REPORT TO THE CONGRESS

Analysis Of Cost Estimates For The Space Shuttle And Two Alternate Programs

B-173677

National Aeronautics and Space Administration

BY THE COMPTROLLER GENERAL OF THE UNITED STATES

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

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

This is our report on the analysis of cost estimates for the Space Shuttle and two alternate programs of the National Aeronautics and Space Administration that we prepared at the request of Senator Walter F. Mondale.

Our review was made pursuant to the Budget and Accounting Act, 1921 (31 U.S.C. 53), and the Accounting and Auditing Act of 1950 (31 U.S.C. 67).

Copies of this report are being sent to the Director, Office of Management and Budget, and to the Administrator, National Aeronautics and Space Administration.

Elmer B. Staats

Comptroller General
of the United States

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ABBREVIATIONS

DOD Department of Defense

GAO General Accounting Office

NASA National Aeronautics and Space Administration

COMPTROLLER GENERAL'S REPORT TO THE CONGRESS

ANALYSIS OF COST ESTIMATES FOR THE SPACE SHUTTLE AND TWO ALTERNATE PROGRAMS
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D I G E S T

WHY THE REVIEW WAS MADE

On March 15, 1972, the National Aeronautics and Space Administration (NASA) said that its cost estimates indicated the Space Shuttle would cost about $5.2 billion less than an expendable alternative for performing the same mission. The General Accounting Office (GAO) refers to that alternative as the current expendable systems.

Senator Walter F. Mondale asked GAO to review the cost estimates for these two alternatives and a third alternative which GAO calls the new expendable systems.

On April 27, 1973, NASA provided GAO with new preliminary estimates based on further studies of Shuttle utilization; NASA stated that these estimates are within the same general annual budgetary requirements as its March 15, 1972, estimate. A comparison of the two estimates is shown below.

	Total program cost estimates	
	March 15, 1972	April 27, 1973
Number of flights planned	581	779
	(billions)	
Cost:		
Current expendable systems	$48.3	$66.2
Space Shuttle	43.1	50.2
Estimated savings	$ 5.2	$16.0

Reports prepared by NASA's contractor, the Aerospace Corporation, provided GAO with the information for the new expendable systems cost estimated at $45.7 billion for 581 flights. NASA did not include this estimate in its March 1972 estimates, and it did not make an estimate for the new expendables for 779 flights.

The March 1972 estimates cover the period to 1990; the April 1973 estimates cover the period to 1991. The March 1972 estimates are stated in 1971 dollars (i.e., at price levels prevailing in 1971), and the April 1973 estimates are stated in 1972 dollars.

With the Senator's agreement, this report is being released to the Congress because of the widespread interest in the Space Shuttle.

Background

The Space Shuttle is a proposed space transportation system which, as planned, would be sent into orbit and return to earth to be reused on other flights.

For the most part, the expendable systems are existing systems which have been used on other space missions. As a system they are not reusable, although some components of the systems can be recovered economically and used again.

The Space Shuttle is a manned space transportation vehicle; the expendable systems have limited capability in this regard. The orbiter portion of the Space Shuttle will have a crew of four who will fly it back to earth for an unpowered, airplane-like landing.

The Shuttle would be used to achieve various objectives for NASA, the Department of Defense, and others during the 1980s and later. The scientific equipment which the space vehicle carries to achieve these objectives is called the payload.

The Shuttle is to perform certain functions that the alternative expendable transportation systems cannot, e.g., retrieve payloads from orbit and bring them back to earth for repair, refurbishment, and reuse. This difference in payload concept makes economic comparisons complex and uncertain because the specific design and cost of payloads for each mission depends on the space transportation system available.

FINDINGS AND CONCLUSIONS

GAO is not convinced that the choice of a launch system should be based principally on cost comparisons. GAO cites five other issues which it believes should be considered in the decision. These issues are:

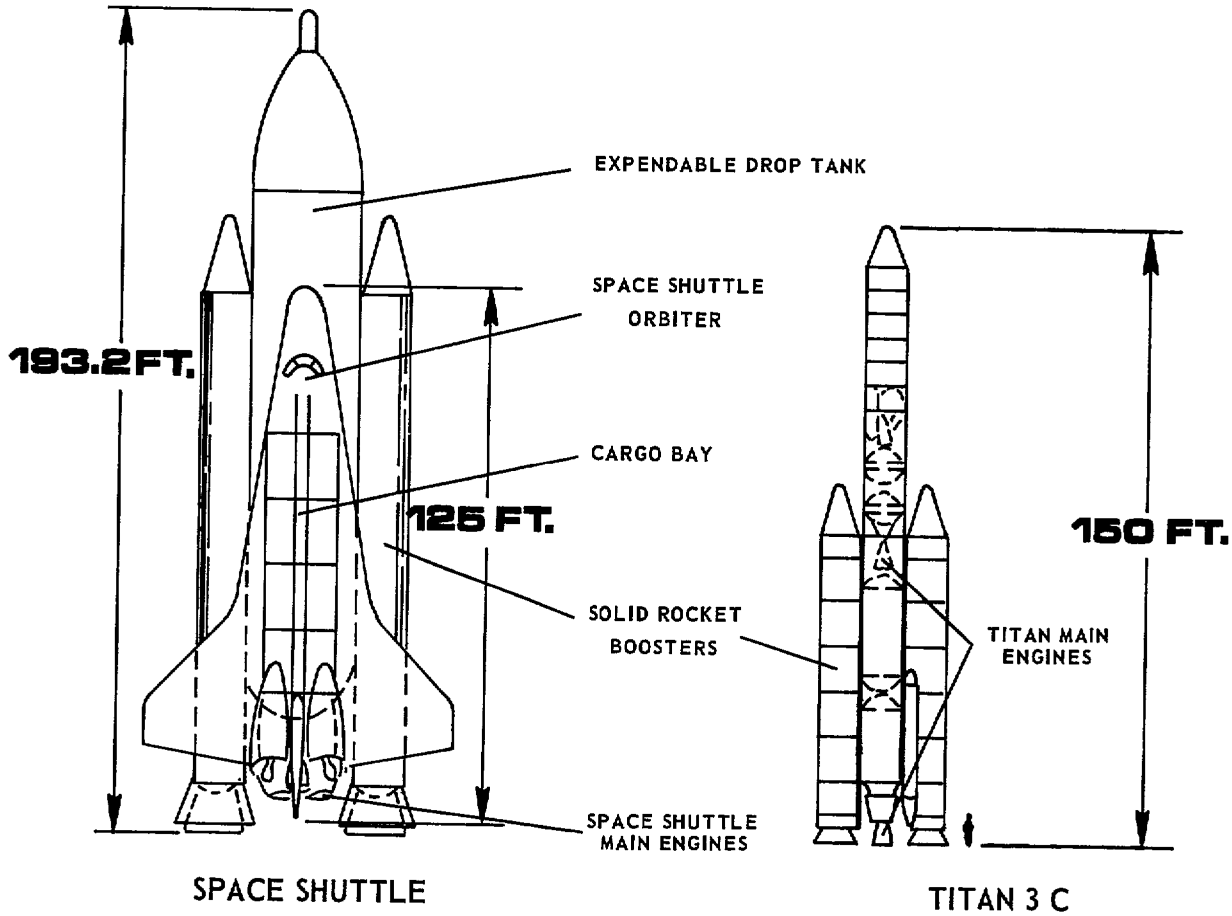
1. Whether the space programs rank sufficiently high among national interests to justify the estimated commitment of about $8 billion to develop and procure the Space Shuttle. This depends on whether the United States will need and want to make substantial use of space in the years to come--not just to 1990 or 1991 but for the indefinite future. NASA believes that space activities are already recognized as essential continuing needs for both civil and military purposes, that the benefits of space will increase in the future, and that the Nation will continue to support space activities.

2. Whether the value of the new technology that might result from the Space Shuttle Program would justify its selection.

3. Whether the Space Shuttle offers unique capabilities and the kind of flexibility which the U.S. space program should have. NASA believes that it does have unique capabilities--such as the retrieval of unmanned satellites for refurbishment and reuse and the routine use of men in space to enhance scientific research, civil applications, and national security activities and to take advantage of as yet unforeseen opportunities in space--and that these valuable capabilities are one of the important justifications for the Space Shuttle.

FIGURE 1-1

COMPARISON OF SHUTTLE WITH TITAN III C



this as an effort involving only about 1-1/2 man-years and does not believe these vehicles are realistic alternatives to the Space Shuttle.

Aerospace Corporation identified the new expendable launch vehicle family as consisting of current low-cost technology based primarily on Titan III which is the present launch vehicle family with the lowest cost per pound for placing payloads in earth orbit.

The new expendables alternative developed by the Aerospace Corporation comprises only 3 families and 16 separate configurations. There is 1 configuration in the Scout family and 12 in the Titan family. Saturn is dropped and two larger Titan configurations are added, providing maximum weight capacity to 100-nautical-mile orbit of 91,000 and 98,000 pounds. The Thor family is dropped and a new family using solid rocket booster and standardized second stage is substituted.

SCOPE OF REVIEW

During the course of our review, we visited NASA's headquarters in Washington, D.C., and the following NASA centers: Johnson Spacecraft Center, Houston, Texas; Kennedy Space Center, Cape Kennedy, Florida; and Marshall Space Flight Center, Huntsville, Alabama. We also visited the Aerospace Corporation and the Air Force's Space and Missile Systems Organization, El Segundo, California, and Air Force's headquarters, Washington, D.C.

To the extent that resources and time permitted:

1. We assessed comparative cost estimates of alternative space transportation systems. We selected those areas which, after preliminary review, we deemed most subject to question.

   We also considered whether there was likely to be data from prior experience with which to judge the reasonableness of individual estimates.

2. We used NASA-supplied procedures to show the impact of NASA's March 1972 cost estimates on the future levels of NASA's annual budgets.

3. We compared NASA's estimates of the long-range costs of the Space Shuttle Program and alternatives using a procedure called discounting to consider the time value of money.

We discussed our findings with NASA staff and considered their comments in preparing this report. We made no judgment about the economic or other worth of the missions or payloads for which the Space Shuttle Program or alternative systems would be used, nor did we consider whether NASA's selection of the Space Shuttle Program was justifiable on such noneconomic grounds as advancement of space technology or national prestige. It is clear without detailed review that the economic justification for the Space Shuttle Program depends on the priorities which the Nation places on future space exploration and experimentation.

In arriving at its March 1972 cost estimates, NASA assumed numbers and types of missions which it stated are consistent with a NASA budget level of about $3.4 billion in 1971 dollars. (See app. I.) If the Nation would not require some of these missions and flights in the 1979-90 period, the economic justification of the Shuttle would deteriorate because the $8 billion of development and procurement costs would be amortized over fewer missions and because fewer launches would increase the cost per launch. NASA assumes that the Nation would perform an even greater number of missions and flights in this period; if so, the economic justification for the Shuttle would be improved. NASA stated that this greater number of flights is a superior mission model and that they can be accomplished within the previous annual budget level of $3.4 billion.

CHAPTER 2

REVIEW OF NASA'S COST ESTIMATES

We examined the support for (1) NASA's estimates of costs and cost savings for the Space Shuttle Program as presented in its March 1972 public release and subsequent congressional testimony and (2) comparable estimates for the alternative systems. The designations of the 3 estimates examined and the amounts involved to 1990 based on 581 flights were as follows:

System	Program cost to 1990
	(billions)
Current expendables	$48.3
New expendables	45.7
Space Shuttle	[a]43.1

[a]Shown as two amounts in NASA's March 1972 public release:

1979 to 1990 costs	$35.0 billion
Procurement and development	8.1 billion
	$43.1 billion

NEW ESTIMATES SUBMITTED BY NASA ON APRIL 27, 1973

Our timetable for completion of this work had to be entirely revised when NASA presented us with new estimates on April 27, 1973, which were substantially different from the estimates we were reviewing. The three principal changes were:

1. A new forecast of future space flights, or a mission model, was developed; it contained 779 flights of the Space Shuttle, an increase of 34 percent over the 581 flights.

2. About one-third of the flights are now planned to be performed in a sortie mode. In sortie missions, the Shuttle takes experiments and other payloads to orbit where the entire mission objective is accomplished. It contrasts with the use of a space station for the

manned experiments and use of the Shuttle as a vehicle for visiting the station and returning from it. The prior Shuttle estimates did not include sortie missions. The expendable systems cannot perform these sortie missions; they still require the use of a space station for manned experiments.

3. A later design of the drop tank was made available. It is intended to facilitate low-cost manufacturing techniques.

NASA's present estimated total program costs using the Shuttle or the current expendables through 1991 follows, compared to its March 1972 estimates through 1990.

System	March 1972 estimate (billions of 1971 dollars) (1971-90)	April 1973 preliminary estimate (billions of 1972 dollars) (1971-91)
Current expendable	$48.3	$66.2
Space Shuttle	43.1	50.2
Savings from Shuttle	$ 5.2	$16.0

Changes of such significance cannot be properly assessed without considerable study, and we have not had the opportunity to do this. Accordingly, we have not traced our conclusions on individual cost elements into NASA's April 1973 preliminary estimate. However, we can draw general conclusions regarding NASA's cost comparisons.

ISSUES REGARDING NASA'S COST ESTIMATES

After reviewing NASA's estimates we are not certain whether the Space Shuttle will or will not produce cost savings--and it is probably unrealistic to use this cost data as a primary basis for choosing between the Shuttle and the alternative systems. In fact, in its statements to GAO on April 27, 1973, NASA said:

"NASA reiterates its long-held position that the Shuttle justification in the first instance is not economics--that there are many other reasons for undertaking its development."

There are three principal reasons for questioning the use of these cost comparisons as a primary basis for supporting the Shuttle.

1. The choice of system will be determined more by mission assumptions than by launch system hardware considerations. Between March 1972 and April 1973 the number of flights increased from 581 to 779. The investment represented by the development of the Shuttle must be amortized over whatever number of flights will actually be flown. This number may be more uncertain than the costs of the transportation systems themselves.

2. Acceptance of an indefinite use for the Space Shuttle may improve its economic advantage but, in all assumed useful life periods, the economic difference (discounted costs) is not very significant.

3. It appears unrealistic to assert either precise cost estimates or economic benefits for the Space Shuttle today, since the system will be in development until 1979 and any performance savings must accrue over a long period of years.

NASA's March 1972 claim of $5.2 billion savings for the Space Shuttle has two significant limitations.

--The Shuttle is an undeveloped system for which only early estimates are available. However, its claimed economic advantage is based on comparisons with the current expendables which are operational items of hardware. Past experience with early estimates of major military weapons system costs reveals that the average growth between the estimate at beginning of system development and the actual cost has been substantial.

--Analysis of assumptions underlying the March 1972 Space Shuttle estimates reveals a number of areas where the estimate appears to involve uncertainties amounting to hundreds of millions of dollars.

We developed the following nine issues during our analysis of the March 1972 estimates and presented them to NASA for assessment. A number of areas other than the nine we reviewed are also uncertain and could be investigated. We believe that these issues illustrate the kinds of uncertainties which exist in comparing the costs of the Space Shuttle with the expendable systems.

Issue 1--Are five orbiters enough?

NASA's 1972 plan called for 5 orbiters to support 581 Shuttle flights over a 12-year period. A draft Air Force memorandum submitted to the Department of Defense (DOD) estimated that three additional, or a total of eight, orbiters may be needed. Present plans call for it to provide funds for two orbiters and its launches will depend on the availability of orbiters.

NASA disagrees that additional orbiters may be needed and states that, assuming a 2-shift, 5-day week, 3 vehicles would support the 581-flight program, leaving the other 2 to cover flight schedule variances, turn around, and possible loss of vehicles. NASA advised us that, in formulating its estimate of orbiter needs, it considered that no more than one vehicle would be lost in the first 1,000 flights and that the rate of loss would improve thereafter. On the basis of NASA's rationale for procuring five orbiters, it might be necessary to replace any losses--particularly if they occur early in the program. Orbiters cost about $250 million each. NASA's March 1972 estimate did not specifically provide for such replacements.

In its comments NASA states that there is adequate contingency in the procurement estimate to procure another orbiter (the sixth) without additional funds should a loss occur.

We did not review the procurement estimate of the Shuttle for inclusion of contingencies, and time restraints did not permit us to do so after receipt of NASA's comments.

Thus, we have not reviewed the basis for NASA's statement regarding the contingency; however, other data described below indicates it is doubtful whether even six vehicles would be sufficient. Since the Space Shuttle will be a new development, no good basis for comparison exists. Three indicators we considered which admittedly are not closely comparable to the Shuttle are the experiences of the X-15 test vehicle and the F-111 aircraft and insurance rates of commercial airlines. These would indicate that Shuttle losses might be expected to be as shown below:

--Commercial airlines--1 to 2 vehicles.

--X-15 test vehicle--1 to 2 vehicles.

--F-111 (based on the first 40,000 flying hours, about the same amount of flying hours as would be required for 581 Shuttle flights)--about 12 vehicles

Although we do not accept any of these as being comparable enough to draw firm conclusions, we believe they suggest that NASA may be optimistic in its estimate and that it is conceivable that the NASA estimate does not adequately provide for costs that ultimately may be required for acquisition of the orbiters.

The Shuttle also will carry hazardous payloads. NASA has realized this danger and the fact that these hazards are subject to the individual design philosophy of the various users of the Shuttle. NASA has prepared a preliminary safety criteria document "Safety Criteria Guidelines on Preliminary Hazard Analysis of Potential Space Shuttle Payloads."

Issue 2--Cost refinements needed

We found four cost elements that either were overlooked or could have been estimated more carefully in NASA's Shuttle cost estimate. The four cost elements follow.

--Although the orbiter hydraulic system is a small item, we noted that NASA's estimate did not include its costs. Using cost estimating methods developed by the Aerospace Corporation, we estimated this cost to be about $58 million. Contractor estimates for hydraulic systems also support this cost.

NASA responded that, although this element had been omitted, it should be absorbed within its overall contingency fund and that the add-on might be as little as $2 million. We believe that such known elements should be explicitly included in cost estimates.

--The estimate of the Space Shuttle cost included launch operation site costs as though all launches were to be made from one site. Actually, NASA and the Air Force plan to use two launch sites. Because certain fixed costs of operating a site are incurred regardless of usage, it is more expensive to operate two sites than one, even though the number of launches does not change. NASA agreed and estimated that this would add another $100 million to the original cost estimates.

--About $100 million of the costs estimated for the Space Shuttle had already been incurred and should be excluded from the estimate for purposes of comparing alternatives.

--NASA changed the number of flights from an earlier determination of 440 to 581 without changing quantity discounts on certain components. Allowance for quantity discounts on the additional procurements for the Shuttle reduces the estimate by about $200 million.

Issue 3--Drop tank costs

A major item of cost is the external tank which contains liquid oxygen and liquid hydrogen used to propel the Space Shuttle orbiter vehicle into orbit. The external tank is dropped off after launch and after the orbiter engines have used all the needed fuel contained in the tank. Hence, a new tank must be procured and used for each flight.

NASA's March 1972 estimate was based on a cost-weight relationship, using experienced cost for the Saturn launch vehicle. These estimates indicated that, on a cost-per-unit-weight basis, large cost reductions relative to Saturn experience can be achieved for the Shuttle drop tank. Estimates of these reductions are based on (1) the differences in technical characteristics and requirements between Saturn stages and the Shuttle tank design and (2) identification by NASA and industry of specific low-cost design and manufacturing approaches to the tank design.

Using the cost-weight relationship based on these studies, NASA estimated that the expendable drop tank involved in its March 1972 estimates would have a very significant average procurement cost and would also represent a very significant portion of the annual costs during the operational life of the Shuttle.[1]

On April 27, 1973, NASA provided us with what it called a "grass roots" estimate based on an in-depth technical cost analysis for the tank and described its latest design. NASA states that this design is simpler than that included in the March 1972 estimate and that these revisions will facilitate the use of various low-cost manufacturing techniques--such as spray-on insulation and electron beam welding.

NASA stated that, because of the great importance of the drop tank, its design effort on the tank has been more extensive than on any other part of the Shuttle. NASA stated that its estimate may be overstated.

We believe that, in view of the unknowns in the development of the tank--which we understand will be awarded under a cost-plus award fee arrangement--considerable uncertainty as to the final costs will continue to exist, although the cost reduction actions described above are commendable. The importance, however, of even a small cost growth on this expendable item is underscored by the latest NASA mission model which calls for 779 flights and, therefore, will require 779 tanks.

If, as has happened for other major U.S. systems, the tank design changes, and if NASA's planned cost reduction techniques are not as successful as planned, experienced

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[1]Because contractor selection for tank research and development was in process, NASA requested that the specific cost not be revealed.

cost-weight relationships indicate that costs could be as much as 100 percent more than NASA's estimate.

Issue 4--Contractor engineering support

Contractor engineering support includes the cost of engineering effort that directly supports manufacturing and product improvement throughout the system life.

In analyzing the March 1972 estimates, we found that the orbiter contractor engineering support did not continue during the Shuttle operational period. NASA said that this support would be unnecessary for the orbiter after completion of the development and production program and that necessary engineering was provided in the cost for launch operations. This seemed to be an optimistic assumption in view of past experience in the production of aircraft, launch vehicles, and spacecraft where allowances have been made for contractor support costs including product improvement.

Using a cost-estimating relationship built into the Aerospace Corporation cost model which is based on past experience, we estimated that such costs (engineering in support of manufacturing and product improvement) might run over $1 billion. NASA responded by itemizing $460 million included in the original estimate for engineering in support of manufacturing. NASA also stated that engineering in support of manufacturing included in the NASA estimates for the solid rocket motors and external tanks exceeded amounts actually spent under current contracts for similar items under production.

NASA stated the cost of contract engineering support for product improvement should not be included in the Shuttle estimates at this time because (1) such costs are not included in the costs of expendable systems and (2) product improvements will be undertaken in the future only if they reduce costs or if increased capability is desired beyond that required to carry out the current mission model. NASA states that these will be separate decisions made on the economic merits of each case.

We believe NASA has overlooked the fact that product improvement costs are often incurred in bringing system performance up to expected standards as well as in upgrading a system. This has been recently demonstrated in current aircraft and missile programs. However, NASA stated that there is adequate contingency in its $8.1 billion estimate of acquisition costs to insure that product improvement costs will not be required for this reason. Our time constraints did not permit us to review the basis for NASA's statement regarding contingency. We believe that product improvement costs will undoubtedly occur in the Space Shuttle Program and, if not provided for, will become an element of cost growth.

Issue 5--Reuse of solid rocket boosters for the new expendable systems

NASA acknowledges that the new expendable program could save $400 million by reusing solid rocket boosters. This saving was omitted from the 1972 cost estimate. As pointed out earlier, NASA does not consider the new expendable systems a realistic alternative to the Space Shuttle and gave only cursory attention to estimating the cost of the systems.

NASA agrees this is a valid point if new expendables were to be given further attention.

Issue 6--Launch systems operations and maintenance

We reviewed the manpower levels and costs that NASA estimated would be required to launch the Shuttle and maintain (refurbish) it after landing, and the costs required to launch the expendable systems. NASA estimates that the manpower required to launch the Shuttle will be less than that currently required for the smaller, unmanned Titan IIIC.

We found that the manpower required for maintenance of the Shuttle was roughly the same as that required to maintain the Air Force's C-5A. The procurement cost of the Titan IIIC and the C-5A is less than half the cost of the Shuttle. We believe that optimistic assumptions have been used for the launch and maintenance of the Shuttle.

NASA states that our assessment of Shuttle maintenance manpower needs could be based on errors in analysis of both C-5A and Shuttle manpower data. Our inquiries failed to elicit adequate information from NASA to explain what these errors might be.

We also found that NASA intends to increase the role of the civil servants in its Shuttle operation. This will reduce the labor rate compared to what is used on expendable launch vehicles--which depend heavily on higher cost contractor support for launches. NASA did not apply this difference in philosophies--i.e., civil servants versus contractor personnel, to the expendable systems--and we feel that the expendable systems should also benefit from this low-cost management philosophy. Hence, we believe that the launch cost for the expendable systems should be reappraised using similar assumptions. NASA did not formally comment on this aspect of the issue.

Issue 7--Indirect range support costs

These costs are for such services as facility and equipment maintenance, range safety, and base support. We were struck with the estimate of $1.7 billion of such costs chargeable to the expendables, but less than $0.3 billion chargeable to the Space Shuttle--a difference of $1.4 billion. NASA advises that, while the estimates for the expendables were rough, they are realistic since they are less than current range costs which support lower activity levels than contemplated in the future.

NASA said that the large difference, which favors the Shuttle, is due, in part, to the fact that range safety will be handled by the crew of the Shuttle. Range safety presently is a ground function which provides for destructing malfunctioning launch vehicles so they will not continue out of control and possibly seriously damage facilities or communities on the ground.

NASA appears to us to assume that, in any cases of malfunction, the Space Shuttle crew--without assistance from the ground--will be able to disengage the orbiter from any malfunctioning booster components, destruct them, and fly the orbiter back to earth for a safe landing. To our knowledge, crew-operated range safety measures of this type have not been tried before during launch of manned flights; therefore, there is doubt that all requirement for ground control will be eliminated and some cost growth seems possible.

The difference in range support costs between the Shuttle and the expendables is so sizable that we believe it needs additional evaluation. The Air Force, which operates the test ranges, is unable to predict the extent of any reductions in cost for their launches until the Shuttle's system design reaches a higher degree of maturity.

Issue 8--Effect on costs due to reliability assumptions

Another principal cost area that we tested was reliability. The costs involved are those due to mission abort and eventual reflights. Our initial findings suggested that NASA may have underestimated these costs for the Shuttle and overestimated them for the expendables.

NASA uses a design goal for reliability of 99.5 percent for the Shuttle and cites as its precedent the experience on the Gemini and Apollo programs in which vigorous analyses identified opportunities for elimination of failure points by redesign and redundancy.

NASA's experience for the Gemini and Apollo programs do show 100-percent success for the launch vehicle; however, if aborted missions are considered, mission success was less than 95 percent. Since the estimates involved here relate to the total mission rather than to just the launch vehicle, NASA's estimates should be compared using the probability of mission success and not only launch success. Thus, we believe the 99.5 percent for Shuttle mission success is an overestimate.

NASA uses this design goal for reliability as though it was the average for the entire Space Shuttle Program. Granting the capability to approach perfect reliability, we wonder if, for the purpose of NASA's analysis, it is not more realistic to assume a lower initial reliability of, perhaps, 90 percent and a final reliability of 99.5 percent. Because the rate of improvement typically slows as 100 percent is approached, the expected average over the 12-year period would then be 97 percent, instead of 99.5 percent. We also found an Air Force-funded study showing that an average Shuttle reliability was determined by using a lower initial reliability than that estimated as the later reliability.

With regard to expendable vehicles, NASA uses a 97-percent reliability estimate for all three systems rather than a more precise computation. We made computations of the rates to arrive at the following:

Alternative	Percent
Current expendables	97.7
New expendables	97.3
Space Shuttle (note a)	95.3

[a]Applies only to 40 flights during the Shuttle's phase in period when expendables will be used for some flights.

The current expendables and new expendables alternatives produce different results because the current expendables require about 170 more flights than the new expendables to perform the same mission.

NASA disagrees with our findings on reliability for the Shuttle and expendables; NASA states that its long experience with both manned and unmanned launch vehicles has fully demonstrated one point: reliability must be designed and built into the vehicle; it cannot be attained merely by flying more and more vehicles. Thus the Titan II used in Gemini and the Saturn launch vehicles used in Apollo achieved their very high reliability (much higher than any unmanned launch vehicles) through the design of highly reliable redundant systems and subsystems (independent of the number of launches). NASA stated that the Shuttle is designed with these same principles and that the competitive expendable systems are not. Therefore, NASA concludes that the expendable systems could only begin to approach the reliability of the Shuttle if they were redesigned and if appropriate reliability features were added. This could be done, but according to NASA, it would be expensive. NASA states that we did not include the costs for such reliability improvement of the expendable systems in our cost analyses.

We have used past experience in our analyses, and we believe that it supports our method of computing average reliability. With regard to expendable vehicles, NASA has not addressed the computational aspect of our issue in its comment but, rather, questions whether expendables can reach reliability as high as the Shuttle.

From 1965 through 1969, the expendable launch systems were about 95 percent reliable, an increase from about 85 percent experienced in the previous 5 years. Therefore, despite what NASA says to the contrary, experience has shown that reliability tends to improve as more launches are made.

Our issue, however, deals with the different methods in estimating the launch reliabilities and, hence, costs of the alternatives, and this should be corrected.

This correction would raise the reliability estimate for the expendable programs and lower it for the expendables used in the Shuttle Program. It would lower the cost estimate of the expendable programs and increase the Shuttle cost estimate, causing a net change in the difference between these estimates of several hundred million dollars.

Issue 9--Understatement of research and development costs for expendable systems

Performing the proposed missions in either the March 1972 or in the new mission model with expendables would require using a space station and developing an orbiting and reentry vehicle, capable of carrying 12 men, which could be launched with the expendable launch vehicles. Such a 12-man, 18,000 pound reusable vehicle has been considered as an outgrowth of the Gemini program and the closely related Air Force manned orbiting laboratory program; thus, it has been called the Big Gemini.

NASA said that, for a more precise comparison, a further analysis should be made of research and development costs required to complete development of certain Titan components, the expendables' manned vehicle Big Gemini, and to integrate these with various upper stages. NASA statements indicate that this might increase the development cost of the new expendable systems by about $1 billion.

There are uncertainties which might cause these research and development costs to increase; we believe that this further illustrates the large area of uncertainty which has characterized NASA's comparative cost analyses.

NASA emphasizes that the new expendable was an economic screening benchmark favored with optimistic cost assumptions which did not win a competition with the Shuttle. NASA states that it did not pursue this alternative since it was apparent that more detailed study would lead to increased cost for an already noncompetitive option. NASA states further that, although we have recognized its views on the new expendable family of launch vehicles, the impression remains that this launch system is a strong contender for the most effective space transportation system.

We agree that NASA's estimate was a cursory one, but we have found areas of cost uncertainty that make us wonder whether a complete, detailed estimate might not have been warranted as a basis for decisionmaking. (See issues 5 and 6, pp. 18 and 19.) NASA has admitted that it did not use the same cost reduction techniques in the new expendable estimate that it used in the Shuttle. Reports of NASA's contractor, Mathematica, Inc., on the economics of the Space Shuttle stated that the study of the new expendable concepts has received too little attention.

Conclusions

NASA's estimates do not remove our reservations that the Space Shuttle will produce cost savings; however, it probably is unwise to use this aspect of the matter as a principal determinant. We base our view on several factors:

First, while there is uncertainty in cost estimates for both the Shuttle and expendable systems, we believe the degree of uncertainty for the Space Shuttle estimates is greater than for the expendable systems. With these differences in the degree of uncertainty in launch system costs, we do not consider it prudent to place too much confidence in the projected cost savings. Technical problems and the cost overruns that usually follow such problems are more likely on the Shuttle and, if they occur, could turn the projected savings into increased cost.

Second, there may be even greater uncertainty in the estimated costs of payloads for all alternatives. NASA's March 1972 estimates include payload development and procurement costs of $35.1 billion for the expendable alternatives and $26.8 billion for the Shuttle. The Aerospace Corporation prepared these estimates for use in its studies. Because detailed engineering design has not yet begun on most of these, the cost estimates are based on statistical estimating techniques which are appropriate for advance planning but which are not as refined as detailed engineering design. Also, the greatest impact on cost of the new sortie mode is in the payload area. In the time available, we have not been able to perform even preliminary review of the methods used to estimate these costs. NASA's revised estimates given us on

April 27, 1973, with the new mission model, include payload costs of $50.1 billion for the expendables and $30.2 billion for the Shuttle. Clearly, the additional savings NASA now attributes to the Shuttle are nearly all based on payload cost estimates.

Our review suggests that a congressional decision to continue the Space Shuttle Program should be made on other than economic grounds. The Congress can also keep open the option of selecting one of the expendable systems in lieu of the Shuttle should cost growth become unacceptable.

CHAPTER 3

ECONOMIC AND EFFICIENCY COMPARISONS

NASA has compared expendable systems with the Space Shuttle in terms of economic justification (i.e., cost adjusted to consider the time value of money). NASA also computes what it calls an efficiency index that shows, for the alternatives, the cost for placing a pound of payload in orbit. For the Shuttle and the expendables, both of these comparisons are sensitive to certain assumptions which must be made in performing the analysis. We tried to assess the reasonableness of both of these comparisons.

THE ECONOMIC JUSTIFICATION ISSUE

In March 1972 NASA stated that justification of the Space Shuttle was not based on the details of Space Shuttle economics alone. Because of the interest of the Office of Management and Budget and others in this aspect, NASA has made calculations which show that by 1990 the Shuttle investment (development and procurement) will have saved billions compared with the expendable alternatives.

The economic justification for the Space Shuttle requires that the savings from its operation compared with the costs of an alternative system must be sufficient to offset the $8.1 billion estimated cost of developing and procuring the Space Shuttle. Whether this amount can be offset by the savings depends on the nature and the total number of launches required by the Nation during the useful life of the Shuttle. Furthermore, these costs must be adjusted to consider the time value of money.

The analyses which follow relate to the 581-flight estimates of March 1972. We did not have time to consider the impact of NASA's April 1973 mission model on the analyses which follow. However, data provided by NASA on May 21, 1973, but not reviewed by us, is shown in appendix II.

ECONOMIC COMPARISON METHOD

Generally accepted practice provides that, in making economic comparisons among alternatives, consideration should be given to the time value of money through a discounting procedure. The results of this procedure do not produce a cost estimate of actual dollars that might be spent if the various alternatives were funded; rather, it provides a basis for eliminating the effects produced by variations among the alternatives in the years in which the costs are to be incurred.

By time value of money, we mean that a dollar in a future year will have a different value than a dollar today because of interest and related costs. If we need $1 in 1980, 42 cents invested in 1971 at a 10 percent annual rate of return will be worth $1 in 1980. If $1 is needed in 1990, the amount invested in 1971 at 10 percent need be only 16 cents. If $1 is needed in each of 20 years, 1971-90, $9.36 invested at 10 percent in 1971 is needed. The $9.36 is the present value of the $20 total. Similarly, amounts computed for alternative future requirements determine present values of the alternatives which are directly comparable in an economic sense today.

ECONOMIC COMPARISON OF SPACE TRANSPORTATION SYSTEMS

Office of Management and Budget Circular A-94 provides that, in making economic comparisons with the discounting procedure described above, the discount rate (annual rate of return) prescribed is 10 percent unless a different rate is prescribed for the particular case.

In comparing the Space Shuttle with two expendable systems alternatives, we used the 10-percent discount rate prescribed by OMB Circular A-94, that was the rate used by NASA's contractor, Mathematica, Inc., in the estimates it made for NASA. We have not determined whether a different discount rate might be more appropriate for comparison of space transportation system alternatives.

If the operational life of alternative systems is known, the annual costs are discounted over that number of years. In most cases, there is some uncertainty about the lifetime for a number of reasons, including technological obsolescence and changes in program objectives or priorities over a long time frame. OMB Circular A-94 provides that each year's expected yearly cost be multiplied by its discount factor and then summed over all years of the planning period.

NASA's 581-flight mission model extends through 1990. However, NASA states that the Shuttle's useful lifetime will extend many years beyond that. We believe it may be interesting to consider how the alternatives compare in an economic sense at various points in time during the 40-year useful life estimated by NASA. NASA used average annual costs (1986-90) as its basis for extending estimated annual costs of the alternatives from 1991 to the year 2020. Table 3-1 shows the NASA estimates of total estimated life cycle costs which will have been expended by 1990, by the year 2000, and by the year 2020, depending upon the alternative selected. The discounted costs are also shown; i.e., the amount, which if invested at 10 percent in 1971, would provide these amounts in the years required for each alternative.

Table 3-1

Life Cyclè Costs of Alternatives
Over Various Time Periods
Considering Time Value of Money

	Current expendables	New expendables	Space Shuttle
	(billions of 1971 dollars)		
Life-cycle costs:			
To 1990	$ 51.0	$ 48.1	$ 44.5
To 2000	90.0	85.0	70.8
To 2020	168.1	159.3	123.4
Above discounted at 10 percent:			
To 1990	14.2	13.4	14.4
To 2000	17.8	16.7	16.8
To 2020	19.7	18.5	18.1

The discounting procedure reduces dollar amounts more in each successive future year. The cost of the Shuttle in shorter time periods is greater than those for the expendable alternatives because of the $8.1 billion cost of developing and procuring the Shuttle. The greater the number of years of Shuttle useful life, the less effect this initial cost has on the comparison.

Also, as shown in chapter 2, our review has identified significant issues regarding NASA's cost estimates that lead us to believe that the cost of the Space Shuttle may be higher than indicated in NASA's estimates. If costs ultimately turn out to be significantly different from those estimated by NASA, the results of these computations might be significantly changed.

We made no judgment regarding the useful life of the Space Shuttle. NASA's March 1972 cost estimates were based only on the mission requirements model for 1979-90. Therefore, we did not have comparable costs for the alternatives for different periods extended beyond 1990.

NASA did not think it fair to end the comparison at 1990, so we asked NASA if comparable costs could be provided to extend the March 1972 cost estimates beyond 1990 for purposes of economic comparison. NASA provided adjusted estimates of costs to 1990 to provide for procurement needed to maintain a similar level of flights beyond 1990. For this reason, costs at 1990 in table 3-1 are higher than those estimated at March 15, 1972. (See ch. 2.) NASA estimated that beyond 1990 current expendables program costs would be about $3.9 billion and Space Shuttle program costs would be about $2.6 billion annually. These are the 5-year (1986-90) average costs contained in the adjusted cost estimate to 1990.

As previously explained, the comparisons in table 3-1 have been extended to the years 2000 and 2020. However, we question whether it is realistic to project constant annual costs for the alternatives (or savings for the Shuttle) indefinitely beyond the period for which a definite mission model has been prepared. The underlying assumption used to justify this is that the Shuttle will be useful until replaced by a new system which improves on the future economic benefits available from the new Shuttle.

There are various reasons to question this assumption. First, there could be technological obsolescence or technological advances which would cause a new Shuttle or other new type of system to be acquired for reasons other than its future economic benefits. Second, the costs of the current Shuttle could grow, as we have stated; requiring many more years before it could show savings compared with current expendables. For such reasons, the first Shuttle might have incurred losses, not savings, when its useful life ends. The significance is that for economic comparisons now there is a possibility that the second Shuttle would, in effect, need to absorb losses from the first if it is viewed, as NASA does, as a follow-on phase of a continuing program.

Also, it is accepted practice in economic analysis to estimate "salvage" or "residual" value of the assets remaining at the end of whatever useful life is considered. In computing these space transportation system discounted costs, we have not credited the Space Shuttle with residual value of its reusable orbiter and space tug because no sound estimate of residual value was available. The residual value depends upon the flights each could still perform, after completing the 581 flights required by 1990. However, we do not consider this significant; for, even if these items were valued in 1990 at full value (as though no deterioration had taken place), the discounted credit to the Space Shuttle would not reduce its total discounted cost at 1990 of $14.4 billion significantly below the current expendables figure of $14.2 billion. Residual value becomes even less in later years.

Economic comparison of space transportation system alternatives is complex and uncertain. We found that, if we used costs which NASA supplied on the basis of its March 1972 estimates and if we accept all of NASA's assumptions, the Space Shuttle is economically favored by a small margin in the year 2020. We did not have time to review similar computations for NASA's April 1973 estimate. The information provided by NASA is shown in appendix II. However, because of the large cost and other uncertainties discussed elsewhere in this report, we believe the question of economic justification has not been resolved.

TOTAL LAUNCH SYSTEM COSTS PER POUND OF PAYLOAD PLACED IN ORBIT

We were requested to compute the average cost for placing a pound of payload in orbit on the basis of NASA's March 1972 estimates for the Space Shuttle Program and the two expendable alternatives. The results of this computation are summarized below.

Table 3-2

Comparison Of Costs Of Placing Payloads In Orbit

	Current expendables	New expendables	Space Shuttle
Total launch system cost for aggregate payload weight as scheduled in the 80-mission, 581-flight model:			
Aggregate weight (millions of pounds 1979-90)	4.3	4.5	4.6
Total launch system cost through 1990 (billions of 1971 dollars)	$ 13.3	$ 11.6	$ 16.1
Total launch system cost per pound of payload in orbit (1979-90)	[a]$3,100	[a]$2,600	[a]$3,500

[a]Rounded to nearest $100.

The average cost per pound shown in table 3-2 was estimated using launch system costs and payload weights associated with a particular mission model--the 80 mission, 581-flight model involved in NASA's March 1972 estimates--as follows:

1. Identifying and summing the total estimated weights of all payloads to be placed in orbit by the alternative launch systems for the 80-mission model in the 1979-90 period. If the number or mix of various payloads varied, this total would be different.

2. Identifying and summing NASA's estimates of launch systems costs for the alternative systems for the same 12-year period. This total would vary if the number of flights changed from 581.

3. Dividing the 12-year launch system cost estimate by the total payload weight to be launched during the period. The result of this computation is shown in table 3-2. As indicated, these average costs are

meaningful only with regard to the particular mission model used.

NASA has stated that the above computation will be confusing and has no place in cost-benefit analyses. We agree that this index is not a measure of economic justification or cost benefit. However, NASA included its $160 per pound index in its public statement in March 1972 which otherwise dealt with economic justification, and we were asked to prepare the above table to show comparative figures.

NASA's EFFICIENCY INDEX

The $160 launch system cost for placing a pound of payload in orbit was cited in congressional testimony concerning the cost and efficiency of the Space Shuttle Program. In its March 1972 fact sheet on the Space Shuttle, NASA stated that an index of the Shuttle's efficiency is the fact that the cost per pound placed in orbit when the Shuttle is loaded to maximum capacity (65,000 lbs.) will be about $160 compared with $900 to $5,600 per pound for various conventional launch vehicles (various capacities). NASA's efficiency index is computed by dividing the cost of launching the Shuttle or the expendables by the maximum payload (in pounds) each can place in a 100-nautical-mile orbit.

The difference between the $160 per pound shown above for the Space Shuttle and $3,500 shown in table 3-2 is:

1. The cost of development and procurement of the Shuttle ($8.1 billion) was not included in NASA's figures.

2. The maximum capacity of the Shuttle was used in computing NASA's figure, whereas the average payload weight to be used in the 581-flight model is only about 12 percent of capacity.

Because many of the planned missions do not require full Shuttle capacity and because no development or procurement costs or amortization thereof is included in NASA's efficiency index for the Shuttle, we believe that the comparison made by NASA in its March 1972 statement was not a meaningful one.

CHAPTER 4

FISCAL YEAR FUNDING ANALYSIS

We were asked to determine whether NASA's March 1972 cost estimates for the Space Shuttle Program and alternative systems are compatible with a ceiling on the NASA budget (annual fiscal year funding requirement) through 1990. NASA's fiscal year 1973 budget is $3.407 billion. NASA testified that the Space Shuttle could be developed, together with other continuing programs, within approximately current budget levels (i.e., about $3.4 billion in 1971 dollars according to NASA's March 15, 1972, fact sheet entered in the record of hearings before the Subcommittee for Housing and Urban Development, Space, Science, Veterans, Senate Committee on Appropriations, pp. 159-165, on NASA's fiscal year 1973 budget.) We were also requested to consider a ceiling of $3.2 billion.

NASA does not normally propose annual funding requirements more than 5 years in advance (e.g. fiscal year 1978 at the time their fiscal year 1974 budget was proposed). However, the Aerospace Corporation did prepare estimates of total annual cost streams for the Space Shuttle and expendable systems through 1990. We used these time-phased cost estimates and other information supplied by NASA to prepare the information contained in this chapter on NASA's fiscal year funding requirements.

Specifically, we projected NASA's annual funding requirement for each alternative space transportation system by adding the following cost estimates.

1. Payload costs estimated and time-phased over the 1974-90 period by the Aerospace Corporation for each alternative transportation system.

2. Space transportation system costs estimated and time-phased over the 1974-90 period by NASA for the Space Shuttle Program and by the Aerospace Corporation for the current expendable systems and new expendable systems.

3. Space station development and acquisition costs estimated and time-phased by NASA over the 1974-90 period.

4. NASA's 5-year (1974-78) budget forecasts required for costs of completion of programs contained in the fiscal year 1974 budget (run-out costs). NASA officials recently presented these forecasts to the Subcommittee for Housing and Urban Development, Space, Science, Veterans, Senate Committee on Appropriations.

5. NASA's fixed annual estimates of cost for three budget categories--"Aeronautics and Space Research and Technology," "Research and Program Management," and "Tracking and Data Acquisition."

For the 17-year period (fiscal year 1974-90) covered by our assessment, we found that projected annual fiscal year funding requirements for NASA's March 1972 estimates exceeded both the $3.2 billion and the $3.4 billion ceiling in several years, as shown in table 4-1. The Space Shuttle alternative exceeded the ceilings in 3 or 7 years, respectively. Both current expendables and new expendables exceed the ceilings in a number of years.

Table 4-1

Number of times and maximum amounts by which annual funding requirement exceeds ceilings (based on combined NASA and Aerospace Corporation estimates related to the March 1972 estimate)

	Number of years ceiling (in constant 1971 dollars) is exceeded		Years in which ceiling exceeded		Maximum amount by which ceiling may be exceeded in one year (in constant 1971 dollars)	
	$3.2 billion	$3.4 billion	$3.2 billion	$3.4 billion	$3.2 billion	$3.4 billion
Space Shuttle Program	7	3	1977-83	1978, 80, 81	$0.37	$0.17
Current expendables	9	6	1980-88	1981-86	.65	.45
New expendables	8	6	1981-88	1981-86	.51	.31

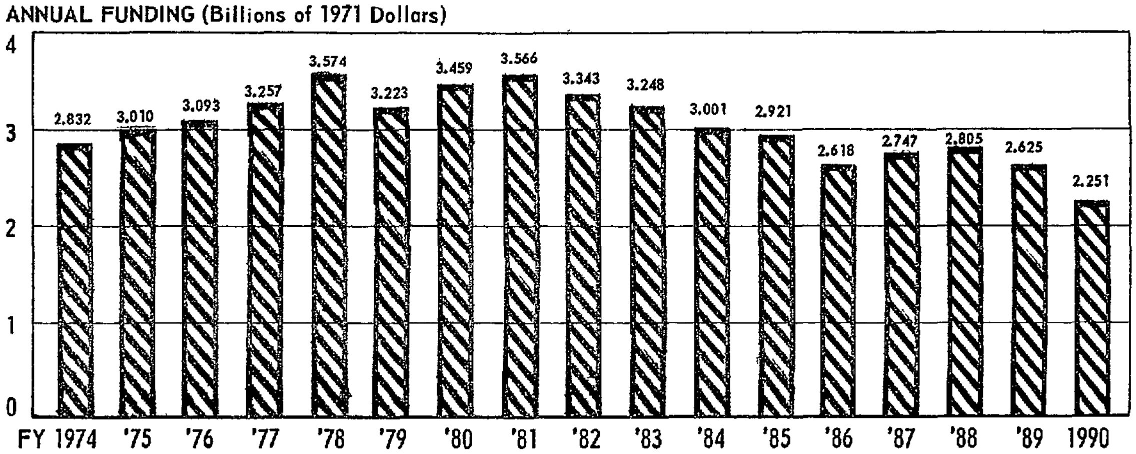
Figure 4-1 presents a graphical comparison of our projections of the NASA fiscal year funding requirement, in constant 1971 dollars, through 1990. The annual funding requirement based on combined estimates obtained from NASA and the Aerospace Corporation for each year is represented by a vertical bar.

NASA advised us on April 27, 1973, that they have prepared estimates of annual funding requirements for the Shuttle in a different way. These are included in appendix II.

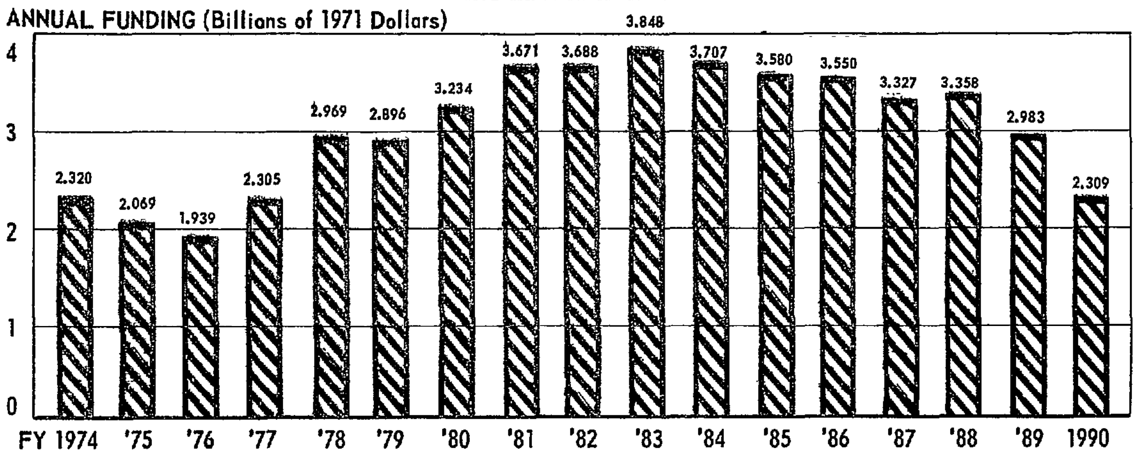
FIGURE 4 - 1

EFFECT OF COST OF ALTERNATIVE SPACE TRANSPORTATION SYSTEMS ON NASA's ANNUAL FUNDING REQUIREMENTS

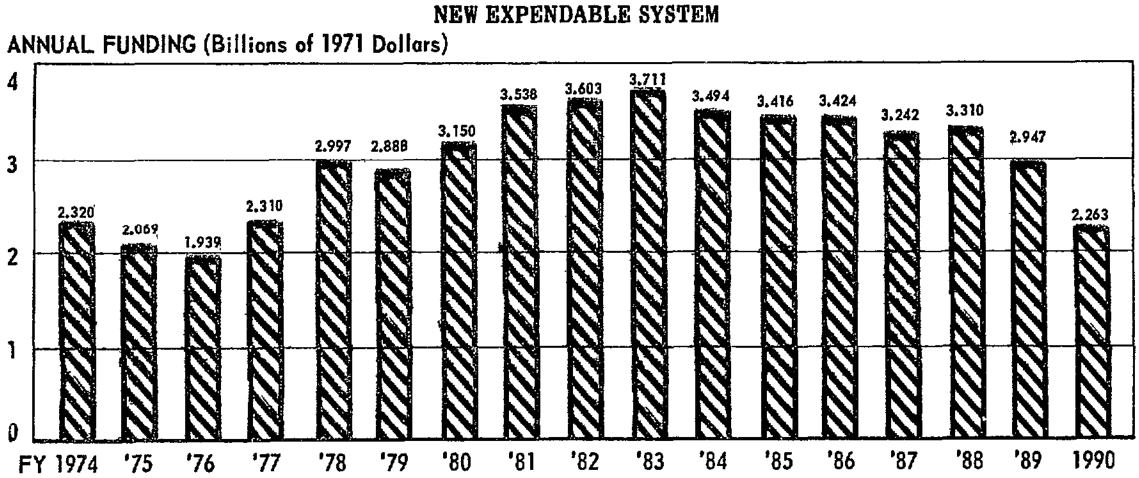
COMBINED ESTIMATE FROM NASA AND AEROSPACE CORPORATION DATA
SPACE SHUTTLE PROGRAM



ESTIMATE FROM AEROSPACE CORPORATION DATA
CURRENT EXPENDABLE SYSTEMS



ESTIMATE FROM AEROSPACE CORPORATION DATA
NEW EXPENDABLE SYSTEM



CHAPTER 5

AGENCY COMMENTS

In a May 21, 1973, letter the Administrator of NASA commented on a draft of this report. (See app. III.) The Administrator's letter contained general comments on the report, and an attachment to the letter contained specific comments on the nine issues mentioned in chapter 2. The substance of NASA's specific comments have been included in chapter 2. NASA's general comments are summarized below.

> The Administrator states that NASA's economic models have erred, if at all, on the side of conservatism and that this is more true today than when the Shuttle was approved in 1972.

As we have indicated in chapter 2, we believe NASA has been optimistic about the Space Shuttle estimates and that it did not refine the expendable estimates to the same degree that it did the Shuttle estimates. Although NASA believes its estimates are conservative, our experience with estimates for large systems involving significant uncertainties has taught us to view such estimates with a healthy skepticism. If the Shuttle is fully approved and NASA is able to keep it within the current cost estimates, we will be among the first to applaud its achievement.

> The Administrator states that NASA can conduct the program within the overall NASA budget level that prevailed when the Shuttle was approved ($3.4 billion). He further states that GAO tables indicate this.

As explained in chapter 4, our analysis indicated some years in which this budget level was exceeded for the 581-flight estimate. NASA might, however, be able to shift costs around among years to eliminate these overages if it is able to stay within the costs estimated for the Shuttle. The GAO table to which NASA refers is the one in appendix II, which is not a GAO table but one supplied by NASA on April 27, 1973, for the 581-flight model that we have included in our report without verification.

The Administrator states the belief that GAO's chapter on economic comparisons limits its attention to the rather narrow question of sensitivity analysis rather than dealing with a matter of fundamental importance, e.g., the proper social rate of discount to use. He further states that lower discount rates produce effects favorable to the Shuttle.

Our review addressed the specific areas we were requested to look into. The economic comparison discussed in chapter 3 was one such issue. The scope of our work did not include an inquiry into what social discount rate might be appropriate; therefore, we formed no opinion on what rate is appropriate here. The rate used was the one prescribed by the Office of Management and Budget, which NASA is required to use. This is the same rate used by Mathematica, Inc., in the work it did for NASA on the Space Shuttle.

We agree that, if a lower discount rate is used, the Shuttle is favored. However, a higher rate would produce the opposite result.

We do not agree that our sensitivity analysis involving useful life deals with a rather narrow question. We believe there is abundant experience, in both commercial and Government investments, where a premature end of useful life has been a major reason for failure to achieve planned economic results.

The Administrator states that GAO bases a finding of uncertainty about the NASA estimates on the history of cost performance in various DOD weapons systems, a general feeling of uncertainty as to future payload costs, and a modest list of specific areas where questions are raised. NASA states that it brought in the Apollo program--one of the most complex undertaken--without overrun. Consequently, NASA does not accept the idea that since various large systems in the past have cost more than estimated, the Space Shuttle economics are somehow suspect.

NASA's achievements in the Apollo program are commendable; however, we have not reviewed their estimates and cannot comment on the assertion that the Apollo program involved no overruns. In any case, there is much experience in Government to show that bringing one system in on target does not guarantee that it can be done for another system. There are many technical problems to be overcome in the Space Shuttle Program. Previous governmental experience shows that difficulty in overcoming just one of them could produce significantly higher costs.

NASA is correct that we view the payload costs with some skepticism--mainly because the Congress has not considered the worth of these programs to decide if they merit funding. Moreover, because of uncertainty in the mission assumptions, it would have taken more time than we had available to perform a meaningful review of estimated payload costs; however, our brief look into payload costs noted two major areas of cost uncertainty.

1. Savings from payload reuse and refurbishment costs which are a major basis for the difference between estimated payload costs of the Shuttle and expendable alternative.

2. Extended payload lifetimes through increased reliability. Payload reliability has increased significantly on recent programs. The estimate of Shuttle payload cost would be reduced less from this than would the cost of either expendables alternative. Since NASA has not continued to seriously consider expendables, the possible reductions may not have been reflected in NASA's estimates of payload costs for expendables.

The reader may judge for himself whether the questionable cost areas we reported are "a modest list" by reading chapter 2.

Finally, there is no prior system exactly like the Space Shuttle from which cost growth experience can be obtained. There is a substantial amount of experience on growth in costs of major weapons systems involving a great variety of technical requirements. This experience involves much of the same aerospace industry on which NASA must depend for the acquisition of the Space Shuttle.

Past experience with early estimates of military weapon systems costs reveals that the average growth between the estimate at the beginning of system development and the actual cost has been substantial.[1]

The possibility of overrun in Shuttle costs appears to us quite likely because--as stated in our discussion of issues 1, 2, and 4 in chapter 2--NASA has stated that several omissions or optimistic estimates we have identified will be provided for adequately by the contingency in its $8.1 billion estimated acquisition cost. Thus, the contingency appears to be applied to known uncertainties and there is a question as to whether adequate provision has been made for any problems that may arise that have not been anticipated.

We did not have time or resources to examine in detail all components of the research and development cost of $5.15 billion, which is included in the $8.1 billion. We did review NASA's analysis and found other major cost areas which we believe may involve considerable uncertainty--e.g., systems integration, flight testing, management, and airframe and thermal protection system development. We found that $1.6 billion of the $8.1 billion includes mainly costs for DOD and NASA launch site facilities and the space tug. The tug configuration has been a matter of uncertainty; we have noted that NASA's April 27, 1973, estimate increases this item by about $300 million. Of the $8.1 billion, $1 billion is for the refurbishment of orbiters built in the research and development program and procurement of three more. Most uncertainties in these costs would be related to the uncertainties in the $5.15 billion research and development program.

> The Administrator states that NASA has refined its designs since the Shuttle costs were firmed up in early 1972 and that it has now given the estimates a

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[1]GAO report, "Cost Growth in Major Weapon Systems" (B-163058, Mar. 26, 1973, p. 26.)

thorough treatment. The Administrator further states that, with an appropriate continuity of development funding, NASA will bring the Shuttle in within the estimate. He states further that there is no way NASA can see for Shuttle costs to erase Shuttle savings.

Time constraints prevented us from reviewing the new NASA estimates which were presented to us on April 27, 1973, so we cannot comment on what NASA has done to firm up its estimates. We do not agree that Shuttle savings could not be erased. We believe a sizeable reduction in the number of flights to be performed--if planned missions were reduced--could change the economic picture to favor the expendable systems. We have indicated that, if cost overruns approach even the average of recent weapon system cost overruns, savings NASA expects to achieve could be erased.

The Administrator also states that GAO infers in various ways that if NASA does not know what space missions are to be flown in the 1980s or 1990s, then there are serious uncertainties as to the worth of the Shuttle. He concludes that the impression is conveyed that the cost-benefit situation is extremely sensitive to mission assumptions and that NASA considers this incorrect. He continues that precisely all the missions to be flown in the 1980s or 1990s cannot now be predicted but that NASA knows the kinds of operations involved. He concludes that sound planning requires (1) that the missions in total represent the kind of program that the Nation can reasonably expect to perform in space in the future, (2) that the program appears acceptable in overall size, and (3) that the mission models are not unduly sensitive to size or content of the programs. He believes NASA mission models meet such conditions.

We do consider the missions to have a great effect on the economies of the situation because the Shuttle is reusable and more flights are necessary to amortize its development costs. We concur with the Administrator's view regarding sound planning but suggest that the Congress should review its assumptions as to program size and content to see if it agrees with NASA's views on these matters.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

After our study of the Space Shuttle versus expendable systems issue, we are not convinced that the choice should be based principally on cost comparisons. Five other issues have come to our attention which we believe would bear much consideration in deciding this matter. These issues are:

1. Whether the space programs rank sufficiently high among national interests to justify the estimated $8 billion to develop and procure the Space Shuttle. This depends on whether the United States will need and want to make substantial use of space in the years to come--not just to 1990 or 1991 but for the indefinite future. NASA believes that space activities are already recognized as essential continuing needs for both civil and military purposes, that the benefits of space will increase in the future, and that the Nation will continue to support space activities.

2. Whether the value of the new technology that might result from the Space Shuttle Program would justify its selection.

3. Whether the Space Shuttle offers unique capabilities and the kind of flexibility which the U.S. space program should have. NASA believes that it does have unique capabilities--such as the retrieval of unmanned satellites for refurbishment and reuse and the routine use of men in space to enhance scientific research, civil applications, and national security activities and to take advantage of as yet unforeseen opportunities in space--and that these valuable capabilities are one of the important justifications for the Space Shuttle.

   On the other hand, if limited budget resources required an austere future space program, the current expendables may offer more flexibility for the most economical choices among fewer missions.

4. Whether the prestige which the United States might get from development and use of the Shuttle would justify its selection.

5. Whether it is in the national interest to commit the Nation to manned space flight when some think that manned flight is not necessary to achieve scientific objectives and when the space program could be adversely affected by public reaction if lives were lost. NASA's position is that, in addition to its other merits, the Space Shuttle offers the best way to insure a productive capability for manned space flight for the United States.

We do not know what weight should be given to these factors but we wish to bring them out for consideration.

We are not sure that the Space Shuttle is economically justified (is less costly when the time value of money is considered), even though NASA's calculations show that it is. Although there is uncertainty in cost estimates for both Space Shuttle and expendable alternatives, we believe the degree of uncertainty for the Space Shuttle cost estimates is greater than for the expendable systems' estimates. With these differences in the degree of uncertainty in launch system costs, we do not consider it prudent to place too much confidence in the projected cost savings. Technical problems and the cost overruns that usually follow such problems are more likely on the Shuttle and, if they occur, could turn the projected savings into increased costs by 1990. Our findings with respect to nine cost issues involving the space transportation systems appeared in chapter 2. We believe, however, that payload, not launch system, costs are the principal issue when total program costs are concerned and that there may be even greater uncertainty in the estimated costs of payloads. The cost of the payloads and the ultimate worth of the scientific data obtained from these payloads is, we believe, of overriding concern. NASA's April 1973 estimates for the Space Shuttle and the expendables are as follows:

Cost element	Cost of alternative systems		Cost differences
	Space Shuttle	Expendable systems	
	(billions of 1972 dollars)		
Transportation systems	$10.1	$10.4	$ 0.3
Payload systems	30.2	50.1	19.9
Research and development and other	9.9	5.7	-4.2
Total	$50.2	$66.2	$16.0

These figures clearly show that the $19.9 billion difference in payload cost is far more significant than the difference in transportation system costs. This difference is due to NASA's estimates of low-cost design which it believes can be incorporated into Space Shuttle payloads because many manned missions will be used and because payloads will be recovered, refurbished, and reused. Therefore, the controversy over which alternative to choose should be centered on the effect of these alternatives on total mission costs--notably the cost of payloads rather than the absolute cost of the launch system itself. Furthermore, the types and numbers of payloads have a significant bearing on which alternative transportation system is the most economical. This, in turn, is related to the total level of space activity which is used in the analysis.

The most basic difference in the two systems is that the Shuttle is reusable and the expendables are not. Thus, the greater the number of flights, the greater the advantage to a reusable system. Conversely, the fewer the flights, the smaller the advantage of reusability and the more attractive the expendable systems become from a cost point of view. Therefore, if it were decided not to fund some of the missions which NASA is considering in the 779-flight program, it could result in a different choice than might be made if it were decided to accept all of these missions. (Missions planned for the sortie mode could not be performed in the same manner if the Shuttle was not selected. We have not tried to analyze these missions, but we believe and NASA has also indicated that many of them might be performed with a space station and expendable vehicles.)

In response to our comments, NASA states that the payloads represented in the mission model are a logical extension of present activity and that those cost elements for which NASA would have responsibility will fit within an essentially constant budget level. We express no judgments on these points since they deal with questions outside the scope of this work.

So far as we can ascertain, the Congress has not had an opportunity to review these missions in detail. Does the Congress want to fund these missions in lieu of competing Federal programs? Does it believe that the results of the missions will be worth the cost? These questions cannot be fully answered unless the Congress is provided more data on costs associated with payloads and a decision as to which of these payloads are of a high enough priority to use as a basis for current decisions.

RECOMMENDATIONS

To enable the Congress to reach the most prudent decision on the funding of the Space Shuttle or the alternative expendables system, we recommend that the Congress consider the future space missions used in NASA's economic analysis of the Space Shuttle to determine whether these missions are a reasonable basis for space program planning at this time. In addition, we recommend that, as part of the NASA authorization and appropriation process, the Congress review the estimates for the Space Shuttle annually, giving due consideration to the appropriateness of the missions used in making those estimates.

If the Congress chooses to accept our recommendation that it review the proposed space missions and if significant revisions are made, it may be appropriate to direct NASA to reestimate the costs--particularly for payloads--for the Space Shuttle and expendable systems to see whether the relative merits of the alternatives might be significantly affected.

MISSIONS COMPRISING THE

80-MISSION, 581-FLIGHT MISSION MODEL

This appendix summarizes the projected payload costs through 1990 to meet the 80 missions that constituted U.S. requirements for space transportation assumed by NASA and DOD for NASA's March 1972 estimate and used in subsequent Congressional testimony. Of the 80 missions, 52 are NASA missions, 19 are DOD missions, and 9 are to be performed for other Government and non-Government agencies ("other"). Information concerning the classified DOD missions is presented in this appendix only in an aggregate form.

The payload system costs are broken down by major users--NASA, DOD, and others--in figure I-1. Costs are presented for each of the three alternative space transportation systems considered by NASA.

NASA has categorized its 52 missions into 5 space programs. Costs for other users represent costs for another 4 space programs. Costs for the NASA and "other" programs are presented in figure I-2. Costs for individual classified DOD programs are not presented in this appendix.

The allowance for losses shown in figure I-2 is a reliability adjustment which recognizes the expected aggregate cost of payload losses based on past U.S. experience.

The NASA programs are broken down into their constituent missions in figures I-3 through I-7. The "other" programs are broken down into their constituent missions in figures I-8 through I-11.

FIGURE I-1

PAYLOAD COSTS BY MAJOR USERS

Major user	Payload costs associated with alternative space transportation systems		
	Current expendable	New expendable	Space Shuttle
	(billions of 1971 dollars)		
NASA	$18.5	$17.8	$14.6
Other	2.6	2.4	2.0
DOD	12.2	12.0	9.6
Additional costs for expected payload losses--all users	2.0	1.9	.8
Total	$35.3	$34.1	$27.0

FIGURE I-2

TOTAL PAYLOAD COSTS BY SPACE PROGRAM

FOR NASA AND OTHER USERS

	Current expendable systems	New expendable systems	Space Shuttle system	Number of payloads
	(billions of 1971 dollar)			
NASA:				
Physics and astronomy	$ 7.657	$ 7.501	$ 5.594	[a]90
Earth observations	1.996	1.632	1.309	43
Communication and navigation	2.924	2.854	2.408	69
Planetary	2.847	2.733	2.749	21
Space station	3.072	3.072	2.541	38
Total	18.496	17.792	14.601	261
OTHER:				
Communication	.847	.847	.690	58
Navigation	.151	.151	.161	16
Meteorology	.518	.466	.460	24
Earth resources	1.115	.953	.663	30
Total	2.631	2.417	1.974	128
DOD:				
Classified	12.241	12.002	9.614	
Total	12.241	12.002	9.614	
PLUS ALLOWANCE FOR EXPECTED PAYLOAD LOSSES FOR ALL USERS	1.992	1.941	.807	
Total	1.992	1.941	.807	
TOTAL PAYLOAD COST FOR NASA, DOD, AND "OTHER" USERS	$35.360	$34.152	$26.996	

[a]Applies to the expendables; the 581-flight Space Shuttle mission model would include only 81.

FIGURE I-3

NASA's REPRESENTATIVE PHYSICS AND

ASTRONOMY PROGRAM: 1979-90

Mission designation	Mission objective	Total payload cost if transported by: Current expendable system	New expendable system	Space Shuttle system
		(million of 1971 dollars)		
Astronomy Explorer	Independent investigations of solar and stellar behavior in the ultraviolet, x-ray, and radio spectral regions. Not part of observatory.	$ 402	$ 402	$ 308
Radio Explorer	Same as above.	313	313	265
Lower Magnetosphere	To conduct investigations of the environment of the lower magnetosphere, neutral air chemistry and density and ionospheric behavior.	340	340	252
Middle Magnetosphere	To measure ionospheric current systems and behavior with respect to solar activity, also neutral atmospheric studies.	334	287	247
Upper Magnetosphere	To monitor space weather and the boundary of the geomagnetic field as it interacts with the solar wind.	329	289	264
Orbiting Solar Observatory	Monitor temporal variations of the sun's brightness in the ultraviolet, x-ray, and gamma-ray regions.	56	44	41
General Relativity A-B	To experimentally test Einstein's general relativity theory. Gyroscopes in an earth-orbiting satellite will experience two relativistic precision effects.	226	169	147
Radio Inter, ferometer	To measure radio spectra and radio diameter of space objects, also velocities.	409	409	409
Solar Orbiter A-B	To monitor all the solar sphere simultaneously and to continuously provide information on flares, sunspots, and solar wind.	278	277	277
Optical Inter-ferometer A-B	To measure stellar diameters and infrared spectra. This is achieved by using two spacecraft, A and B.	265	265	265
High Energy Astronomy Observatory	To perform a survey of the celestial sphere with primary emphasis on the galactic belt region. Secondary objective is pointing at specific celestial target.	1,554	1,554	1,079
Large Stellar Telescope	Extent space astronomy capability to diffraction limited 3 m diameter optical technology. High resolution spectronomy and imaging of planetary bodies.	1,092	1,093	650
Large Solar Observatory	Conduct high resolution visual and ultraviolet studies of solar granular structure and areas of high solar activities. Continue ultraviolet and x-ray observations with higher spatial and spectral resolutions (man maintenance).	1,240	1,240	780
Large Radio Observatory	Understand physical processes in the solar corona and in the magentosphere of the planets, especially Jupiter and Earth.	819	819	610
	Total payload cost	$7,657	$7,501	$5,594

FIGURE I-4

NASA's REPRESENTATIVE

EARTH OBSERVATIONS PROGRAM: 1979-90

Mission designation	Mission objective	Total payload cost if transported by: Current expendable system	New expendable system	Space Shuttle system
		—(millions of 1971 dollars)—		
Polar Earth Observation Satellite	To design, develop, and operate a space observatory system to perform meteorological and earth resources surveying by advanced remote sensing techniques.	$ 782	$ 636	$ 461
Synchronous Earth Observation	Research satellite to investigate and develop remote sensing techniques for measurement of the earth's surface and atmosphere from synchronous altitude.	282	226	187
Earth Physics Satellite	To make precision measurements of the earth's land and sea areas to determine (1) continental drift, (2) mass distribution, (3) surface strain, and (4) variation of gravity, sea altitude, and mass.	223	189	155
Synchronous Meteorological Satellite	Develop and operate a synchronous meteorological satellite for Department of Commerce's Environment, Science, and Service Administration.	119	93	83
Tiros	System demonstration of the 4th-generation series of operational meteorological satellite for Department of Commerce's Environment, Science, and Service Administration.	57	57	68
Polar Earth Resources Satellite	To design, develop, and operate a space observatory system to perform meteorological and earth resources surveying by advanced remote sensing techniques.	317	260	223
Synchronous Earth Resources Satellite	To design, develop, and a operate satellite system for remote sensing of the earth's surface and the lower regions of the atmosphere from synchronous orbital altitudes.	216	171	132
	Total payload cost	$1,996	$1,632	$1,309

FIGURE I-5

NASA'S REPRESENTATIVE
COMMUNICATION AND NAVIGATION
PROGRAM: 1979-90

Mission designation	Mission objective	Total payload cost if transported by: Current expendable system	New expendable system	Space Shuttle system
		—(millions of 1971 dollars)—		
Application Technology Satellite	Earth to geo-stationary orbit communication power, high gain multi-beam satellite antenna, general application technology (meteorology, earth observations, etc.)	$ 976	$ 976	$ 761
Small Applications Satellite A-B	To design, develop, launch, and operate a series of small research and development satellites for the experimental application of research and technology developments in spacecraft and sensor subsystems.	865	797	725
Cooperative Applications A-B	Communications satellites to be flown in partnership with other nations which will provide corresponding technical and funding assistance.	95	93	94
Medical Network Satellite	Facilitate applications of space technology and satellite systems for medical data transmission purposes.	95	95	95
Education Broadcast	Facilitate applications of space technology and satellite systems for educational broadcast purposes.	122	122	122
Follow-on Systems Demonstration	System demonstration satellites for law enforcement, air traffic control, land traffic control type missions.	621	621	471
Tracking and Data Relay	Develop and operate a command, tracking, and data relay of low orbiting satellite from synchronous satellite to a few centrally located mission control centers.	150	150	140
Total payload cost		$2,924	$2,854	$2,408

FIGURE I-6

NASA'S REPRESENTATIVE

PLANETARY PROGRAM: 1979-90

Mission designation	Mission objective	Total payload cost if transported by Current expendable system	New expendable system	Space Shuttle system
		(millions of 1971 dollars)		
Mars Viking	To provide information regarding the possible existence and nature of life on Mars, the atmospheric and surface characteristics of the planet, and the nature of the planetary environment.	$ 331	$ 331	$ 331
Mars Sample Return Lander--A	The exploration of Mars and the return of physical samples of the planetary surface to earth. Orbiter/Bus vehicle.	374	374	374
Mars Sample Return Lander--B	The exploration of Mars and the return of physical samples of the planetary surface to earth. Lander/return probe.	349	349	349
Venus Explorer Orbiter	Measure planet magnetosphere, magnetosheath, detached bow shock wave, and tail and wake region. Investigate internal composition, structure, and magnetic field.	90	77	71
Venus Radar Mapping	Detailed surface mapping of Venus to a resolution of 50 meters, using radar imaging.	210	184	210
Venus Explorer Lander--1st	Analysis of surface properties and environment on Venus. Measurement of atmospheric properties during descent, surface mapping by orbiter.	208	184	168
Venus Explorer Lander--2nd	Orbiting microwave and infrared spectral instruments for surface, atmosphere, and cloud studies. Landed seismometer, x-ray diffraction, composition measurement, environmental dynamics.	195	170	156
Jupiter Pioneer	Measure particles and field environment to 5 AU, particle density of asteriod belt, magnetic and radiation fields of Jupiter, and provide Jupiter imaging.	135	110	135
Grand Tour	Obtain first, general flyby data of Uranus and Neptune. Correlate spatial effects in cosmic flux and solar wind with JSP mission.	181	181	181
Jupiter Top Orbiter/ Probe	Monitor particles and field environment, measure ring composition, and atmospheric characteristics and profiles.	204	204	204
Uranus Tops Orbiter/ Probe	Mapping, composition analysis, and time dependent measurements of the atmosphere. Determine the extent and intensity of planetary fields.	219	218	219
Asteroid Survey	Define micrometeoroid, particle, and field environment in asteriod belt. Prove solar electric propulsion over long duration.	113	113	113
Comet Rendezvous	Close-range, long-duration examination of comet. Determine physical state, structure, composition, and mode of interaction with the interplanetary environment.	238	238	238
	Total payload cost	$2,847	$2,733	$2,749

FIGURE I-7

NASA'S REPRESENTATIVE

SPACE STATION SUPPORT

PROGRAM: 1979-90

Mission designation	Mission objective	Total payload cost if transported by: Current expendable system	New expendable system	Space Shuttle system
		(millions of 1971 dollars)		
Space Station	Long-term manned space operations.			
Space Station--Crew/Cargo	Support the logistics requirements of the integral space station as documented in NASA document MSFC DRL-160 (Contract NAS8-25140).	$2,322	$2,322	$1,903
Physics Lab	Support of earth survey, materials sciences lab, fluid physics lab, and remote maneuvering unit experiments.	210	210	210
Life Science Lab	Support of x-ray, stellar, solar, high-energy stellar, material science and processing, and space biology experiments.	201	201	150
Earth Observation Lab	Support of x-ray, stellar, solar, high-energy stellar, material science and processing, and space biology experiments.	203	203	180
Comm/Nav Lab	Support of earth survey, materials sciences lab, physics lab, and remote maneuvering unit experiments.	136	136	98
	Total payload cost	$3,072	$3,072	$2,541

FIGURE I-8

REPRESENTATIVE "OTHER"

COMMUNICATION PROGRAM: 1979-90

Mission designation	Mission objective	Total payload cost if transported by: Current expendable system	New expendable system	Space Shuttle system
		—(millions of 1971 dollars)—		
Communication Satellite	Provide operational services in information networks navigation.	$117	$117	$113
U.S. Domestic Communication	Provide operational services in communication networks, cable TV, broadcast TV, radio, telephone, teletype, etc.	394	394	315
Foreign Domestic Communication	Provide operational services in communication networks for South America, Canada, Australia, European Space Resource Organization, South Africa, India, and neighboring countries.	336	336	262
	Total payload cost	$847	$847	$690

FIGURE I-9

REPRESENTATIVE "OTHER"

NAVIGATION PROGRAM: 1979-90

Mission designation	Mission objective	Total payload cost if transported by: Current expendable system	New expendable system	Space Shuttle system
		——(millions of 1971 dollars)——		
Navigation Traffic Control--A	Data collection satellite to gather data from remote mobile platform and scattered transmitters and centralize the outputs into a common data center.	$ 97	$ 97	$104
Navigation Traffic Control--B	Navigation data over oceans and domestic areas.	54	54	57
	Total payload cost	$151	$151	$161

FIGURE I-10

REPRESENTATIVE "OTHER"

METEOROLOGY PROGRAM: 1979-90

Mission designation	Mission objective	Total payload cost if transported by: Current expendable system	New expendable system	Space Shuttle program
		(millions of 1971 dollars)		
TOS Meteorological Satellite	Observe global clouds, day and night, cloud top heights, heat balance, vertical temperatures, and water vapor profiles.	$248	$248	$222
Synchronous Meteorological	Operational meteorological satellite operating from synchronous altitude for Enviromental Science and Service Administration.	270	218	238
	Total payload costs	$518	$466	$460

FIGURE I-11

REPRESENTATIVE "OTHER"

EARTH RESOURCES PROGRAM: 1979-90

Mission designation	Mission objective	Total payload cost if transported by: Current expendable system	New expendable system	Space Shuttle program
		(millions of 1971 dollars)		
Polar Earth Resources	Operational satellite to continually survey earth resources and to perform meteorological survey with high resolution sensor and transmitting data to earth.	$ 881	$719	$453
Synchronous Earth Resources	Operational remote sensing and measurement of the earth's resources and lower atmosphere.	234	234	210
	Total payload cost	$1,115	$953	$663

ADDITIONAL UNREVIEWED

DATA SUBMITTED BY NASA

This appendix summarizes information supplied by NASA on or after April 27, 1973, which we were unable to review before publishing this report. We are including this information in our report in accordance with NASA's request.

1. Funding data

NASA advised us on April 27, 1973, that they had prepared different estimates of annual funding requirements for the 581-flight schedule of the Shuttle. These are included in figure II-1. The estimates show that funding would exceed $3.4 billion only in fiscal year 1978 and only by $5 million. In figure 4-1 (ch. 4) we show the funding requirements that we had accumulated for the same program.

2. Costs for NASA's 1973 mission model--581-flight version

The data shown in table II-1, which was supplied to us on May 21, 1973, summarizes NASA's estimates of costs for 581 flights using their 1973 mission model and payload mix including sortie missions as a basis.

Table II-1

581 Flight Version of 779 Flight
1973 Mission Model
Summary Cost Comparison

	Current expendable	Shuttle system	Benefits
	(billions of 1972 dollars)		
Payload	$41.2	$27.5	$13.7
Transportation	8.5	8.3	.2
Nondistributed	5.0	9.3	-4.3
Total	$54.7	$45.1	$ 9.6

3. NASA's discounted life cycle costs for its April 1973 mission model

NASA's estimate of life cycle costs for two versions of its 1973 mission model are shown in table II-2. The basic model is planned to use 779 Space Shuttle flights. NASA also provided an estimate for comparative purposes using the 1973 mission concepts, including sortie missions, but limited to 581 flights.

Table II-2

LIFE CYCLE COSTS OF ALTERNATIVES

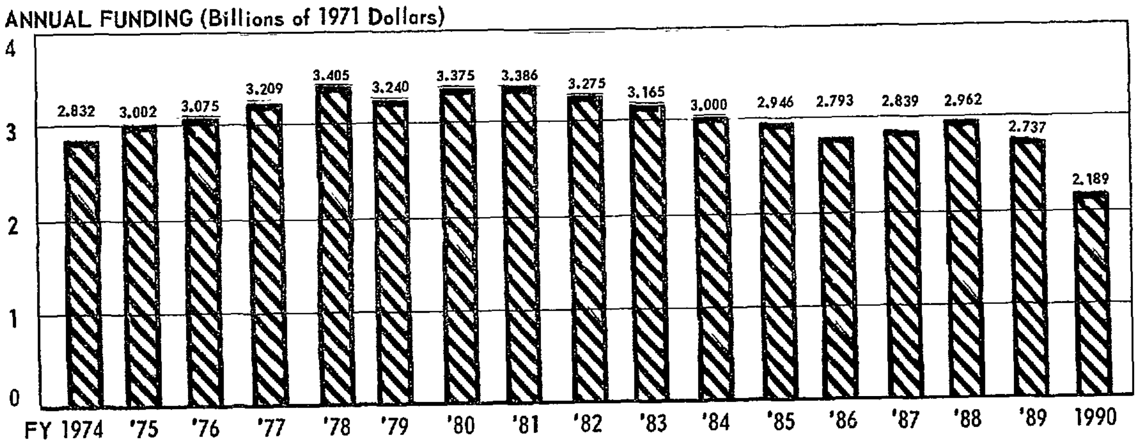
OVER VARIOUS TIME PERIODS

CONSIDERING THE TIME VALUE OF MONEY

	Current expendable	Space Shuttle
	(billions of 1972 dollars)	
1973 mission model--779 flights:		
Life-cycle costs (NASA estimates):		
To 1990	$ 61.0	$ 46.4
To 2000	110.6	77.2
To 2020	209.6	138.9
Above discounted at 10 percent:		
To 1990	16.8	14.4
To 2000	21.3	17.2
To 2020	23.8	19.1
581-flight version of 1973 mission model:		
Life-cycle costs (NASA estimates):		
To 1990	50.4	41.8
To 2000	90.2	68.8
To 2020	170.0	122.9
Above discounted at 10 percent:		
To 1990	14.1	13.4
To 2000	17.8	15.9
To 2020	19.7	17.2

FIGURE II - 1

NASA's ANNUAL FUNDING REQUIREMENTS INCLUDING THE SPACE SHUTTLE PROGRAM



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

OFFICE OF THE ADMINISTRATOR

May 21, 1973

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

Dear Mr. Staats:

I am forwarding my comments on the draft of the proposed GAO Report "Analysis of Cost Estimates for the Space Shuttle and Two Alternate Programs," received on the afternoon of May 19, 1973.

The GAO conclusions list five broad issues that are seen to surround the shuttle and to loom larger than do comparative cost considerations. These issues do indeed exist and both outweigh and shape the economics. We favor the sense of the GAO recommendation that Congress examine the models of future space mission programs to check their appropriateness as representative, for planning purposes, of what the nation will do in space in the time period of the Eighties and beyond.

To hold that the primary justification for the shuttle is not an economic one is not, however, to imply that economic and budgetary issues are to be submerged, and they have consequently been the object of study by the NASA and GAO. We believe that NASA's economic models have erred, if at all, on the side of conservatism; and that this is more true today than when the shuttle was approved in early 1972. We also believe that the NASA program can be conducted within the overall NASA budget level that prevailed when the shuttle was approved - as the GAO tables indicate.

In the GAO chapter on economic comparisons,[1] we believe that the GAO approach is an unfortunate one in limiting attention to a narrow question of sensitivity analysis (and by a methodology which we believe to be questionable) rather than dealing with a matter of fundamental importance on which the GAO is very well qualified to speak, namely the proper social rate of discount to use. Indeed, if one employs, in place of the ten percent annual discount rate, lower rates for which there is excellent economic support, the favorable effects on indicated shuttle economics are very great. (NASA has viewed the ten percent rate as a part of its overall conservative approach, as mentioned earlier.)

The GAO has studied various aspects of shuttle costs and has expressed a finding of uncertainty in the shuttle cost picture, citing, in support of this, the history of cost performance in various DOD weapons systems, a general feeling of uncertainty as to future payload costs, and a modest list of specific areas wherein questions are raised.

General doubts about cost will always exist in large novel systems; however, after a considerable amount of work, GAO has not found any evidence of substance to lend flesh to their doubts with respect to the shuttle; and they have been silent in regard to the large benefit-of-the-doubt that NASA gave to the alternative launchers so as to follow, as stated earlier, a conservative approach to the economic justification of the shuttle. GAO's set of specific complaints about various features of the shuttle cost estimate are, in our view, essentially baseless; and I am appending hereto a series of comments on these items in which we summarize our contrary beliefs.

We also do not accept the idea that since various large systems in the past have cost more than estimated, the space shuttle economics are accordingly somehow suspect. NASA brought in the Apollo program - one of the most complex development programs ever undertaken - without overrun.

[1] The section on cost-per-pound also appearing in this chapter will only further confuse the man-in-the-street; and, of course, has no place in rigorous cost-benefit-analysis. We completely disagree with what is said in this section because of questionable assumptions about the costs of expendables and the proper method for including development costs of each system considered.

At the time shuttle costs were firmed up in early 1972, the background of study, design, and engineering was already greater than for most development programs; this started the program off on a sound basis. NASA included in its estimates sufficient funding to meet contingencies, normal design changes, etc. which are inherent in advanced development programs. Last summer the development contract was let for the orbiter, the key element, and since that time designs have become more firm and the previous cost estimates have held up well. Normally, when cost overruns do occur in a development, this becomes evident during such a period as we have been through, and this has not been the case with the shuttle. In short, NASA has given the shuttle estimate a thorough treatment. I am personally committed to the result.

Given an appropriate continuity of development funding, we shall bring the shuttle in within the estimate. In any event, with the large magnitude of the benefits projected, overrun does not pose a palpable threat to shuttle economics. In other words, there is no way that we can see for shuttle costs to erase shuttle savings, as apparently feared by GAO.

The GAO finally infers in various ways that if we do not know precisely what space missions are to be flown in the Eighties or Nineties, then there are serious uncertainties as to the worth of the shuttle - in other words, the impression is conveyed that the cost-benefit situation is extremely sensitive to mission assumptions.

We believe that this idea is incorrect. Of course, one cannot tell, precisely, all the scientific, military, applications, and other missions we shall want to fly in the Eighties or Nineties, but we know the kinds of operations involved. In this circumstance, sound planning requires (1) that set or sets of space missions, or so-called mission models properly represent the kind of program the nation can reasonably expect to do in space in the future; (2) that it is a program that appears to be acceptable in overall size; and (3) that the mission models are not unduly sensitive to size or content of the programs. NASA mission models meet such conditions.

Sincerely,

James C. Fletcher
Administrator

Enclosure

NASA COMMENTS ON CHAPTER 2 OF GAO DRAFT REPORT "ANALYSIS OF COST ESTIMATES FOR THE SPACE SHUTTLE PROGRAM"

1. Are Five Orbiters Enough? The answer is yes. Three Orbiters are adequate to perform the mission model; NASA has provided two additional orbiters to provide flexibility. Also, the contingency in the procurement estimate is adequate to procure another orbiter without additional funds should a loss occur.

2. Overlooked Cost. GAO has identified two areas of "overlooked" shuttle costs which amount to between $102M and $158M. The GAO staff also identified $300M of overlooked Shuttle benefits which were not included by NASA and were omitted from the GAO report. [See GAO note.]

3. Drop Tank Costs. The GAO contends, without any proof, that the cost per tank could be substantially higher, perhaps as much as 100% over NASA's current estimate. We strongly disagree. Because of the great importance of the drop tank in the entire space shuttle system our drop tank design effort, and especially our analysis of drop tank costs, has been more extensively done than almost any other part of the shuttle. As a result of all of this work, we find that the drop tank costs, as used in the 1972 estimate, are probably overstated, and that actual drop tank costs will prove to be below those used in our cost analyses.

4. Contractor Engineering Support. NASA has demonstrated to GAO that the shuttle estimates contain funding for engineering support in excess of historical experience on analogous systems.

5. Reuse of Solid Rockets. A valid point in the event the so-called new expendable systems were to be given detailed attention (see item 9).

6. Space Shuttle Launch Operations and Maintenance. The GAO report contends that the shuttle launch costs are optimistic when compared with existing systems. NASA

GAO note: These items were inadvertently omitted from the draft sent to NASA for comment but are included in this report.

has provided detailed support and explanations for the derivation of the launch cost estimate. There are indications that the GAO assessment is based on error in analysis of both C5A and shuttle manpower data.

7. Indirect Range Support Costs. No Comment.

8. Effect on Costs of Launch Reliability Assumptions. NASA disagrees with the GAO finding on reliability because it contradicts experience. NASA's long experience with both manned and unmanned launch vehicles has fully demonstrated one point: reliability must be designed and built into the vehicle and cannot be attained merely by flying more and more vehicles. Thus the Titan II used in Gemini and the Saturn launch vehicles used in Apollo achieved their very high reliability (much higher than any unmanned launch vehicles) through the design of highly reliable redundant systems and subsystems. The space shuttle is designed with these same principles. The competitive expendable systems are not. Therefore, the expendable systems could only begin to approach the reliability of the space shuttle (independent of the number of launches) if they were redesigned and if appropriate reliability features were added. This could be done, but it would be expensive. The GAO did not include the costs for such reliability improvement of the expendable systems in their cost analyses.

9. Understatement of R&D Costs for Expendable Systems. Although the GAO report recognizes NASA views on the new expendable family of launch vehicles, the impression remains that this launch system is a strong contender for the most effective space transportation system. It should be emphasized again that the new expendable was an economic screening benchmark favored with optimistic cost assumptions which did not win a competition with the shuttle. NASA did not pursue this alternative since it was apparent that more detailed study would lead to increased cost for an already noncompetitive option.

PRINCIPAL OFFICIALS OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION RESPONSIBLE FOR THE ACTIVITIES DISCUSSED IN THIS REPORT

	Tenure of Office From	To
Administrator:		
James C. Fletcher	Apr. 1971	Present
Deputy Administrator:		
George M. Low	Dec. 1969	Present
Associate Administrator:		
Homer E. Newell	Oct. 1967	Present
Comptroller:		
William E. Lilly	Feb. 1967	Present
Associate Administrators for Manned Space Flight:		
Dale D. Myers	Jan. 1970	Present
Charles W. Mathews	Dec. 1969	Present
Director, Shuttle Program:		
Myron S. Malkin	Apr. 1973	Present

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