn will continue until the orbiter and external tank (ET) are near orbit velocity. The ET will then be detached and will land at a predetermined remote ocean site. Using its orbital maneuvering subsystem, the orbiter will continue into low-earth orbit. A pictorial profile of a shuttle mission is shown below.



The space shuttle will be able to place 65,000 pounds in a 150 nautical mile due-east orbit and 32,000 pounds into a specified 100 nautical mile near-polar orbit. The shuttle will be able to deliver lower payload weights to higher orbits.

The space tug is a propulsive or upper stage that extends the capabilities of the shuttle to greater altitudes than those achievable by the orbiter alone and is expected to be operational by late 1983. During the 1980-83 period, an orbit to orbit stage (OOS), which is to be a modification to an upper stage currently being used with expendable launch systems, will be used but will have limited capabilities. The space tug and the OOS are presented in Chapter 7.

HISTORY

After the first decade in space operations, the national space program was confronted by (1) a mix of promising and important space mission opportunities for the mid-1970s and beyond, and (2) a high cost of then current flight hardware and ground support operations for recurring orbital transportation operations.

Based on NASA's experience in space systems development and the large number of space flights anticipated, consideration was given to a reusable manned space shuttle which would operate between earth and low-earth orbit. NASA has projected economies in launch system costs and in payload development and procurement costs through the use of a space shuttle. NASA has stated, however, that the justification for the shuttle is not based on economics alone. Another fundamental reason is the necessity to have a means for routine quick reaction to space and return to earth in order to achieve the benefits of the scientific, civil, and military uses of space.

The United States Air Force (USAF) has been designated by the Department of Defense (DOD) as the organization responsible for making certain that DOD's interests are considered in the design and development of the shuttle.

Initially, NASA studied a two-stage fully recoverable shuttle configuration consisting of an orbiter and a booster, each of which would be operated by a two-man crew. Both stages were to use high-pressure oxygen/hydrogen engines and were to have internal tankage for both fuel and oxidizer. The shuttle was to take off vertically, and the booster rocket engines were to carry the orbiter to the fringe of the atmosphere. The booster would then separate from the orbiter and fly back to earth for an airplane-like landing using conventional air-breathing jet engines.

The orbiter would proceed under its own rocket power to orbit, perform its mission, and return to earth, landing horizontally like an airplane. The orbiter and the booster would maneuver in the earth's atmosphere using conventional air-breathing jet engines, and would be designed to be reusable for 100 or more flights.

During the fiscal year 1973 budget hearings, NASA testified that this fully reusable system would have maximum payload flexibility and would provide the least costly operational space transportation. However the annual funding and peak-year funding required during research and development were relatively high, so NASA extended its studies to cover new configurations which could be developed within anticipated funding constraints.

Subsequent alternatives considered before the present configuration (described on page 16) included the use of expendable hydrogen tanks and the use of liquid pump-fed or pressure-fed boosters.

When operational, the space shuttle is to accomplish most launches of NASA, DOD, and others. Shuttle launches and landings will be at the Kennedy Space Center (KSC) (to be operated by NASA) and a launch site at the Vandenberg Air Force Base (to be operated by the USAF).

NASA is to fund development of the space shuttle and construction of almost all facility requirements except those at Vandenberg Air Force Base. The USAF will fund facility costs at Vandenberg and plans to purchase two production orbiters and associated flight and ground support equipment.

STATUS

The shuttle effort is currently progressing under combined design and development phases of NASA's four-phase developmental approach--(1) Preliminary Analysis, (2) Definition,(3) Design,and (4) Development and Operations.

SPACE SHUTTLE RESPONSIBILITY

NASA has the primary responsibility for overall program management and integration. NASA also takes the lead in inline functions of softwear development, SRB integration, and operational planning.

The responsibility for development, production, and operational support for the space shuttle will be divided among four prime contractors and numerous subcontractors. Rockwell International's Space Division, is charged with the development and planned production of five orbiter vehicles. It is also charged with overall integration responsibility of the system's major components: orbiter, SSME, ET, and SRB.

The remaining contractors are (1) Rockwell International's Rocketdyne Division - SSME, (2) Martin Marietta Corporation, Denver Division - ET, and (3) Thiokol Chemical Corporation - Solid rocket motor portion of the SRB. The selection of Thiokol as the solid rocket motor (SRM) prime contractor is under award protest by Lockheed Propulsion Company and the outcome has not yet been determined. The Marshall Space Flight Center (MSFC) will perform SRB design and integration during the initial phases of the program. Details concerning the contracts are shown in Appendix I.

The contracts have been let in increments and the value of each successive increment will be subject to negotiations. The amounts of the initial increments of the major contracts are (1) $459.6 million for Rockwell International's Space Division, (2) $442.4 million for Rockwell International's Rocketdyne Division, and (3) $107.2 million for Martin Marietta, Denver Division.

RESTRICTIONS ON REVIEW

Numerous restrictions and delays by NASA on access to information limited the depth of our review. Our attempts with NASA to resolve access issues have not yet been completed. We anticipate changes which could improve matters and allow future reviews to be conducted more effectively. NASA is currently preparing a management instruction for its various activities to follow in their relations with GAO.

Restrictions on access to information stemmed from application and interpretation of preliminary guidelines concerning the GAO review which were prepared by NASA and issued by the Johnson Space Center (JSC) to other space centers and contractors. NASA Headquarters never officially approved the guidelines, but they nevertheless governed the release of information to GAO.

Limitations were placed on access to support for fiscal year 1975 and prior years' budgets, run-out cost estimates on individual contracts, and "planned actions, proposed dates, and future milestones." Application of the guidelines delayed receipt of essential information as long as three months. On occasion, requested supporting documentation such as contractor estimates on impact of delay in production, key issues and problem areas for facility projects, and detailed cost estimates used for internal management of the program was not released to the GAO.

CHAPTER 2

SPACE TRANSPORTATION SYSTEM COST

Cost, schedule, and technical performance baselines serve as a starting point in our reviews of major acquisitions to measure the status of a program and as a basis for tracking its progress through the acquisition cycle.

One of our review objectives was to identify the baselines which had been established for the STS. Baselines play an important role in the management of a program. They permit management to measure, control, and evaluate the progress of a program. Established baselines provide a benchmark against which subsequent estimates may be compared.

Also, the comparison of baseline cost estimates and current estimates aids the Congress in making decisions on whether a program should continue, be modified, or terminated. Without baseline and current cost estimates, the Congress may not be afforded an opportunity to effectively monitor the program with confidence that it is achieving its goals.

ESTIMATED COST OF THE SPACE TRANSPORTATION SYSTEM

NASA has not developed a cost estimate for the total cost of development and operation of the STS, but has established baseline cost estimates for four STS elements.

NASA stated that baseline cost estimates should be identified with definitive program content and/or specific system configurations. We believe that baseline estimates should be prepared early in program definition and that, if necessary, a range of costs may be provided to bracket the various system configurations under consideration.

When the present shuttle configuration was approved in March 1972, NASA presented to the Congress the results of an analysis of the development and operations of the STS from 1972 through 1990 based on a mission model of 581[1] flights. The purpose of the analysis was to compare the economics of the projected space effort for NASA, DOD, and others, using the STS and alternate programs of existing and/or new expendable launch systems.

NASA informed the Congress of other categories of cost required for the STS but did not provide cost estimates for future years for some of these categories.

The following table presents the cost estimate from the STS/alternate programs analysis as presented to the Congress in March 1972. It includes DOD costs and STS operating costs from 1979 through 1990.

NASA officials stated that they have confidence in the estimates for defined program elements identified as baselines, whereas, the other estimates are considered preliminary or planning estimates which are likely to change when the final configurations have been established.

[1]NASA has updated its mission model throughout the program. Therefore, matters presented in the staff study involve 439, 581, or 782 flight mission models.

TABLE 1

Estimated Space Transportation System Costs
Through 1990 (1971 Dollars in Billions)

Elements		Cost Estimate
Non-recurring Costs:		
Developmental Costs--Research, Development, Test and Evaluation (RDT&E)		$ 5.150[a]
Orbiter Inventory (Refurbishment of the two development orbiters and production of three orbiters)		1.000[a]
Modifications and Requirements for Expendable Upper Stages		.290
Facilities (Including two launch sites):		
NASA	$ .300[a]	
DOD	.500	.800
Reusable Space Tugs:		
RDT&E	$ .638	
Investment	.171	.809
Total		$ 8.049
Recurring Costs During Operations		8.050[b]
TOTAL		$16.099

[a]Baseline estimate.

[b]A baseline estimate has been established for the average cost per flight of the space shuttle based on a 439 flight mission model rather than the 581 flight mission model used in this analysis.

STS ELEMENTS WHICH HAVE BEEN BASELINED

NASA made in-depth reviews of the cost estimates for three STS elements included in the analysis and considers them to be baseline cost estimates. These estimates are (1) $5.150 billion for RDT&E[1] of the space shuttle, (2) $300 million for NASA's space shuttle facilities, and (3) $1.0 billion for refurbishment of two development orbiters and production of three orbiters. Apart from the March 1972 analysis, NASA established a baseline estimate of $10.45 million as the average cost per flight[2] for the shuttle based on a 439 flight mission model.

In addition to shuttle facilities to be funded within NASA's $300 million baseline estimate, some facility and facility related costs are chargeable against the $5.150 billion RDT&E baseline estimate. These costs are for:

Unforseen facilities requirements - When facilities requirements of $25,000 or less are not forseen at budget submission or are forseen but not validated, authority provided by recent authorization acts is utilized by NASA to fund them from its Research and Development (R&D) Appropriation if they cannot be deferred to the next budget cycle. This same authority can be used if the facilities have been made urgent by changed circumstances after preparation of the annual budget. According to NASA, the funds spent for all such projects are periodically reported to the Congress and have totaled less than $1 million to date.

[1]Also referred to by NASA as Design, Development, Test, and Evaluation

[2]The $10.45 million per flight estimate was based on a 439 flight mission model rather than the 581 flight mission model considered in developing the $16.1 billion STS cost estimate.

Off-installation facilities - Authority provided in authorization acts allows NASA to use R&D funds for facility items, other than land, at locations other than installations of the NASA Administrator when they are used in the performance of R&D contracts. By exercising this authority, NASA has obligated and charged to the RDT&E estimate $18.4 million for SSME test and assembly facilities at Conoga Park and Santa Susana, California.

Locally funded projects - New construction and additions to existing facilities up to $10,000 and rehabilitation and modifications up to $25,000 are not charged against the $300 million estimate. These projects are charged against the RDT&E estimate when the facilities uniquely support shuttle requirements. We did not determine the funds spent on such projects, if any.

Non-collateral equipment - Non-collateral equipment is defined by NASA as equipment that "...can be severed and removed after erection or installation without substantial loss of value or damage thereto or to the premises where installed." By definition non-collateral equipment are not facility items and are therefore not charged against the $300 million estimate. Examples of this type equipment include office furnishings and laboratory equipment. According to NASA personnel, shuttle related non-collateral equipment is charged to shuttle RDT&E and, to the extent possible, is disclosed to the Congress in annual construction of facility budgets and other documents. Non-collateral equipment costing about $31.5 to $35.5 million will be required for projects included in NASA's fiscal year 1974 budget estimates.

STS ELEMENTS WHICH HAVE NOT BEEN BASELINED

NASA purposely excluded certain costs from the analysis because they were considered equally applicable to all programs under analysis. These costs included shuttle related costs paid through NASA's Research and Program Management (R&PM) Appropriation and certain costs not defined by NASA as shuttle RDT&E costs. Also, the $16.1 billion estimate was in 1971 dollars and therefore, did not consider inflation over the life of the program.

The following are STS elements which do not have baseline cost estimates. The cost estimates shown are in some instances contractor estimates and have not been subjected to in-depth reviews by NASA.

	Cost Estimate March 1972 (millions)
Elements considered in the March 1972 STS analysis:	
Modifications and requirements for expendable upper stages	$ 290
Development and investment for reusable space tugs	$ 809
DOD facilities	$ 500
Recurring STS operating costs exclusive of the space shuttle operating cost	See below
Elements excluded from the March 1972 STS analysis:	
R&PM costs	See below
R&D costs not defined as development cost chargeable against the STS	See below
Inflation	See below

Operating costs

The March 1972 economic analysis included STS operating costs of $5.050 billion from 1979 through 1990. A baseline estimate has been established only for cost per flight of the space shuttle, however, it was based on a 439 flight mission model rather than the 581 flight mission model that was used in formulating the $16.1 billion estimate. Operating costs not baselined included such items as the cost per flight for (1) expendable upper stages which NASA estimated to range from $1 million to $10 million (1973 dollars) and (2) the space tug which NASA estimated to be about $1 million (1973 dollars).

Shuttle Related R&D Costs

Funds expended from the OMSF's space shuttle budget line item of NASA's R&D Appropriation are the only charges made against the development baseline estimate of $5.150 billion. These charges do not include some additional R&D effort related to shuttle development. NASA officials stated that a definite dividing line does not exist between R&D effort which should be charged against the space shuttle estimate and R&D effort which should not.

One member of the Senate Authorization Committee on Aeronautical and Space Sciences expressed concern about NASA's accounting practices. This Senator stated that:

> "My own feeling is that at the outset of a project such as this (space shuttle), where there is bound to be some controversy, I think that for the purposes of your credibility factor and ours, it would be best to have this (space shuttle appropriation) as a separate line item, and have everything in R&D included there ... Then nobody can accuse either you or the committee of having hidden costs."

The NASA Administrator said this could be done, but no action has been taken to include all R&D costs in the space shuttle line item.

We identified about $116.6 million of R&D obligations through November 1973 which appeared to be shuttle related and was not reported against the RDT&E estimate or as a cost of the Space Shuttle Program. If this amount were considered and added to the reported program obligations, total R&D obligations would be $583.2 million or 25 percent greater. The obligations we identified are discussed below.

Shuttle Technology and Shuttle Vehicle and Engine Definition

Shuttle Technology and Shuttle Vehicle and Engine Definition funds of $12.4 million from funds appropriated in 1970 are not considered by NASA as chargeable to their RDT&E estimate. These obligations were primarily incurred during early developmental phases and were excluded by an informal agreement reached between NASA and the Office of Management and Budget. According to NASA, they should not be charged against the baseline estimate because they were for feasibility studies rather than for development.

Supporting Research and Technology

By examining research and technology project definitions for NASA organizations, we identified about $93.0 million (Table 3) obligated by the OMSF and the Office of Aeronautics and Space Technology (OAST) for research and technology projects which appear to be in support of shuttle development.

TABLE 3

Shuttle Related Research Activity
Obligations by Fiscal Years (In Millions)

Organization	Prior to 1970	1970	1971	1972	1973	1974 thru 11/30/73	Total
OAST	$1.2	$10.6	$30.1	$23.3	$6.8	$ .3	$72.1[a]
OMSF	0.0	4.4	5.6	8.4	2.3	.2	20.9
TOTALS	$1.2	$15.0	$35.7	$31.7	$9.1	$ .5	$93.0[a]

[a]Figures do not add due to rounding.

NASA officials said that there is no clear distinction between R&D efforts represented by these obligations and those efforts which are charged against the RDT&E estimate.

Concerning OAST effort, NASA stated in 1972 Congressional testimony that "The OAST Shuttle technology program will ... support the Office of Manned Space Flight Shuttle program activities as appropriate to help assure that the shuttle vehicle will be built on schedule and within the available funds."

NASA stated that non-shuttle funded supporting research generally concentrates on "state-of-the-art technology" with broad potential application in future programs while shuttle funded tasks concentrate on development of a particular approach consistent with the shuttle system configuration and other requirements.

This explanation did not appear to be consistently valid for the research projects we examined. For example, the justification for a 1973 OMSF research project entitled Space Shuttle--Aerothermodynamics, the funds for which are charged to the RDT&E estimate (about $876 thousand obligated through June 30, 1973), reads in part as follows:

"This effort is designed to provide current state-of-the-art technology studies in support of the engineering design analysis on the space shuttle vehicles. It includes analytical studies and experimental testing as necessary to analyze vehicle aerothermodynamic characteristics and to accurately define performance capabilities...."

The justification for another 1973 OMSF project with the same title, the funds for which are not charged to the RDT&E estimate (about $319 thousand obligated through November 30, 1973), reads almost identically:

"The objective of this... is to provide support for the aerodynamic and thermodynamic development of the Space Shuttle vehicle. The tasks listed are of analytical and experimental nature. They involve the development of criteria and methods in those areas where adequate knowledge or prediction tools exist for the definition of aerothermodynamic environments or design values. The following items listed below have been selected because of their critical impact on the shuttle design: (1) Aerodynamic Study of Space Shuttle Vehicle Concepts, (2) Shuttle Load Distributions, (3) Booster Staging Environment,..."

Development, Test, and Mission Operations

Shuttle related R&D costs are also paid from the OMSF Development, Test, and Mission Operations (DTMO) portion of NASA's R&D Appropriation. DTMO funds provide a variety of contractual general support costs for manned space flight activities. No estimate was made for the amount of these costs related to the STS, although NASA informed the Congress that some DTMO costs would be related to shuttle development. NASA officials stated that the shuttle RDT&E estimate was made under the assumption that DTMO funding would be maintained at an annual level of about $200 million (1971 dollars).

Some of the general support programs planned that will benefit the shuttle include materials testing at the White Sands Test Facility and electrical power instrumentation testing at JSC. Future decisions on whether developmental tasks will be accomplished by shuttle R&D contractors or by contractors providing NASA's institutional support will normally determine whether they are charged to the shuttle RDT&E estimate or to DTMO. Only the cost of those tasks performed by shuttle R&D contractors are charged to the RDT&E estimate.

As an example of DTMO funding, $11.2 million of DTMO costs were incurred at MSFC in direct support of the Space Shuttle Program from July 1972 through December 1973. This amount represents about 10.4 percent of the total DTMO funds allocated to MSFC for fiscal years 1973 and 1974.

Research and Program Management

Consistent with the NASA appropriation structure, civil service manpower costs and logistics, technical, and administrative support costs are funded by the R&PM appropriation. For fiscal years 1972 and 1973, NASA identified 1,234 and 2,300 positions, respectively, as direct effort on the Space Shuttle Program. This number was expected to increase to about 5,000 at the peak of the development program. Shuttle related costs of $84.6 million were funded by this appropriation from July 1969 through November 1973. R&PM costs are not charged against the shuttle's baseline estimate. Therefore, future decisions on whether tasks will be accomplished by NASA personnel or by shuttle contractors will determine whether the costs are charged against the baseline estimate.

Inflation

Inflation can constitute a major portion of a program's total cost and the total amount of inflation incurred can be influenced by management decisions affecting the rate and timing of expenditures. Consequently, we believe inflation should be considered in the decision-making process and included in estimates made by Federal agencies. Our position was presented to the Congress in a report entitled "Estimates of the Impact of Inflation on the Costs of proposed Programs Should Be Available to Committees of the Congress," dated December 14, 1972 (B-176873).

The potential inflationary impact of a recent decision on total shuttle program costs is presented below for illustration:

> During fiscal year 1974 Senate authorization hearings, NASA announced that the shuttle development program had been extended by 9 months in order to hold fiscal year 1974 spending to the targets set by the President. This extension will result in inflationary increases because more funds will be expended duing the later years of the program than previously planned. Projected inflationary increases due to this change are shown in the following table. An inflationary factor of 5 percent per year[1] was assumed in the calculation.

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[1] A 5 percent per year factor was selected by GAO because NASA had previously used this rate as the inflation factor for 1972.

TABLE 2

Estimated Inflationary Cost
Increases in RDT&E (In Billions)

	Estimate Before 9-Month Delay	Estimate After 9-Month Delay	Estimated Inflationary Increase
RDT&E Estimate Without Inflation	$5.150	$5.150	$ -0-
Inflationary Cost	1.406	1.482	.076
Total Estimate Including Inflation	$6.556	$6.632	$ .076

Additional inflationary cost increases can be anticipated from other management decisions. A delay of the first manned orbital flight by an additional 4 to 6 months as announced by the NASA Administrator in February 1974, and a 2-year delay in production of two orbiters should increase STS costs because of inflation. Additionally, changes made in the timing of funding for facilities should result in similar increases.

In view of the impact of inflation, NASA has undertaken discussions with the Office of Management and Budget to recognize the influence of inflation in projecting funding levels for its programs in the future.

CHAPTER 3

STATUS OF STS ELEMENTS WITH BASELINE COST ESTIMATES

The status of three[1] STS cost elements for which NASA has made baseline cost estimates--space shuttle RDT&E, NASA funded facilities, and cost per flight--is set forth below.

SPACE SHUTTLE RESEARCH, DEVELOPMENT, TEST AND EVALUATION

NASA's baseline estimate of $5.150 billion was for the cost to design, develop, test, and evaluate two orbiters (including the SSME) and the SRB and ET needed to fly six development missions. This estimate was evaluated in detail by NASA, and the NASA Administrator made a commitment to develop the space shuttle within the estimate. NASA has subdivided the estimate into ten major categories. This subdivision together with recorded obligations through November 30, 1973, is shown in the following table:

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[1] The status of the baseline estimate for refurbishment of two development orbiters and production of three new orbiters is not discussed because the Space Shuttle Program is still in the design and development phase.

TABLE 4

RDT&E Estimates and Recorded Obligations
(In Millions)

Category	Original Estimate in 1971 dollars[a] (March 1972)	Current Estimate in Real Year Dollars[b] (December 1973)	Obligations November 1973
Vehicle and Engine Definition		$ 83.4	$ 99.9
Technology		21.1	21.8
Main Engine			135.9
Solid Rocket Booster		4,911.5[c]	.4
External Tank			2.6
Orbiter			211.9
Airbreathing Engines		21.9	0.0
Launch and Landing		482.0	.5
System Management		1,078.9	.5
Contract Administration	-	76.8	5.4
Subtotal	$5,150.0	$6,680.6	$ 479.0[d]
Less: $12.4 million excluded by NASA from RDT&E baseline		-	12.4
Total	$5,150.0	$6,680.6	$ 466.6

[a]Detailed estimates were not prepared by NASA.
[b]The estimate in real year dollars is the estimate in 1971 dollars increased by assumed inflation factors.
[c]Estimates for the orbiter, main engines, external tank, and solid rocket booster were combined at NASA's request so as not to hinder contract negotiations with space shuttle contractors.
[d]Figures do not add due to rounding.

The obligations shown above account for about 55 percent of the $853.5 million budgeted for the Space Shuttle Program for fiscal years 1971 through 1974. NASA officials stated that through April 1974, $761.6 million, or about 89 percent of the funds budgeted for the Space Shuttle Program, had been obligated.

As of December 31, 1973, NASA expected to complete the RDT&E portion of the program within the $5.150 billion estimate. On February 4, 1974, however, NASA announced a revised cost estimate of $5.2 billion and a revised development schedule due to a reduction in its fiscal year 1975 budget request from $889 million to $800 million. The $50 million increase was described as tentative since NASA had not had an opportunity to work out the details of the new schedule with its contractors. Projected RDT&E funding prior to this announcement is shown in the following table:

TABLE 5

Projected RDT&E Funding Requirements
(1972 dollars in Millions)

Fiscal years	Amount
1975	$ 850
1976	1,100
1977	990
1978	873
Balance to Complete (1979 & 1980)	728
Total	$4,541

CONSTRUCTION OF FACILITIES

NASA's $300 million baseline estimate for construction and modification of test, development, and launch and landing facilities represents 37.5 percent of the $800 million estimate for all facilities. DOD facilities comprise the remainder. Included in NASA's estimate are facilities planning and design, both preliminary and final; engineering services of about 10 percent; collateral equipment[1]; and a 10 to 15 percent contingency.

Although the facilities estimate comprises only a small portion of projected STS costs, facilities are critical to the program's success. Completion dates for some facilities are linked directly to and are necessary for the shuttle development effort. NASA stated that the shuttle program will be delayed if these projects are not completed on time. For example, a 1-year funding delay for the SSME sea level test facilities would result in a corresponding delay of the shuttle vehicle program. NASA personnel have testified that any further delays will cause major increases in the cost of the shuttle program.

Current Construction of Facilities Estimate

As of December 31, 1973, NASA's estimated facilities cost was $285 to $310 million, as shown in Table 6. The amounts shown depict anticipated costs through 1980 and are expressed in 1971 dollars.

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[1] Collateral equipment is defined as that equipment which, if removed, would impair the usefulness, safety, or environment of the facility. Examples include elevators and heating, ventilating, and air conditioning systems.

TABLE 6

Cost of Facilities Estimate
FY 1971 - 19[illegible]
(Millions of 1971 Dollars)

Facility category	Baseline Estimate March 15, 1972	Current Estimate December 31, 1973	Variance from Baseline
Technology	$ 8.0	$ 9.0 - $ 9.0	$ 1.0 - $ 1.[illegible]
Engine	20.1	16.6 - 16.6	(3.5)- (3.[illegible]
Manufacturing and Final Assembly	12.0	26.4 - 28.4	14.4 - 16.[illegible]
SRB Production and Test	46.0	37.0 - 42.0	(9.0)- (4.[illegible]
Ground Test	40.9	38.7 - 41.7	(2.2)- .[illegible]
Launch and Landing	150.0	135.7 - 148.7	(14.3)- (1.[illegible]
Total Projects	$ 277.0	$ 263.4 - $286.4	$(13.6)- $ 9.[illegible]
Plus:Facilities Planning and Design	23.0	21.6 - 23.6	(1.4)- .[illegible]
Total	$ 300.0	$ 285.0 - $310.0	$(15.0)- $ 1[illegible]

NASA's explanation for the above variances was not furnished in time for our evaluation but is included as Appendix II. Moreover, the specific projects for which cost growth is projected by NASA were not identified in the information furnished. However, we noted during our review that potential cost growths have been identified by NASA on at least three projects: orbiter landing facilities, mobile launchers, and SSME test facilities. Even if these cost growths materialize, however, NASA's goal is to complete the facilities program within the $300 million estimate because of offsetting changes which might occur in other facility requirements.

Orbiter landing facilities - NASA stated on December 14, 1973, the fiscal year 1974 funding for construction of orbiter landing facilities at KSC may increase from $28.2 million to $29.3 million. The anticipated increase reflects potential cost growth attributable to shortages of materials and supplies and to the energy crisis. However, we were subsequently advised by NASA that they were able to obtain fuel allocations for this construction and resolve other uncertainties related to material escalation. During March 1974, a fixed price contract was awarded for these facilities. Based on the contract award, the current estimated cost is within the budgeted amount; and therefore NASA does not anticipate a cost increase related to this facility.

Mobile launchers - KSC officials have identified a requirement for a third mobile launcher to support the projected launch rate of 40 vehicles per year. An estimated $10.1 million (1971 dollars) in C of F funds would be required if the third launcher is necessary and is approved by NASA headquarters.

SSME test facilities - In March 1974, NASA identified a potential cost growth of approximately $3.85 million for the SSME test facilities at Santa Susana, California. NASA has advised the appropriate congressional committees of this increase.

Costs Incurred Through November 1973

NASA reports that through fiscal year 1974, the Congress has appropriated $123.5 million for shuttle facilities, or approximately 30 percent of the baseline estimate as adjusted for inflation. Of the $123.5 million, about $47.[illegible] million had been obligated through November 1973.

COST PER FLIGHT

NASA's baseline estimate of $10.45 million for the average cost per flight of the space shuttle was based on a traffic model of 439 flights rather than the 581 flight mission model used for the STS cost estimate in the March 1972 analysis. NASA has a current working estimate of $9.06 million but considers the difference between its baseline estimate and its working estimate a program reserve.

The cost per flight estimates are comprised of several major cost elements and several sub-elements. The net changes between the baseline estimate and the current working estimate as of December 1973 are set forth below.

TABLE 7

Estimated Average Cost Per Flight
(In 1971 Dollars)

Cost Elements	March 1972 Million dollars	December 1973 Million dollars	Program Reserve Million dollars	Program Reserve Percent of March 1972 Estimate
External Tank and Solid Rocket Booster[a]	$ 6.59	$ 5.34	$ 1.25	19
Ground Operational	.27	.52	(.25)	93
Spares	1.40	.70	.70	50
Main Engines	.23	.23	-0-	-0-
Fuel and Propellants	.20	.30	(.10)	50
Program Support	1.76	1.97	(.21)	12
TOTALS	$ 10.45	$ 9.06	$ 1.39	13

[a]These cost elements were combined because they are considered contractor sensitive information, which, if disclosed, could compromise NASA's contract negotiations.

Primary reasons for changes in the estimates are:

	(millions)
<u>External tank</u>	
Decrease resulting from incorporation of contractor proposal[1]	
Increase resulting from weight increase[1]	
<u>Solid rocket boosters</u>	
Decrease resulting from updated component/system estimates and the use of five boosters from RDT&E phase[1]	
Increase resulting from better definition of booster and an increase in attrition rate[1]	
<u>Ground operations</u>	
Increase due to additional manpower for two launch sites (original estimate assumed one launch site)	$.26
Decrease resulting from reduction in manpower rate	(.01)
Net increase	$.25
<u>Spares</u>	
Decrease resulting from deletion of abort solid rocket motors and exclusion of installation costs for thermal protection system	($.54)
Decrease from update of orbiter spare requirement	(.16)
Net decrease	($.70)
<u>Fuels and propellants</u>	
Increase resulting from resizing to larger tank and orbiter	$.03
Increase resulting from additional production facilities for two launch sites	.07
Net increase	$.10
<u>Program support</u>	
Increase resulting from additional manpower requirement for two launch sites	$.21

The change from one to two launch sites resulted in an estimated cost increase of $540 thousand per flight or a total increase of about $237 million.

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[1]Individual figures were excluded because they are considered to be contractor sensitive information by NASA.

CHAPTER 4

SCHEDULE

NASA has stated to the Congress that the space shuttle will be developed within certain timeframes. These timeframes were used to establish controlled milestones for NASA's three levels of Space Shuttle Program management. These levels, called Levels I, II and III, cover the RDT&E and production phases of the program. NASA's objective is to schedule all program phases in the most efficient and economical manner consistent with anticipated annual funding. All Level III milestones have not been officially approved, and consequently, were not included in the scope of this review.

NASA MILESTONES

During fiscal year 1973 congressional hearings, NASA established timeframes for the first horizontal flight, the first manned orbital flight, and operational capability of the space shuttle. These were considered the baselines but were later changed because of funding constraints for fiscal years 1974 and 1975. The original dates and changes as presented in the fiscal year 1974 and 1975 budget submissions to the Congress are as follows:

TABLE 8

[illegible] Milestones

Milestone	[illegible]	Slippage (Months)	Fiscal Year 1974 Budget Submission	Slippage (Months)	Fiscal Year 1975 Budget Submission[a]	Total Slippage (Months)
First Horizontal Flight[b]	Mid 1976	7-9	1st QTR 1977	1-3	2nd QTR 1977	[illegible]
First Manned Orbital Flight	1st QTR 1978	9	By End of 1978	4-6	2nd QTR 1979	13-15
Operational Capability	1st QTR 1979	9	By End of 1978	4-6	2nd QTR 1980	13-15

[a]Data provided by NASA and not verified with supporting documentation.

[b]First Horizontal Flight replaced by Approach and Landing Test.

The initial 7- to 9-month program slippage, according to NASA, was caused by reduced funding which forced it to proceed at a slower pace and delay contractor manpower buildup. NASA said that this would not cause developmental costs to exceed the baseline RDT&E estimate. However, NASA officials testified in the fiscal year 1974 congressional hearings that further cost reductions or delays will start causing major increases in the program's cost.

On February 4, 1974, NASA announced an additional 4- to 6-month program slippage caused by funding constraints. Program adjustments resulting from this slippage will be covered during our next review.

LEVEL I MILESTONES

Level I baseline milestones were issued in April 1972 and were consistent with those made to Congress. Changes in target dates for these milestones are depicted in Table 9.

TABLE 9

Level I Milestones and Target Dates

Milestone	Baseline ([illegible])	Slippage (Months)	Fiscal Year 1975 Budget Submission	Slippage (Months)	Fiscal Year 1975 Budget Submission[a]	Total Slippage (Months)
First Horizontal Flight[b]	Mid 1976	6	Dec. 1976	1	Jan. 1977	7
First Manned Orbital Flight	Mar. 1978	6	Sept. 1978	2	Nov. 1978	8
Operational Capability	Mar. 1979	6	Sept. 1979	2	Nov. 1979	8

[a]Data provided by NASA and not verified with supporting documentation.

[b]First Horizontal Flight replaced by Approach and Landing Test.

The slips reflected above resulted for the same reasons as the slippage in NASA's commitment to Congress. The Level I slippage was not as great because the Program Director wished to provide a contingency for unforeseen problems.

In December 1973, the number of milestones was increased to encompass such program elements as the orbiter, SSME, SRB, testing and facilities. Changes are being made to the Level I controlled milestones to reflect the 4-to 6-month slippage caused by funding limitations on the fiscal year 1975 budget request.

LEVEL II MILESTONES

Level II milestones were officially established in June 1973. Several approved changes to Level II milestones may have a significant impact on both the cost and potential benefits to be derived from the STS. Level II target dates for delivery of orbiters four and five were extended by 24 and

26 months, [illegible]. [illegible] the delay resulted [illegible] their [illegible] DOD's initial [illegible] for the Vandenberg Air Force Base launch site was 1982. NASA's initial Level [illegible] had been established prior to the DOD decision [illegible] a 1983 operational date for Vandenberg.

The original production schedule was established to provide the most efficient flow consistent with anticipated annual funding. NASA stated that production stretch-out may increase program costs because of inflation and less efficient production due to the schedule change.

CHAPTER 5

PERFORMANCE

To attain the objectives of the Space Shuttle Program, the Program Director has established design objectives. These goals, called program performance requirements, serve as guidelines for detailed design and development by the JSC program manager, project managers, and contractors.

Performance goals controlled by the Program Director are referred to as Level I program requirements. They cover a wide range of topics in broad terms. For example, one requirement is for the orbiter vehicle to be capable of (1) use for a minimum of 10 years, and (2) low cost refurbishment and maintenance for as many as 500 reuses. More detailed requirements for attainment of Level I design goals have been established by the JSC program office (Level II), and the project offices (Level III). Level III requirements have not been officially approved and, accordingly, were not included in our review. Numerous changes have been made to program requirements at all levels but, according to NASA personnel, have not significantly altered overall program objectives and cost projections.

LEVEL I REQUIREMENTS

Baseline Level I program requirements for the present shuttle configuration were issued on April 21, 1972. They were revised on May 4, 1973, and an interim supplement was issued on December 12, 1973. We were able to determine the estimated cost impact of only four of the Level I changes although numerous other revisions were made. These four changes resulted in an estimated cost reduction of more than $330 million and a weight reduction of over 1[illegible] pounds. Two substantive changes made to Level I baseline program requirements are enumerated below.

--The shuttle was initially designed to have off-the-pad abort capability through the use of abort solid rocket motors. NASA stated that this requirement was deleted primarily because studies revealed that the degree of safety provided by abort motors was equalled or exceeded by increased redundancy requirements. This change resulted in an estimated cost reduction of about \$238 million; \$20 million for RDT&E, \$214 million for the total program cost per flight, and \$4 million for production. A gross lift off weight reduction of 101,450 pounds was associated with this change.

--The safety requirement for SRB thrust termination was eliminated to realize an inert weight reduction of about 1,566 pounds and a simplification of SRB structural and avionics subsystems. NASA was able to make this change after system abort studies were completed that determined the system ascent mode should continue through SRB burnout for all abort models. According to NASA this eliminated any requirement for SRB thrust termination to effect early separation and resulted in a "safer" system configuration. A total program cost reduction of \$34.8 million is anticipated to result from an \$80,000 cost per flight decrease.

BEST DOCUMENT AVAILABLE

LEVEL II REQUIREMENTS

Level II baseline program requirements were issued on March 20, 1973. Thirteen change packages were approved and issued against the baseline document through January 7, 1974. We were able to determine the impact of only nine individual changes. These changes resulted in a [illegible] [illegible]. We were not able to determine the cost [illegible] of one of these changes, but the remaining eight changes resulted in an [illegible] program cost increase of at least $11 million. [illegible] of Level II changes include the addition of ejection seats in test orbiters and design changes to the thermal protection and thermal control systems.

<u>CONTRACTOR TRACKING OF PERFORMANCE CHARACTERISTICS</u>

NASA's performance management system requires that major shuttle contractors track and report periodically on selected performance characteristics. The status of four requirements being tracked by NASA and Rockwell International's Space Division, is presented below.

<u>Payload-to-Orbit</u> - This refers to the weight the shuttle system is able to place in orbit. The deployment of 32,000 pounds into a near polar orbit (104° inclination) was used as one of the major factors to establish the vehicle's size because this is the most demanding of the shuttle's missions. As of December 1973 the projected capability was 32,100 pounds.

<u>Orbiter Weight</u> - In August 1972, when Space Division received authority to proceed with the contract, the orbiter was designed to have a "dry weight" (weight without payloads, fuel, etc.) of 170,000 pounds. In December 1972 this was changed by NASA to 150,000 pounds primarily in order to reduce the cost per flight and maintain control of the total vehicle size. Space Division's estimated cost per flight for the 170,000 pound orbiter was about $2 million more than NASA's $10.45 million baseline estimate. The cost per flight is lower with the lightweight orbiter because it requires smaller, less expensive, SRB and ET.

Reduction of the orbiter weight to 150,000 pounds also [illegible] 15,000 pound growth margin for contingencies and requirements changes. A vigorous weight reduction program was therefore initiated by Space Division which was to initially provide a weight margin of approximately 13,000 pounds. However, by December 1973, this margin had been reduced to about 1,900 pounds.

The 1,900 pound growth margin provides only about a 1.3 percent margin for contingencies and requirement changes. Space Division had originally planned to have a 10 percent margin at Preliminary Design Review, scheduled for February 1974, because historical data on spacecraft indicated a 10.6 percent weight-growth from that point through the life of the program. NASA officials stated that the planned growth margin at Preliminary Design Review was reduced to 6 percent for the 150,000 pound orbiter. Within certain limits, any dry weight over the 150,000 pound baseline would reduce the payload-to-orbit capability discussed above. Studies are in progress to increase the orbiter weight growth margin, and according to NASA, several potential weight reduction changes have been identified.

<u>Thermal Protection System</u> - The thermal protection system protects the primary airframe structure of the orbiter vehicle from the effects of aerodynamic heating during ascent and entry. Its function is to maintain the temperature of the structure below 350° Fahrenheit and it is to be capable of at least 100 reuses with only minor repairs and replacements.

The thermal protection system is the program's highest risk area because methods of applying the basic technology have not been fully demonstrated. Some of the characteristics Space Division officials are concerned about included:

--[illegible]: The thermal protection system tiles will be affixed to the orbiter structure in a manner similar to ordinary floor tiles. The amount of heat entering through the tile gaps could damage the orbiter if adequate tile gap insulation and close out design is not provided.

--<u>Reusability</u>: The material has to be reusable for over 100 missions, with 3 to 5 percent projected replacement after each launch. Reusability is critical to keep cost-per-flight within the estimate.

--<u>Other potential problems</u>: Maintaining system design weight of 19,935 pounds and compensating for design changes that affect orbiter weight.

<u>Turnaround Time</u> - This is the time required to refurbish the space shuttle and prepare it for launch after it has returned from a mission. The Level I baseline for turnaround time is 160 working hours over 14 days. As an operational goal, NASA does not expect to meet the 160 hours requirement during the early flights where the scheduled launch rate does not require a two week turnaround capability. Instead, an evolutionary approach will be taken whereby the turnaround time is gradually reduced as experience is gained. According to NASA's April 1974 estimate, the turnaround capability is 211.5 hours, but various studies are under way to reduce this time.

CHAPTER 6

PROGRAM MANAGEMENT

NASA's program management system for the space shuttle has not been fully implemented. Implementation of the management system will continue to evolve as the program progresses. A description of selected elements of NASA's planned system is provided below for informational purposes.

RESPONSIBILITIES AND AUTHORITIES

The overall program planning, direction, and evaluation is conducted by the Space Shuttle Program Director within the Office of Manned Space Flight (OMSF) at NASA Headquarters. He recommends the total program budget, allocates and controls research and development (R&D) resources within authorized level , and defines and controls program requirements. Program requirements controlled by the Space Shuttle Program Director are known as Level I program requirements.

The authority to manage the shuttle program on a day-to-day basis has been delegated to JSC as the lead center. A JSC Space Shuttle Program Office (Level II) has been established to provide management and technical integration for the entire effort in cooperation with project managers (Level III).

Five Space Shuttle Project Managers have been designated: one at JSC, three at MSFC, and one at KSC. Each of these managers, except the KSC manager, is responsible for one of the shuttle's major components, i.e., the orbiter, SSME, ET, or SRB. They must design and develop their projects, manage applicable contracts, and establish Level III requirements.

In addition, an overall projects manager has been designated at KSC and is responsible for all work assigned to that center. The KSC Manager's responsibility includes launch, landing, recovery, and refurbishment operations. He must also assure that all shuttle program activities assigned to KSC are carried out.

PERFORMANCE MANAGEMENT

An integrated performance management system is being implemented by NASA and contractor organizations. As one of the significant management features, this system is intended to provide for the integrated planning and scheduling of the Space Shuttle Program. In addition, the system provides the basic program performance parameters to be considered in the normal technical decision and design process. This includes the measurement of progress in achieving established performance parameters. Elements of the integrated performance management system are (1) performance planning and control, (2) performance change control, (3) performance measurement, and (4) program visibility techniques.

Performance Planning and Control

A work breakdown structure which establishes categories for all work elements will be used to identify, plan, budget, allocate, authorize, schedule, and report on program work and related resources. In conjunction with the work breakdown structure, a program logic diagram will be developed. The diagram will graphically depict the integration of system elements and their interrelationships.

Performance Change Control

The performance change control element of the system will be designed to preclude unauthorized changes to performance baselines. The techniques to be used will assess the cost and schedule impact of changes before approval.

Performance Measurement

An integrated cost/schedule/technical performance measurement system will be established for the orbiter, ET, SSME, and SRB. A performance measurement system is designed to measure progress toward achievement of identified cost, schedule, and technical parameters and to identify potential problems in sufficient time to permit corrective action without adverse effects on the project. The system is to be keyed to the work breakdown structure.

Program Visibility Techniques

Multiple techniques will be used to provide project management visibility. These will include Management Information Centers at NASA and contractor facilities and key issue and problem lists.

CHAPTER 7

UPPER STAGES

The space tug is a propulsive or upper stage that is expected to extend the capabilities of the shuttle to greater altitudes than those achievable by the orbiter alone. The space tug will have the capability to deliver and retrieve payloads to high altitude, particularly geosynchronous orbit, to inject payloads into planetary trajectories and to conduct in-orbit servicing of payloads. It is being designed to be recoverable and reusable. The introduction of the space tug as an operational element of the STS will be in late 1983. An orbit to orbit stage (OOS), with limited capabilities, will be used during the 1980-83 period. A tentative agreement has been reached between NASA and the USAF whereby the USAF will modify an existing upper stage to become the OOS and NASA will continue planning for development of the space tug.

Current tentative plans call for an estimated development cost of up to $100 million (1973 dollars) for the OOS and $400 million (1973 dollars) for the space tug rather than about $770 million (1971 dollars) which was used in NASA's March 1972 analysis. Capabilities under these plans are, however, less than those considered in March 1972.

The importance of the capability to launch high energy payloads (payloads targeted beyond the capability of the shuttle alone) is demonstrated by the fact that 43 percent of the 986 payloads in the 1973 Payload Model for 1980 through 1991 are high energy payloads. Moreover, 65 percent of the automated payloads to be launched by the shuttle were high energy payloads. The 1973 Mission Model concluded that 725 shuttle flights and 60 expendable launch vehicle flights were required. The distribution of the payloads for these flights is given below:

TABLE 10

Distribution of Payloads in the 1973 Mission Model

(1980 THROUGH 1991)

Launch System		Number of Payloads
Expendable launch vehicles		95
Shuttle/Spacelab flights		336
Shuttle/Automated payloads		
Not requiring an energy stage	190	
Requiring a solid kick stage[a]	8	
Requiring an upper stage	357	555
Total		986

[a] A kick stage which is a small expendable propulsive stage can be attached to the payload for missions with extremely high energy requirements.

HISTORY

NASA and the DOD have studied a variety of upper stage approaches including (1) expendable stages not having payload retrieval or in-orbit servicing capabilities and (2) recoverable space tugs with varying performance capabilities (payload delivery; payload delivery and retrieval; or payload delivery, retrieval, and in-orbit servicing).

NASA's March 1972 mission model analysis included expendable Centaur and Agena stages as interim upper stages from 1979 through 1984 and a space tug from 1985 on. This model consisted of 581 shuttle flights and called for 65 Agena and 65 Centaur flights and for 173 space tug flights. Eight Agena kick-stage flights were also called for from 1985 through 1990.

In view of peak year funding problems for development of the shuttle and budget constraints on space effort, a tentative agreement was reached between NASA and the USAF in October 1973 calling for a three-phased upper stage development. The first phase was the OOS, which would be a modified existing stage and would be developed by the USAF. Leading candidates for modification were the Agena, Centaur, and Transtage.

The decision on whether the OOS would be expendable or reusable has not been made. NASA and the USAF are currently looking into performance trade-offs, required mission capabilities, capture characteristics, funding trade-offs, development trade-offs, and safety considerations.

The second phase was an interim space tug which would be operational in 1985. This tug was to be capable of payload deployment, retrieval, and in-orbit servicing of payload based on existing technology through fiscal year 1976 and was to use an existing engine. The third phase was a full-performance space tug which was to be operational sufficiently beyond 1985 to justify the development of the interim tug. This tug would be more powerful than the interim tug and would be based on technology available beyond fiscal year 1975. It would require new engine development to accomplish its desired capabilities.

In December 1973, NASA and the USAF reaffirmed the tentative agreement concerning development of the IUS, but changed from the interim tug/full-performance tug approach to the development of a full-capability tug instead.

NASA stated that the change from the three phased upper stage development to the current tentative plan was made possible by reducing the required roundtrip capability between low earth orbit and geosynchronous orbit from 3,000 pounds (full-performance tug) to 2,400 pounds (full-capability tug). The decrease reduced the technical challenge in tug development because it eliminated the need for development of a new engine. This factor and other projected hardware changes account for a reduction in the estimated development cost from $800 million (1973 dollars) for the full-performance tug to $400 million (1973 dollars) for the full-capability tug. NASA will be responsible for planning related to this tug, and officials of both agencies stated that NASA will probably be responsible for development.

COST

In the March 1972 analysis, NASA included about $132 million for development of expendable upper stages (modified Agena and Centaur stages), $638 million for development of the space tug, and $171 million for investment in space tugs. NASA officials testified in congressional hearings that the estimated cost per flight for the tug was $1 million and that the estimated cost per flight for the Centaur was $8 million.

According to [illegible], the estimated costs relating to the previous three-phase development plan and the current plan are as follows:

TABLE 11

Estimated Cost (1973 dollars) of the Previous Three-Phased Development Plan

	Development	Cost per Flight
	--------(million)--------	
Orbit to orbit stage	up to $100[a]	$ 2 to $ 10[a]
Interim tug	400	$ 1-$2
Full performance tug	800	$ 1-$2

[a]Depending on reusability. There is a tradeoff between development cost and cost per flight.

TABLE 12

Estimated Cost (1973 dollars) of the Current Upper Stage Development Plan

	Development	Cost per Flight
	--------(million)--------	
Orbit to orbit stage	up to $100[a]	$2 to $10[a]
Full capability tug	400	about $1

[a]Depending on reusability. There is a tradeoff between development cost and cost per flight.

SCHEDULE

As stated previously, NASA's March 1972 analysis called for use of modified Agena and Centaur stages from 1979 through 1984 and for a space tug beginning in 1985. The three-phased development plans called for operational dates of 1980 for the OOS and about 1985 for the interim tug. The operational date for the full-performance tug had not been determined.

The current plan [illegible] will be [illegible] operational [illegible] December 19[illegible], following a 5-year development period and an operational date of late 1983 for the full-capability stage following a 5-year development [illegible]. [illegible] analysis of the full-capability [illegible] for fiscal year 1975 so that interface data can be obtained for [illegible] the space shuttle development.

[illegible]

Orbit to orbit stage

NASA stated that the number of flights and cost for modifying an existing upper stage does not appear to justify the development of more than one OOS. Therefore, due to the differences in the size and power of the candidate stages (Agena, Centaur, and Transtage), the OOS will have certain limitations in comparison with the modified Agena and Centaur stages as assumed in March 1972. For example, selection of the Transtage would not allow some high energy missions to be flown without the use of multiple stages. Also, because of the longer length of the Centaur, some DOD missions involving long payloads could not be flown in the shuttle with a modified Centaur stage unless a "short version" were developed. Expendable launch systems will be used during the transition period to the shuttle and one possibility is that more missions will be flown on the expendable launch systems than would have been required under the assumptions in March 1972.

Full-capability tug

The space tug considered in March 1972 was to be operational in 1985 and was to be capable of transporting a 3,000 pound payload round trip between low earth orbit and geosynchronous orbit.

The interim space tug in the three-phased development plan was also to be operational in 1985, but was to have a similar round trip capability of 2,000 pounds. The full-performance space tug (operational date not determined) was to have a 3,000 pound round-trip capability as shown below:

TABLE 13

Upper Stage Capabilities Under the Three Phased Development Plan

Geosynchronous performance from low earth orbit

	Deploy	Retrieve (pounds)	Round Trip
Orbit-to-orbit stage	100-10,000	-	-
Interim tug	6,500	2,400	2,000
Full performance tug	8,000	4,000	3,000

Current tentative plans call for a full-capability tug in late 19[illegible] which will have a round trip capability from low-earth orbit to geosynchronous orbit of 2,400 pounds as shown below:

[illegible]

[illegible]

[illegible]

	Deploy	Retrieve	Round trip
	------------	(pounds)	------------
Orbit to orbit stage	3,5[illegible] (minimum)	a	a
Full-capability tug	8,000	4,000	2,[illegible]

[a]The OOS will not have payload retrieval or round trip capabilities, but payloads launched by the OOS may be recovered by the tug at a later date.

NASA stated that the use of expendable kick stages is being considered to increase payload capability and that the upper stage may be expended on some launches to allow a greater payload capability.

APPENDIX I

SPACE SHUTTLE CONTRACT DATA
(Dollars in Millions)

CONTRACTOR	ITEM	TYPE OF CONTRACT	TARGET COST	BASE FEE	TARGET PRICE	POTENTIAL AWARD FEE
Rockwell International Corporation:						
Space Division	Orbiter-Shuttle Integration Increment I[a]	Cost Plus Award Fee	$440	$ 19.6	$ 459.6	$ 17.8
Rocketdyne Division	Main Engine Phase A & B	Cost Plus Award Fee	$424.6	$ 17.8	$ 442.4	$ 23.1
Martin Marietta Corporation:						
Denver Division (Letter Contract)	External Tank Increment I	Cost Plus Award Fee	$103.6	$ 3.6	$ 107.2	$ 6.2
Thiokol Chemical Corporation	Solid Rocket Motor	-b-	-b-	-b-	-b-	-b-

[a] Increment I is currently under negotiation and when finalized will incorporate a longer timeframe and more effort than currently included. There will, therefore, be significantly larger contract values for this increment.

[b] Information not shown. Award now under bid protest.

NASA EXPLANATION FOR CHANGES IN

SHUTTLE FACILITY ESTIMATES AT

APRIL 15, 1972 AND DECEMBER 13, 1973

This is in response to the above referenced GAO inquiry requesting an explanation of the variances in the shuttle facility runout costs from those originally developed, dated April 15, 1972, and the current estimates dated December 13, 1973.

It is our intention and goal to accomplish space shuttle facility requirements within the $300 million (1971 dollars) commitment. Our latest estimates indicate clearly that we are still on target. Inevitably, however, we expected and experienced some internal variations between the major categories that make up the $300 million total. Broadly speaking, these variances are the result of some changes from the original assumptions, increased requirements in some areas, decreased requirements in other categories, and better definition and improved cost estimates of the facilities as we move from the conceptual stage to the design and construction phases.

Specifically, the thermal protection system (TPS) facilities have increased by approximately one million dollars (1971 dollars). This increase is primarily due to the need for an additional requirement at JSC to provide capability for verification and acceptance testing for the TPS material.

The engine test facilities, on the other hand, experienced a net reduction in the amount of $3.5 million. This was caused by two reasons: (a) Deletion of the requirement for altitude testing of the main engine, after the decision was made to select the "parallel burn" concept, wherein the engines ignite at launch (sea-level) and need not ignite in the altitude environment, (b) Increased requirements for the sea level testing at MTF to provide capability for engine throttling tests.

Concerning the manufacturing and final assembly facilities for the orbiter and external tank, a net increase of approximately $15 million was experienced. The major part of the increase is attributed to the facility requirements at Downey and Palmdale in support of the orbiter manufacturing and assembly. The selection of these plants for this function was predicated on the successful proposal by Rockwell in mid-1972. In our initial estimates, we assumed a different location and a different manufacturing plan for the orbiter assembly functions. Although the Michoud Assembly Facility was baselined for the external tanks, some increase was experienced for these facilities as well. The current figures are based on preliminary engineering effort that was accomplished in the fall of 1972, after Michoud was selected for the external tank activities. These costs have now been confirmed after the Martin Marietta Corporation was selected for the development effort.

For SRB production and test facilities, our original estimates were based on discussions with potential contractors, our present estimates are based on limited preliminary engineering effort which indicate possible savings. It is premature, however, to reach final conclusions concerning these requirements until after the final production place and the related sites are later determined.

The ground test facilities category combines those facility categories previously identified in the April 1972 summary as vehicle development test, systems integration and crew training, mission control and horizontal flight testing. The total for this category is essentially the same now as in the original estimate; although some variations have occurred within the projects involved.

Regarding the launch and landing facilities, our current estimates indicate potential reductions in the amount of $8-10 million. This is based on completed preliminary engineering for several projects and the final design of only one project, the runway. Again, it is too soon to reach final conclusions in this area although we feel confident that the $150 million previously estimated for these facilities, would not be exceeded.