REPORT TO THE CONGRESS

Cost-Benefit Analysis Used In Support Of The Space Shuttle Program B-173677

National Aeronautics and Space Administration

BY THE COMPTROLLER GENERAL OF THE UNITED STATES

JUNE 2, 1972

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

B-173677

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

This is our report on the cost-benefit analysis used in support of the Space Shuttle Program 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

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DIGEST

WHY THE REVIEW WAS MADE

Senator Walter F. Mondale requested that the General Accounting Office (GAO) review the cost-benefit analysis used by the National Aeronautics and Space Administration (NASA) in support of the Space Shuttle Program announced in January 1972. With the Senator's agreement, this report is being released to the Congress in view of widespread interest in the space shuttle.

RESULTS OF REVIEW

NASA has proposed that a space shuttle be developed for U.S. space transportation needs for NASA, the Department of Defense (DOD), and other users in the 1980's. (See p. 7.)

The primary objective of the Space Shuttle Program is to provide a new space transportation capability that will (1) reduce substantially the cost of space operations and (2) provide a future capability designed to support a wide range of scientific, defense, and commercial uses. (See p. 7.)

The space shuttle will be the first space vehicle that can be used again and again. It will be boosted into space through the simultaneous operation of its solid-propellant booster engines and its orbiter-stage, high-pressure, liquid oxygen-liquid hydrogen main engines. The booster rockets will detach at an altitude of about 25 miles and descend into the ocean to be recovered and reused. The orbiter, under its own power, will continue into low earth orbit. The orbiter will look like a delta-winged airplane and will have a crew of four--pilot, copilot, and two specialists--who will fly it back to earth for an airplane-like landing. (See p. 7.)

The orbiter will have a cargo compartment measuring about 60 feet in length and 15 feet in diameter. It will be able to place 65,000 pounds in a 100-nautical-mile due east orbit and 40,000 pounds in a polar orbit. Propulsive stages (tugs) will be used to propel satellites into higher orbits or to achieve escape velocity. (See p. 8.)

NASA analysis

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NASA contracted with Mathematica, Incorporated, for an analysis of how economical the shuttle would be compared with expendable launch systems. (See p. 14.) Mathematica was directly supported by analyses conducted by

Tear Sheet

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The Aerospace Corporation and the Lockheed Missile and Space Company. (See p. 15.) This team used the results of numerous studies concerning space transportation systems and payloads for the 1979-90 period. (See p. 14.)

These analyses were based on a comparison of estimated total space program costs for three alternative space transportation systems.

--The current expendable system.

--The new expendable system.

--The space shuttle system. (See p. 14.)

"Total space program cost" was defined by Mathematica as the sum of (1) launch system life-cycle costs and (2) payload system life-cycle costs. (See p. 14.)

During these analyses, the shuttle was evaluated only in terms of those capabilities common to the three alternative space transportation systems identified. Additional benefits and options that a reusable system might offer were not considered in the analyses. (See p. 14.)

For these analyses NASA and DOD postulated space missions involving different numbers of flights during the 1979-90 period. The studies estimated the costs and other economic characteristics expected for each of the three alternative space transportation systems in performing these missions. (See p. 15.)

GAO analysis

The primary focus of GAO's analysis was the study by Mathematica. NASA and Mathematica officials stated that this study demonstrated the shuttle to be economically justified. (See p. 7.)

GAO examined into the economics of the Space Shuttle Program on the basis of a comparison of estimated total space program costs for the shuttle and the current expendable system. Although the estimated cost of the new expendable system was lower than the cost of the current expendable system, GAO did not consider it in the study because of the (1) uncertainty in cost estimates for any new class of systems, including this one, and (2) lack of time to review the new expendable launch system estimates. (See p. 22.)

GAO did not make an independent cost-benefit analysis of the Space Shuttle Program. GAO worked with estimates received from Mathematica for two representative configurations of the space shuttle--one a reusable solid booster shuttle and the other a reusable liquid booster shuttle. (See p. 11.) GAO did not analyze NASA's March 1972 estimate for the Space Shuttle Program. (See p. 11.) The following table shows the life-cycle (development, procurement, and 12-year operations) costs for the NASA estimate and the two representative configurations from Mathematica. (See p. 34.)

	NASA's March 1972 estimate	Mathematica's cases Solid booster	Liquid booster
	(billions--1971 dollars)		
Expected launch vehicle costs	$16.1	$14.6	$14.2
Expected payload costs	26.8	26.8	26.8
Expected total space program costs	$42.9	$41.4	$41.0

GAO made no judgment about the economic worth of the payloads for which the shuttle or expendable systems would be used. (See p. 12.)

On the basis of reviews of the supporting studies, GAO identified critical areas of uncertainty in the estimated total space program costs received from Mathematica for the two identified shuttles. "Critical areas" are defined as assumptions and/or study elements that influenced significantly the estimated total space program costs. Whenever there is uncertainty in a critical area, it is possible to establish the upper and lower boundaries of the estimate and hence the ranges of cost uncertainty. These ranges were determined by assessing technological or operational uncertainty. (See p. 21.)

GAO made computations using NASA's cost model developed by Mathematica to show the effect of increasing or decreasing selected critical areas within their plausible boundaries. (See p. 18.) Although GAO's review treated each critical area separately, this should not be construed as implying that variations may not occur in several of these areas as the Space Shuttle Program progresses. (See p. 21.)

For example, changes in both payload refurbishment costs and launch system cost could occur during the program's life cycle. According to a recent study, the cost of acquiring major systems has generally increased an average 40 percent after adjustment for quantity changes and inflation. (See p. 24.)

GAO found that the two configurations were economically justified in terms of the 10-percent investment criterion proposed by Mathematica as the basis for evaluating the Space Shuttle Program. This justification assumes that these configurations would be developed, procured, and operated as presented to GAO by Mathematica. GAO identified the following cost increases over the Mathematica estimates as the points at which the two configurations would no longer realize the savings required to meet the 10-percent investment criterion.

Critical area considered	Important conditions	Cost increase allowable (note a)	Chapter reference
Launch system life-cycle costs:	514 flights, 1970 dollars		
Solid booster configuration		25%	4
Liquid booster configuration		20	4
Number of flights:	624 flights, 1970 dollars		
Either configuration		30	5
NASA program changes:	581 flights, 1971 dollars 1985 space station, space tug		
Either configuration		20	6
Operating cost per launch:	514 flights, 1970 dollars		
Either configuration		75	7
Payload retrieval or refurbishment costs:	514 flights, 1970 dollars		
Either configuration		150	8
Range of contractors' estimate given GAO:	514 flights, 1970 dollars		
Solid booster		(b,c)	9
Liquid booster		(d,c)	9
Combinations of the above	None	(e)	-

[a]All other factors held constant.

[b]Highest.

[c]Each contractor very likely developed several estimates prior to submitting its estimate to NASA. Estimates furnished to GAO were not necessarily the highest estimates.

[d]All except highest.

[e]Not determined.

Note: These limits would be reduced if the increases occurred in combination rather than individually.

RECOMMENDATIONS AND CONCLUSIONS

None.

AGENCY COMMENTS AND UNRESOLVED ISSUES

NASA generally agreed with the approach used by GAO in assessing the effects on the economics of the Space Shuttle Program of changes in the cost and mission assumptions used in Mathematica's analysis. NASA stated, however, that the 10-percent investment criterion used by it and by Mathematica was a conservative base point for the economic analysis and was not a decision criterion for proceeding with the Space Shuttle Program. In addition, NASA stated that development of the shuttle would be justified even if NASA had not been able to demonstrate that the shuttle would have a substantial economic return, because of the additional benefits and options that would come with the development of the shuttle. (See p. 12.)

MATTERS FOR CONSIDERATION BY THE CONGRESS

This report should be helpful to the Congress in considering the economic justification for the Space Shuttle Program.

CHAPTER 1

INTRODUCTION

Responding to Senator Walter F. Mondale's February 1972 request, we have reviewed the cost-benefit analysis used by the National Aeronautics and Space Administration in support of the Space Shuttle Program. This analysis was made by Mathematica, Incorporated, of Princeton Junction, New Jersey; its final report was issued on January 31, 1972. The Mathematica analysis is discussed in chapter 2.

Senator Mondale requested that GAO's review include, but not be limited to:

1. Identifying the processes used in making the estimates of the economics of the program.

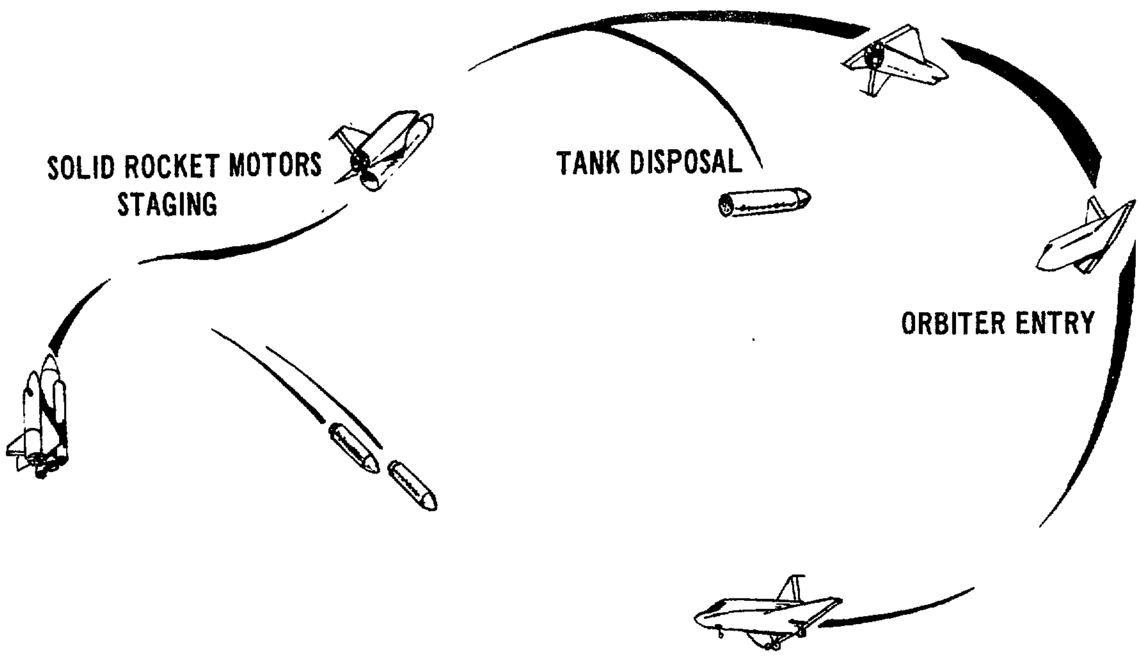
2. Identifying the organizations involved in the processes and the supporting analyses for the estimates.

3. Identifying the significant assumptions and other study elements influencing the estimates.

4. Establishing the ranges of possible effects on the economics of the program due to uncertainties in the significant assumptions and critical study elements.

NASA has proposed that a space shuttle be developed for U.S. space transportation needs for NASA, DOD, and other users in the 1980's. The primary objective of the Space Shuttle Program is to provide a new space transportation capability that will (1) reduce substantially the cost of space operations and (2) provide a future capability designed to support a wide range of scientific, defense, and commercial uses.

The space shuttle is intended to be the first reusable space vehicle. It will be boosted into space through the simultaneous operation (parallel burn) of its solid-propellant booster engines and its orbiter-stage, high-pressure, liquid oxygen-liquid hydrogen main engines. The booster rockets will detach at an altitude of about 25 miles and descend into the ocean to be recovered and reused. The orbiter, under its own power, will continue into low earth orbit. The orbiter will look like a delta-winged airplane and will have a crew of four--pilot, copilot, and two specialists--who will fly it back to earth for an airplane-like landing. A pictorial profile of a shuttle mission is shown below.



The shuttle is intended to place satellites in orbit, retrieve satellites from orbit, permit in-orbit repair and servicing of satellites, deliver propulsive stages (tugs) and satellites to low earth orbit, and conduct short-duration science and applications missions with self-contained experiments in low earth orbit. The orbiter will have a cargo compartment measuring about 60 feet in length and 15 feet in diameter. It will be able to place 65,000 pounds in a 100-nautical-mile due-east orbit and 40,000 pounds in a 100-nautical-mile polar orbit. At lower payload weights the shuttle will be able to deliver satellites to higher orbits. The tug will be used to propel satellites beyond the shuttle's direct-delivery capability, e.g., synchronous orbit and escape velocities.

NASA announced the space shuttle configuration described above in March 1972. At that time NASA issued a request for proposals for developing this configuration of the shuttle.

EVOLUTION OF SPACE SHUTTLE CONFIGURATIONS

NASA's issuance of the request for proposals marked the end of a series of definition and preliminary design studies. These studies represented the second phase of NASA's four-phase approach to the planning, approval, and conduct of major research and development programs. The four phases were:

Phase A	Preliminary analysis
Phase B	Definition
Phase C	Design
Phase D	Development-operations

Initially NASA studied a two-stage fully reusable space shuttle configuration. Two teams of contractors made these studies under simultaneous 11-month contracts. These teams, referred to as phase B contractors, were headed by the North American Rockwell Corporation, Los Angeles, California, and the McDonnell Douglas Corporation, St. Louis, Missouri.

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

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

During the fiscal year 1973 budget hearings, NASA testified that this fully reusable system would have maximum payload flexibility and would provide the least costly operational space transportation system.

The annual and peak-year funding required during research and development, however, were relatively high, and so NASA extended the phase B definition studies to cover new configurations which could be developed within the peak-year-funding constraints anticipated through the coming decade.

During the early stages of the phase B extension studies, NASA found that the use of expendable hydrogen tanks, rather than nonexpendable propellant tanks located in the orbiter, yielded a system requiring lower development costs. This system became NASA's baseline orbiter system. Since this system required higher operational costs, the studies for lower cost systems continued. By removing both the liquid oxygen and liquid hydrogen from within the orbiter, a much smaller, low-cost orbiter with a single, expendable, combined-propellant tank was devised.

Continued studies showed that the shuttle configuration should utilize a solid rocket motor booster or a liquid pump-fed or a pressure-fed booster. All of these boosters could be used with a delta-winged orbiter powered by three new high-pressure engines and fueled from an external hydrogen-oxygen tank. On March 15, 1972, NASA announced that solid rocket motors will be used to boost the orbiter into space. These motors will burn simultaneously with the liquid oxygen-liquid hydrogen engines of the orbiter. This decision was based on the lower cost and lower technical risks shown as a result of the studies of the solid rocket system.

SCOPE OF GAO'S REVIEW

The subject of our review was the economic analysis by Mathematica and funded by NASA. Mathematica's analysis was supported directly by two other contractors--the Lockheed Missiles and Space Company, Sunnyvale, California, in its Payload Effects Analysis, and The Aerospace Corporation, El Segundo, California, in its Integrated Operations-Payload Fleet Analysis. In addition to using data received from Lockheed and The Aerospace Corporation, Mathematica used the reports of various hardware contractors that had been studying the development and estimating the costs of the space shuttle.

We made our review at Mathematica's headquarters in Princeton Junction and at NASA's headquarters in Washington, D.C. We also visited Lockheed and The Aerospace Corporation where we discussed with cognizant officials the data base, methods, and assumptions used in the analysis and examined records and documents related to the analysis.

We did not conduct an independent cost-benefit analysis of the Space Shuttle Program. We worked with estimates received from Mathematica but did not analyze NASA's March 1972 estimate. All of our statements concerning the economic justification of the program are based on only the estimates provided by Mathematica.

We intended to examine into the data base, methods, and assumptions used by various hardware contractors that had been studying the development and estimating the costs of the space shuttle. The Aerospace Corporation and Mathematica used many of these contractors' final reports. At the time of our review, however, these contractors were involved in preparing responses to NASA's March 17, 1972, request for proposals for developing the space shuttle and consequently could not make their records and staff available to us. We therefore confined our review to the final reports submitted to Mathematica by these companies.

As a part of our review, we examined into the sensitivity of the Space Shuttle Program's economic justification to critical areas of uncertainty in the supporting studies. This is referred to as <u>sensitivity analyses</u>. We considered as critical areas those areas wherein the ranges of cost uncertainty would have significant influences on the economic justification of the program.

We did not conduct sensitivity analyses of all aspects of the program. We limited our analyses to those areas of uncertainty identifiable and quantifiable from the reports used as inputs to Mathematica's analysis and from the general body of literature concerned with cost overruns for major systems. Although we believe that we have quantified some of the most significant areas, other areas of significant uncertainty may exist that could change the observations discussed in this report. We made no judgment about the economic worth of the payloads for which the shuttle or expendable systems would be used.

AGENCY COMMENTS AND OUR EVALUATION

NASA generally agreed with the approach used by GAO in assessing the effects on the economics of the Space Shuttle Program of changes in the cost and mission assumptions used in Mathematica's analysis. NASA stated, however, that the 10-percent investment criterion used by it and by Mathematica was a conservative base point for the economic analysis and was not a decision criterion for proceeding with the Space Shuttle Program.

Our analysis was based on the economic analysis made by Mathematica. Mathematica proposed the use of the 10-percent investment criterion for evaluating the economic justification of the program. In addition, the Office of Management and Budget Circular No. A-94, effective March 1, 1972, prescribes that a standard 10-percent discount rate (rate of return) be used to evaluate such programs as the Space Shuttle Program.

NASA stated that development of the shuttle would be justified even if NASA had not been able to demonstrate the substantial economic return indicated in Mathematica's report. NASA stated also that the shuttle would provide additional benefits and options which could not be measured and which were not included in Mathematica's analysis. In its comments NASA listed several examples of additional benefits and options.

We have noted that there may be other benefits and options that a reusable space shuttle can offer the Nation and that these benefits and options were not treated in Mathematica's analysis. Since our review was directly related to Mathematica's analysis, we have not reviewed the basis for NASA's assertions concerning these additional benefits and options and can not take a position regarding their validity.

CHAPTER 2

COST-BENEFIT ANALYSIS USED BY NASA

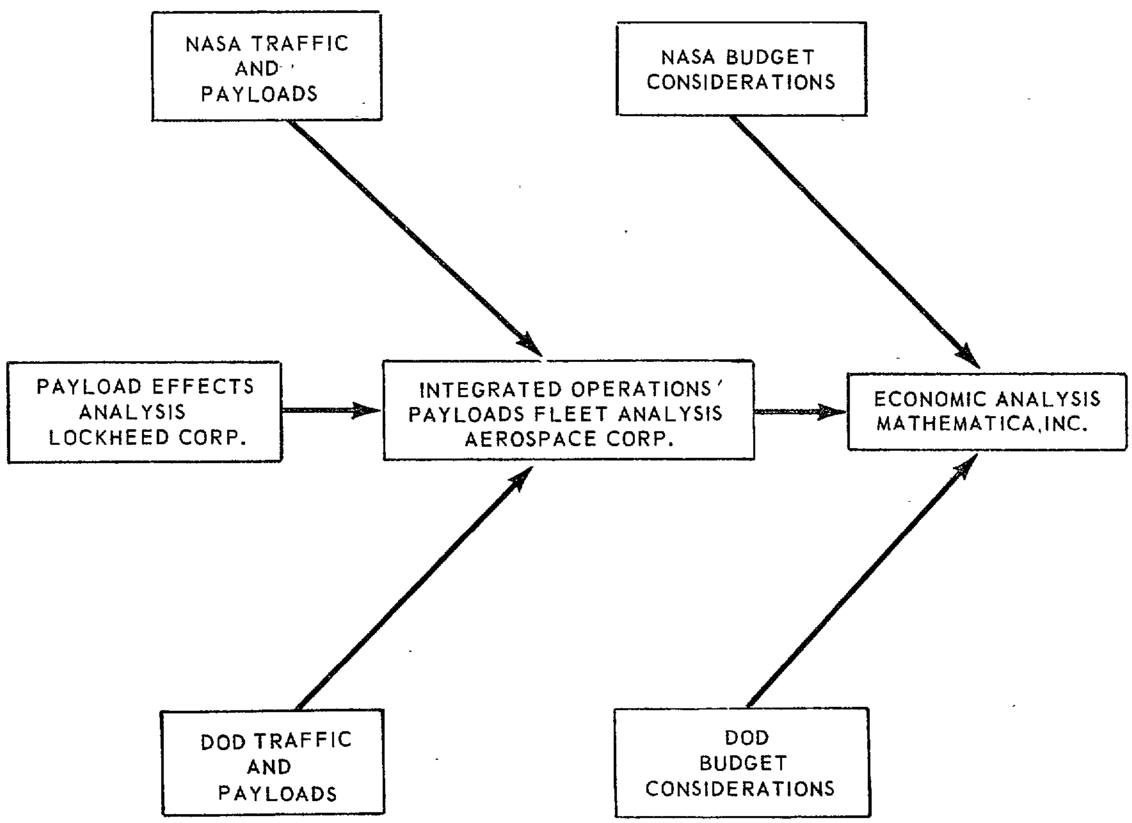
On July 6, 1970, NASA awarded a cost-plus-fixed-fee contract (NASW-2081) to Mathematica for an independent analysis of the economic benefits of a new space transportation system. The objective of this analysis was to find the most economical system capable of meeting expected U.S. space transportation needs of the 1980's and beyond. Three alternative space transportation systems were considered in this analysis: the current expendable, new expendable, and space shuttle systems.

Originally Mathematica's analysis compared the total space program costs of the expendable systems with the cost of a two-stage, fully reusable space shuttle system. "Total space program cost" was defined by Mathematica as the sum of (1) launch system life-cycle costs and (2) payload system life-cycle costs. During the second half of the effort, NASA extended the analysis to include an evaluation of alternative space shuttle configurations--i.e., space shuttle configurations that could be developed within the peak-year-funding constraints anticipated through the coming decade. The first part of Mathematica's analysis was summarized in a report dated May 31, 1971, the second part in a report dated January 31, 1972.

In both parts of the economic analysis, Mathematica did not include missions that would require the special capability of a reusable space shuttle system. Mathematica stated that this approach did not consider the potential additional benefits and options that a reusable system could offer the Nation.

Mathematica was responsible for establishing and approving the overall framework for the analysis, performing cost-effectiveness analyses of the three alternative space systems, conducting sensitivity analyses, and preparing and reporting output data. Since Mathematica's expertise lies mainly in economic analysis, a team of contractors, supported by data from NASA, DOD, and various hardware contractors, was established by NASA to provide the information necessary for Mathematica to conduct the analysis.

This team consisted of Lockheed and The Aerospace Corporation. The flow of data to Mathematica is shown below.



Lockheed was responsible for investigating, in depth, the effects that a reusable space transportation system would have on the expected costs of payloads and space missions in the 1980's. The estimates of these effects in the economic analysis were called payload effects. These effects include possible cost reductions through reuse, updating, maintenance, and in-orbit checkout of satellite payloads in the operating phase of a shuttle system. In addition, Lockheed evaluated the cost of payloads in the 1980's using expendable systems.

The Aerospace Corporation was responsible for estimating total space program costs for the current expendable system, the new expendable system, and the fully reusable space shuttle system, assuming the level of space activity in the 1980's indicated in a DOD-NASA baseline mission model. For DOD, NASA, and commercial users, a total of about 80 different missions were projected in this model.

Each of the three space transportation systems has unique characteristics with respect to launch capability and the cost per launch. The Aerospace Corporation matched these capabilities and costs with the payload requirements from the DOD-NASA baseline missions model to obtain the minimun cost combinations of launch vehicle and payload for each of the three space transportation systems. To arrive at these minimum cost combinations, The Aerospace Corporation utilized data from various hardware contractors as well as the results of the Lockheed Payload Effects Analysis.

During the second part of the economic analysis, Mathematica accumulated the total space program costs for the alternative space shuttle configurations (i.e., those other than the two-stage, fully reusable concept that had been costed by The Aerospace Corporation). In doing this Mathematica received cost data directly from the hardware contractors and NASA.

Recognizing the uncertainty of predicting space activities and costs in the 1979-90 period, Mathematica introduced many variations of the DOD-NASA baseline mission model into the economic analysis. These variations were referred to as scenarios. The scenario approach measured the economic effects of substantially reducing or expanding the overall level of space program activity in the 1980's and assessed the effects of a substantially different mix of space programs among DOD, NASA, and commercial space activities. The scenarios resulted in total space program costs for each of the three space transportation systems, including the various configurations of the space shuttle.

CHAPTER 3

GAO METHOD

In accordance with Senator Mondale's request, our review was concerned primarily with the economic justification for the space shuttle program. This emphasis should not be construed as an indication that we believe that the sole, or even the primary, justification for the space shuttle is economic. Nonetheless much of the opposition and support voiced for the program has been couched in terms of the program's economic justification. The purpose of this chapter is to provide a comprehensive framework in which the program's economic justification should be examined.

CRITERIA FOR INVESTMENT DECISION

A review of the shuttle's economic justification requires identification of criteria to provide a basis for judgment. We used a criterion Mathematica regarded as the basic economic decision criterion in the evaluation of proposed space transportation systems to meet U.S. needs in the 1979-90 period. This criterion is based on the net-present-value concept of an investment project. For our review the most convenient form of the criterion is--the space transportation system having the lowest total space program cost, considering the time value of money, should be acquired by the Government.

Use of this criterion requires selection of an interest or discount rate as a means of considering the time value of money. In accordance with Mathematica's proposal in the January 31, 1972, economic analysis of the Space Shuttle Program, we have used a representative discount rate of 10 percent. This rate also was suggested by the Office of Management and Budget. Accordingly the criterion employed throughout our review is--the space transportation system having the lowest discounted-at-10-percent total space program cost should be acquired by the Government.

The space transportation system satisfying this criterion is defined as the economically justified system. All others are considered to be not economically justified. Application of this criterion assumes that the candidate systems are equally effective. This assumption is maintained throughout the review for the two space transportation systems considered--the space shuttle and the current expendable systems. The new expendable system is included only for illustrative purposes.

An investment decision, such as the selection of a space transportation system, should consider all costs affected by the decision. Accordingly the economic decision to invest in a space transportation system should be based on combined launch system and payload system life-cycle costs--the total space program cost. Launch system life-cycle costs are approximately one-third of the estimated total space program cost affected by the investment decision on the Space Shuttle Program, and payload life-cycle costs are the remainder of the affected costs. The reported savings in cost (benefit) for the space shuttle are due primarily to estimated reductions in payload costs and launch costs.

Mathematica's analysis included the life-cycle costs of both the launch system and the payload system for many configurations of the space shuttle. These configurations were studied by hardware contractors, and Mathematica used the results of these studies to select the most economical configuration. At our request Mathematica provided us with total space program costs for the following two configurations which they felt typified all configurations considered and economically favored by NASA and Mathematica.

1. Solid rocket motor, thrust-assisted orbiter shuttle.

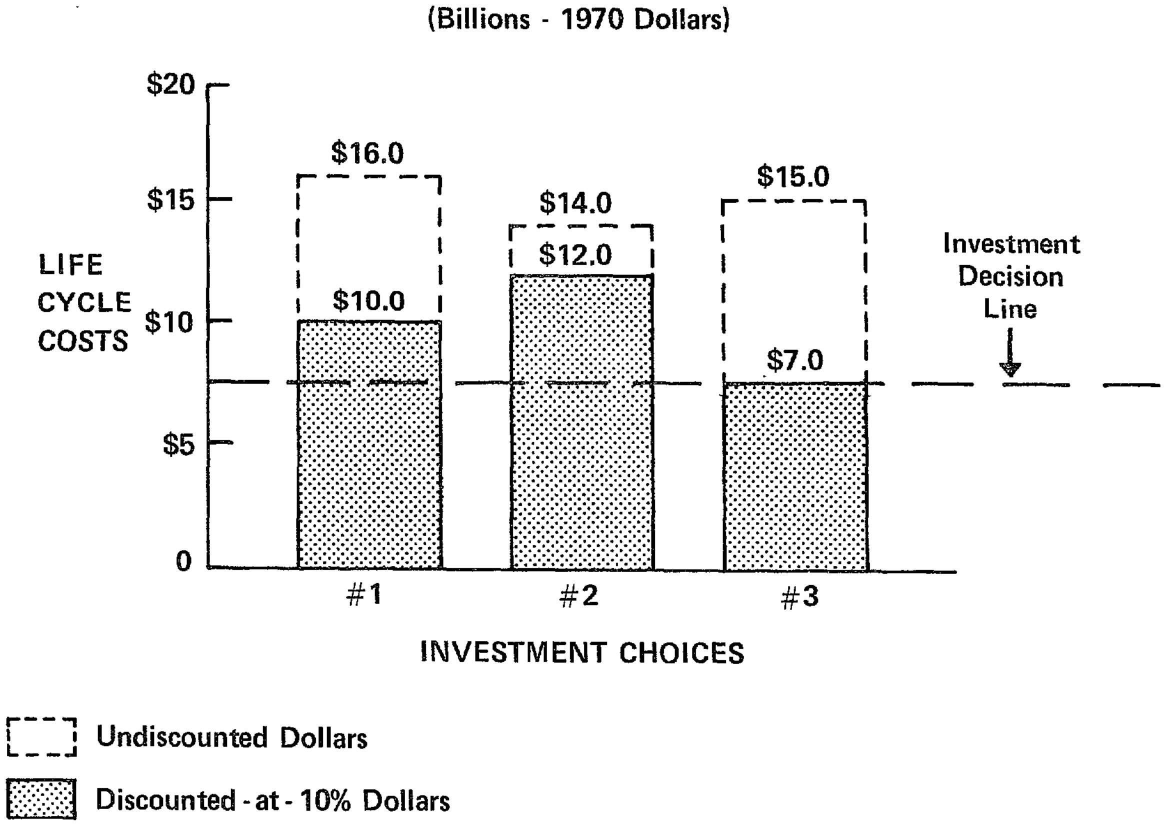
2. Pressure-fed, liquid booster, thrust-assisted orbiter shuttle.

For simplicity, we will refer to these configurations as the solid booster shuttle and the liquid booster shuttle, respectively.

We examined into these total space program costs and identified many of the significant assumptions which influenced the estimates. We also examined into the sensitivity of the shuttle economic justification to major areas of uncertainty in the supporting studies. In doing this we used NASA's cost model developed by Mathematica.

As stated above, the Office of Management and Budget suggested, and Mathematica proposed, that NASA discount the cost estimates at a 10-percent rate. Accordingly, we have used the 10-percent rate in presenting the results of our sensitivity analyses in a manner that, we believe, will facilitate consideration by the Congress of the economics of the space shuttle. Use of the 10-percent rate should not be construed as indicating that GAO has taken the position that 10 percent is the most appropriate discount rate for application to Federal expenditures.

The results of our sensitivity analyses are displayed in bar charts which focus primarily on the discounted-dollar relationship between the total space program costs of each of the three space transportation systems for the 1980's. In addition to displaying discounted-dollars, the bar charts display the total undiscounted space program costs. Following is a sample bar chart.



As shown in the hypothetical case above, the estimates in undiscounted dollars are considerably higher than those in the discounted dollars. Although it is important to know the estimated costs of each of the three systems in undiscounted dollars, the investment decision hinges upon the discounted-dollar relationships. The sample bar chart shows, for example, that, although system 2 is expected to cost the least in terms of undiscounted dollars, system 3 is the best investment, considering the time value of money.

CRITICAL AREAS IN THE ANALYSIS

As a part of his request, Senator Mondale asked that we identify and analyze the assumptions and other study elements (areas) that significantly influenced the estimated cost of the Space Shuttle Program. The most significant areas are termed critical areas. He also requested that we analyze the range of possible effects on the shuttle economic justification of variations in major assumptions or other study elements involved in the treatment of identified critical areas.

Chapters 4 through 9 describe the results of our sensitivity analyses of the listed critical areas. Although our review treated each critical area separately, this does not imply that variations may not occur in several of these areas as the Space Shuttle Program progresses. For example, changes in both payload refurbishment costs and launch system cost could occur during the program's life cycle.

	Chapter reference
Launch system costs--The effects of variations in the fundamental assumption that the space shuttle system will be developed, procured, and operated as projected in Mathematica's January 1972 report on the economic analysis of the space shuttle system.	4
Number of flights--The effects of increasing the number of space shuttle flights.	5
NASA program change--The effects of placing the representative shuttle estimate from Mathematica in the context of NASA's March 1972 announcement.	6
Cost per launch--The effects of variations in cost per launch on the shuttle's economic justification.	7

	Chapter reference
Payload retrieval and refurbishment--The effects of variations in estimated payload refurbishment cost.	8
Range of contractor estimates--The effects of variations in phase B extension contractor's estimates of life-cycle costs to develop, procure, and operate the space shuttle system as projected in Mathematica's January 1972 report.	9

We compared the total space program cost of the space shuttle system to that of the current expendable system. In terms of the cited economic justification criterion, the new expendable system is more economically justified than the current expendable system since its discounted-at-10-percent total space program costs are lower. We have eliminated the new expendable system from consideration throughout this report, however, because of (1) the uncertainty in cost estimates for any new class of systems, including this one, and (2) our inability to review the new expendable launch system estimates in the time available for this review. Using the current expendable system results in a conservative assumption that favors the shuttle. We have included the total space program cost of the new expendable system only for illustration purposes.

NASA officials stated that some cost growth might occur in the current expendable estimate for the yet-undeveloped TITAN III M/Big Gemini launch vehicle which is needed to perform the space station missions. They indicated that such cost growth might partially offset shuttle system cost growth. We found that the Big Gemini represents about 8 percent of the total $42 billion estimated total space program cost for the current expendable system. Accordingly, the effect of increases in the estimated cost of the Big Gemini on total cost of the current expendable system would be relatively small.

In addition to identifying the critical areas listed above, we identified other areas that could significantly affect the economic justification for the space shuttle system. Due to the brief time available, we did not analyze these areas during our review. A partial list of these areas follows.

1. The estimated number of times that the orbiter can be reused.

2. The estimated time between flights for each orbiter.

3. The estimated number of times that the booster engines can be reused.

4. The estimated booster engine recovery and refurbishment cost.

5. The effect of deviations from the space shuttle's payload-capability design specification.

CHAPTER 4

LAUNCH SYSTEM COSTS

Despite determined efforts during the 1960's to improve the outcome of major system acquisition programs by altering contractual approaches and by introducing a variety of management reforms, typical programs continued to exhibit an average cost growth of 40 percent (after correction for quantity changes and inflation), according to a June 1971 study by the RAND Corporation.

This and other studies have identified three sources of cost growth: technical uncertainty, scope changes, and cost-estimating error. Cost growth refers to the ratio of estimated developement and procurement costs made at the beginning of development to the actual cost.

About one-third of the cost growth was attributed to technical uncertainty, about one-half to scope changes, and the remainder to cost-estimating uncertainty. Technical uncertainty during a development program arises from unproven approaches and techniques incorporated in the original development plan. Scope change refers to any fundamental change in program objectives or specifications after the start of development. Estimating uncertainty stems from errors in the cost-estimating techniques employed or from their inapplicability to the situations in which they are employed.

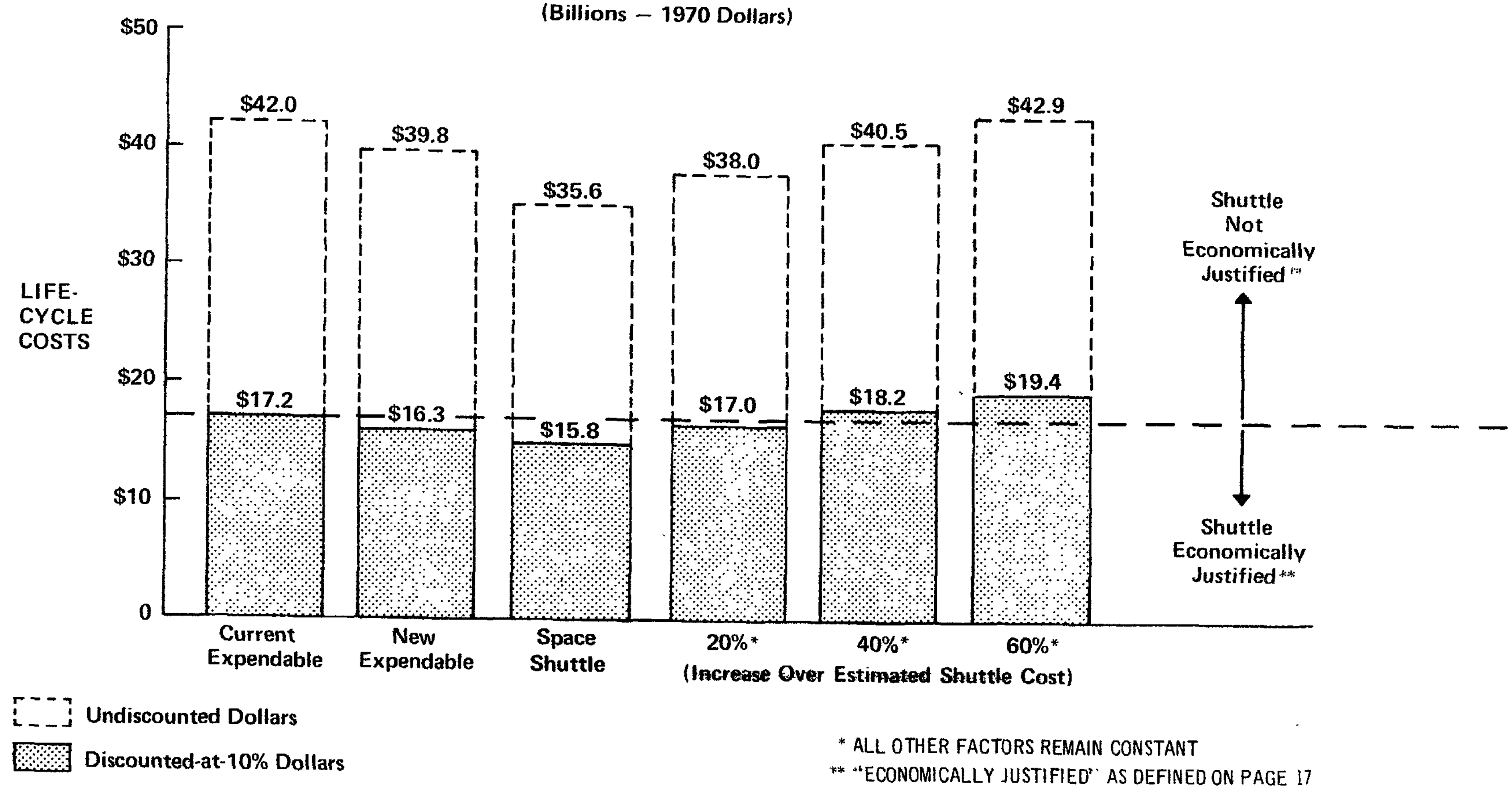
Although no one can accurately forecast the amount, if any, of cost growth that the space shuttle may undergo, the effects of cost growth upon the shuttle's economic justification can be assessed. Thus the extent of life-cycle cost growth that the shuttle could experience and still remain economically justified can be determined.

As part of our review, we examined into the effect of various degrees of cost growth on the shuttle's economic justification. The effects are portrayed in figure 1 for the solid booster shuttle and in figure 2 for the liquid booster shuttle. We found that the degrees of cost growth at which the solid booster shuttle and the liquid booster shuttle were no longer justified were approximately 25 percent and 20 percent, respectively.

These degrees of cost growth were applied to the three components of the launch system life-cycle costs: development, procurement, and 12-year operations costs. We assumed that the percentage cost growth in the combined development and procurement components of the launch system life cycle would lead to a proportionate cost growth in operations.

Figure 1

SOLID BOOSTER SHUTTLE
EFFECT ON ECONOMIC JUSTIFICATION OF GROWTH
IN LAUNCH VEHICLE COSTS*
514 FLIGHTS
(Billions — 1970 Dollars)



* ALL OTHER FACTORS REMAIN CONSTANT
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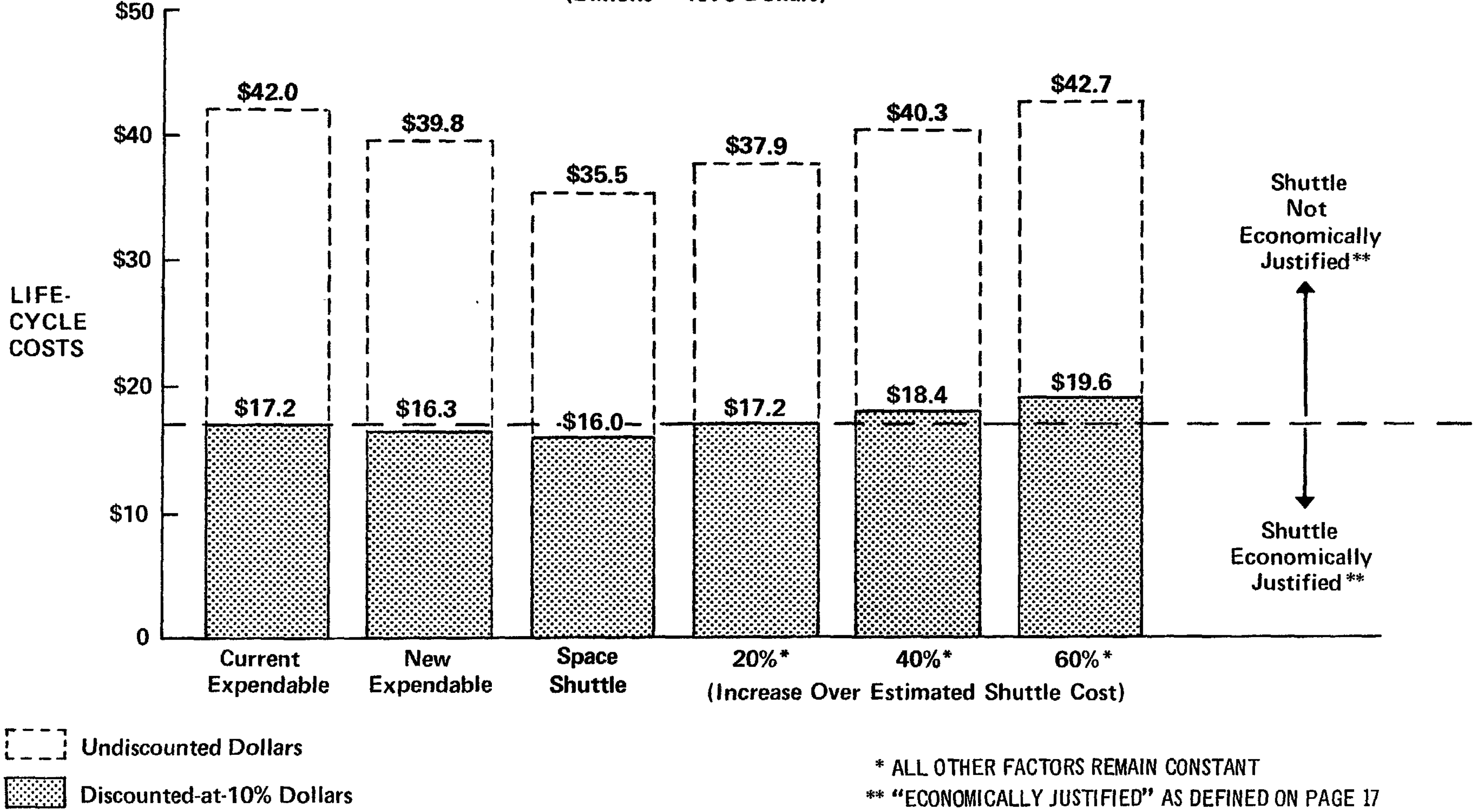
Figure 2

LIQUID BOOSTER SHUTTLE
EFFECT ON ECONOMIC JUSTIFICATION OF GROWTH IN LAUNCH VEHICLE COSTS*
514 FLIGHTS
(Billions — 1970 Dollars)



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CHAPTER 5

NUMBER OF FLIGHTS

The economic justification for the shuttle is based primarily on the expectation that cost savings from the shuttle's predicted reduced recurring costs during the 1979-90 period will at least justify expenditures for development and procurement early in the shuttle's life cycle, if the time value of money through the use of a 10-percent-discount factor is recognized.

"Cost savings" during 1979-90 shuttle operations are defined as the estimated differences between recurring (payload and launch systems) costs for the shuttle and those for the expendable systems. It follows that the estimated average cost per flight of the shuttle (all payload and launch costs considered) is less than that of either the new or the current expendable systems. Because of this it also appears that increasing the number of flights would increase the total cost differences between shuttle and expendable systems during the 1979-90 period and thereby would increase the economic justification for the shuttle.

We reviewed the effect on the shuttle's economic justification of an increase in the number of flights from 514 to 624 during the 1979-90 period. In doing this we used The Aerospace Corporation's study results and processed them using NASA's methods.

The effects of cost growth, ranging from 20 to 60 percent on the economic justification of the solid booster shuttle, are shown in figures 3 and 4 for the 514 and 624 flights, respectively. For 514 flights, the solid booster shuttle is economically justified only if the cost growth remains below approximately 25 percent. As shown in figure 4 for the 624 flights, the solid booster shuttle is economically justified only if the cost growth does not exceed 30 percent.

The effects of cost growth on the liquid booster shuttle's economic justification are portrayed in figures 5 and 6 for 514 and 624 flights, respectively, during the 1979-90 period. Figure 5 indicates, for the 514 flights' that the that the liquid booster shuttle will remain economically justified only if the cost growth does not exceed 20 percent. Figure 6 indicates, for the 624 flights, that the liquid booster shuttle will not be economically justified if cost growth exceeds approximately 30 percent.

Figure 3

SOLID BOOSTER SHUTTLE
EFFECT ON ECONOMIC JUSTIFICATION OF GROWTH
IN LAUNCHER SYSTEM COSTS*
514 FLIGHTS
(Billions – 1970 Dollars)

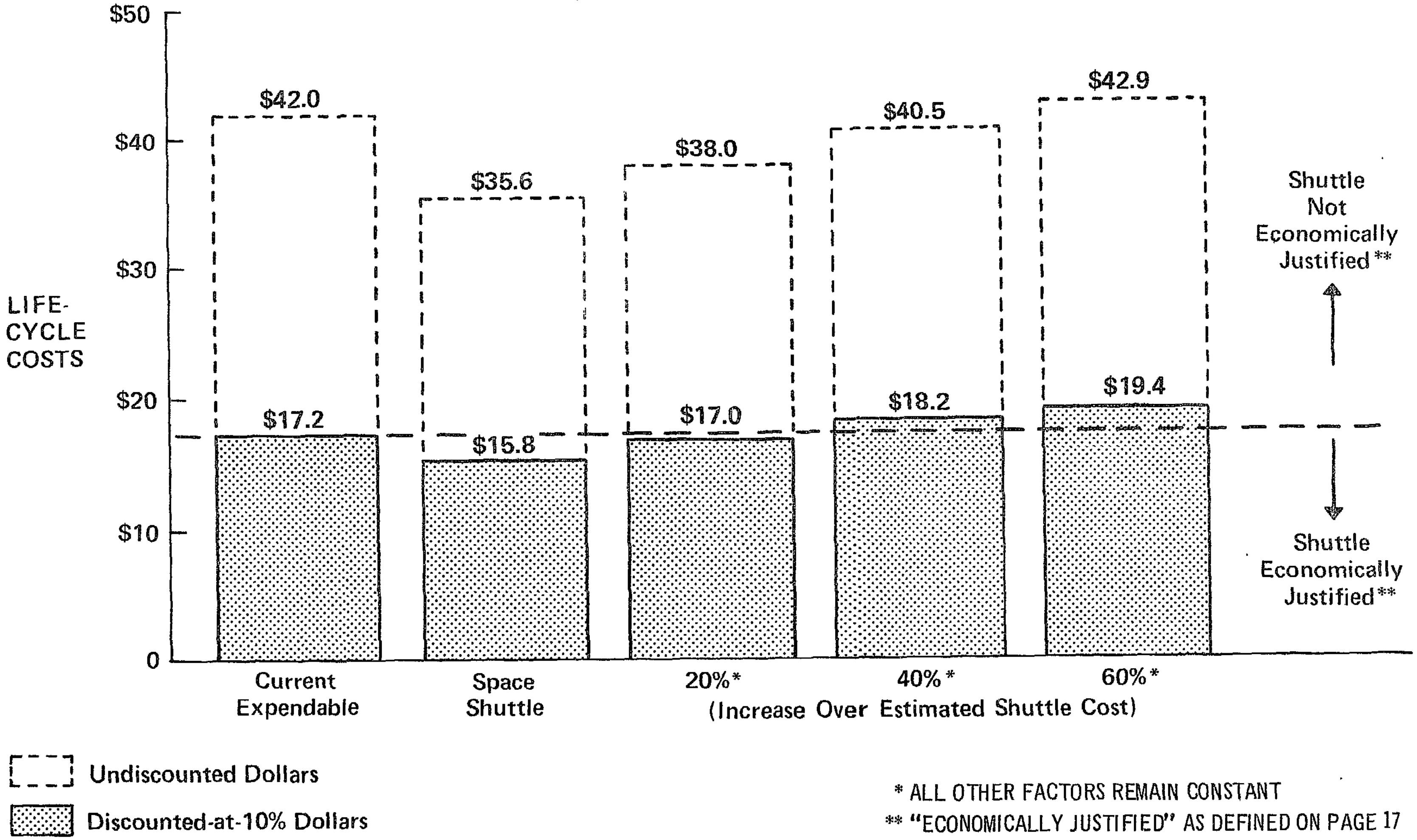

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Figure 4

SOLID BOOSTER SHUTTLE
EFFECT ON ECONOMIC JUSTIFICATION OF GROWTH
IN LAUNCHER SYSTEM COSTS*
624 FLIGHTS
(Billions — 1970 Dollars)

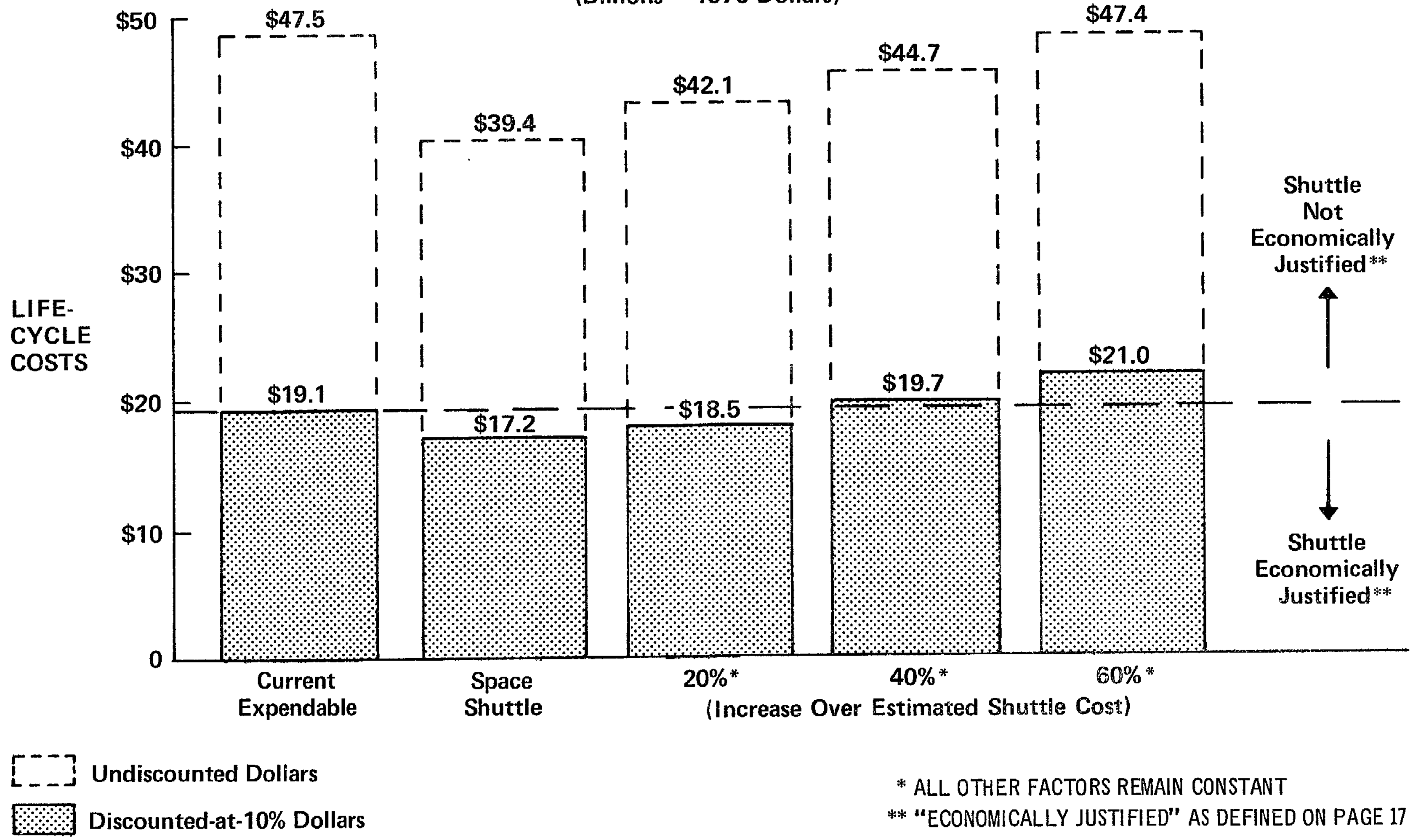

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Figure 5

LIQUID BOOSTER SHUTTLE
EFFECT ON ECONOMIC JUSTIFICATION OF GROWTH
IN LAUNCHER SYSTEM COSTS *
514 FLIGHTS
(Billions — 1970 Dollars)

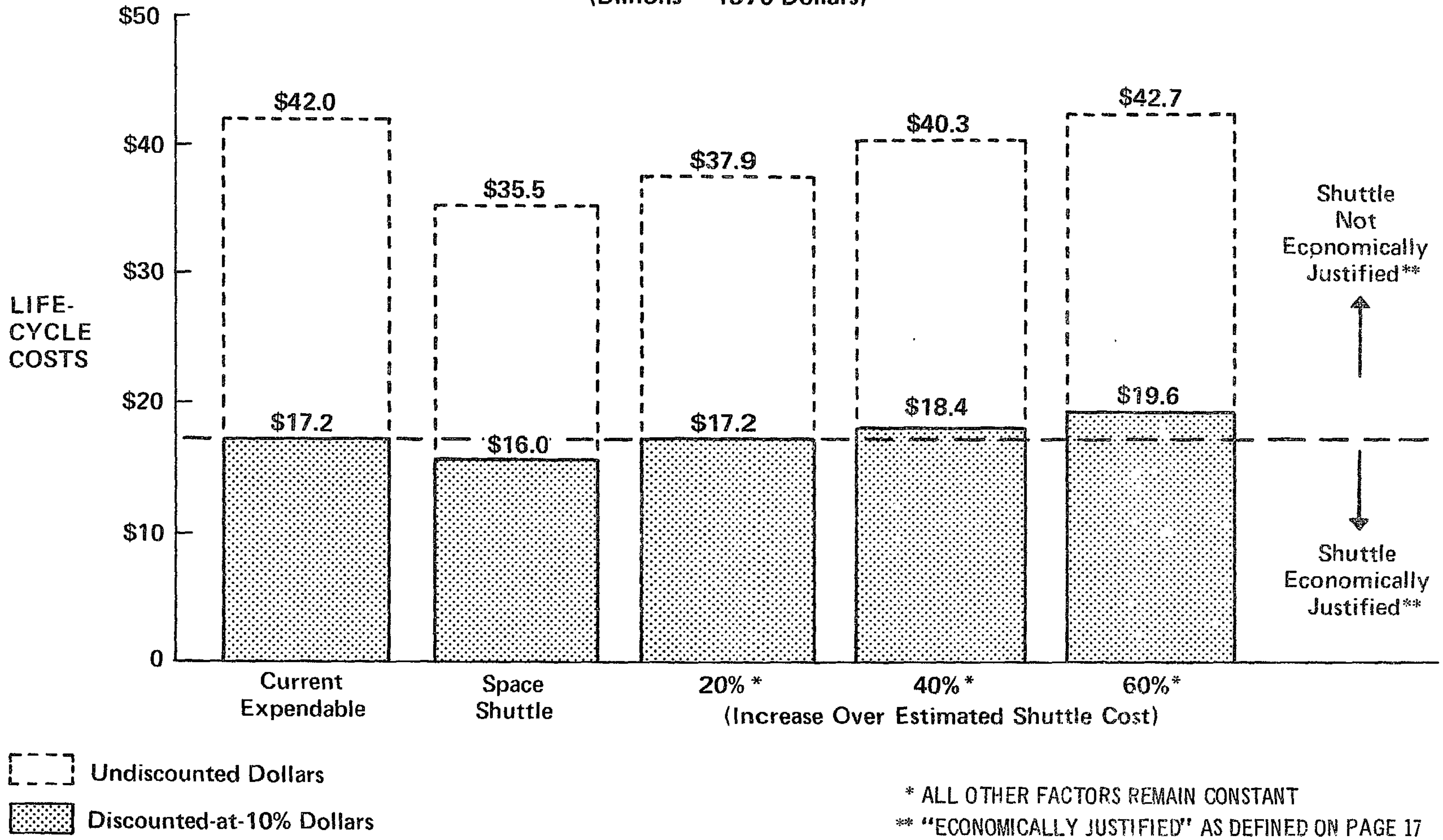

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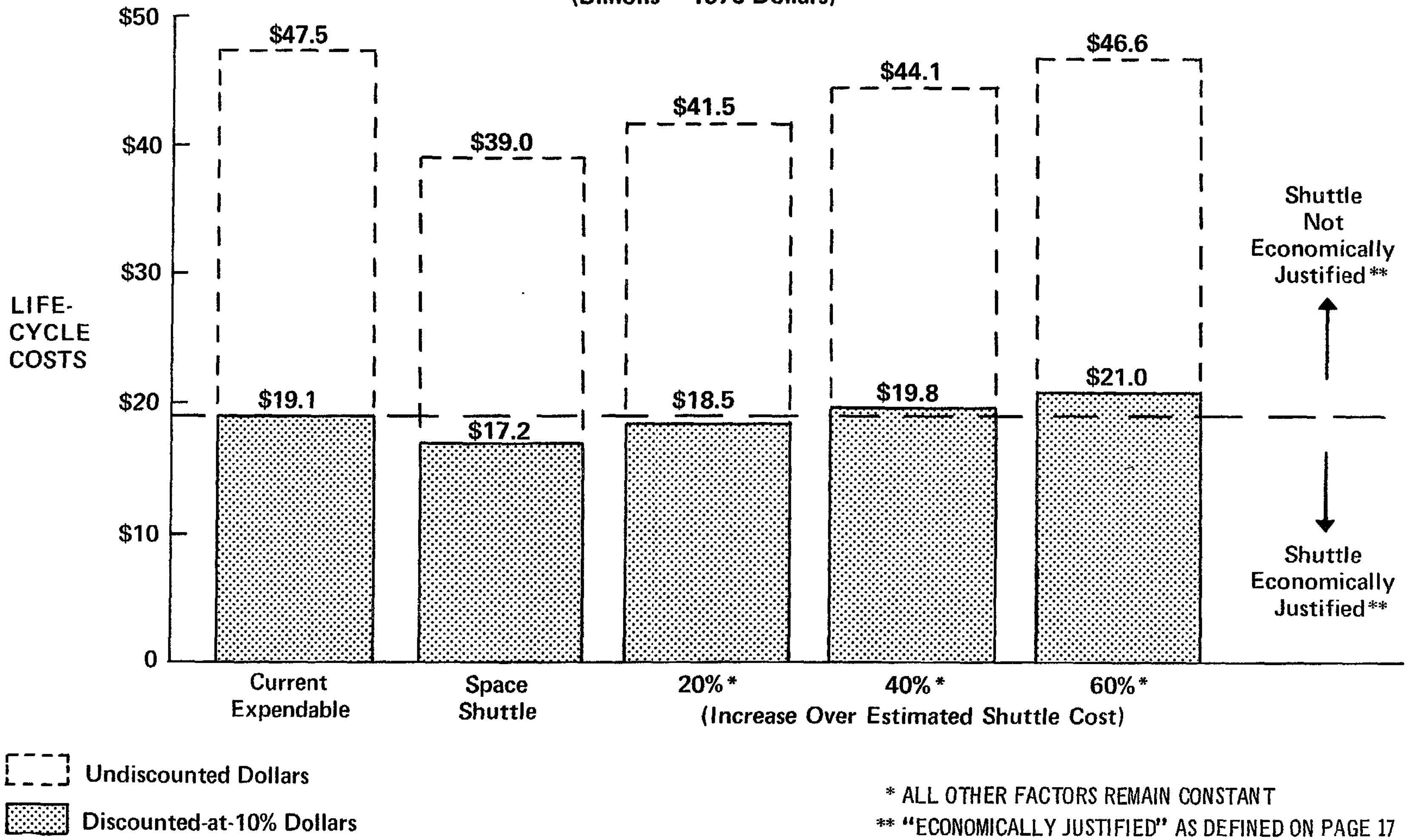
Figure 6

LIQUID BOOSTER SHUTTLE
EFFECT ON ECONOMIC JUSTIFICATION OF GROWTH IN LAUNCHER SYSTEM COSTS*
624 FLIGHTS
(Billions — 1970 Dollars)



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CHAPTER 6

NASA PROGRAM CHANGES

On March 15, 1972, NASA issued a fact sheet that presented its position on the estimated costs of the space shuttle and its economic justification. As a part of our review, we obtained from NASA a breakdown of its figures in a format similar to that used by Mathematica. This is shown in the following table.

	NASA'S March 1972 estimate	Mathematica's cases: Solid booster	Mathematica's cases: Liquid booster
	(billions--1971 dollars)		
Expected launch vehicle costs	$16.1	$14.6	$14.2
Expected payload costs	26.8	26.8	26.8
Expected total space program costs	$42.9	$41.4	$41.0

Costs for the new expendable launch system are not included in this table because NASA did not estimate the cost of this kind of space transportation system. NASA officials stated that the March 1972 estimates shown above included an explicit allowance for cost growth due to scope changes. These officials did not advise us of the amount of this allowance, and we did not verify that an allowance for cost growth had been included in the estimates.

Using procedures followed by NASA, we reviewed the economic justification for the representative configurations from Mathematica--the solid and liquid booster shuttles--in the context of the NASA March 1972 estimates. We did not examine into the economic justification of NASA's March 1972 estimates. These estimates differed from the respective shuttle estimates from Mathematica in the following respects.

1. A tug and space station initial operating capability of 1985 instead of 1979.

2. A flight mission model of 581 flights instead of 514.

3. The costs expressed in 1971 dollars instead of 1970 dollars.

As shown above, placing Mathematica's estimates in the context of NASA's estimate changes the estimated launch system life-cycle cost of the solid booster shuttle from $13.1 billion to $14.6 billion and of the liquid booster shuttle from $13 billion to $14.2 billion.

Figures 7 and 8 show the results of our review of the representative configurations in the NASA context. As shown in both these figures, the shuttles are economically justified, according to the investment criteria of chapter 3, if cost growth does not exceed about 20 percent. If either of the configurations--the solid or the liquid booster shuttle--experiences more than a 20-percent cost growth, it would not be economically justified.

Figure 7

SOLID BOOSTER SHUTTLE
EFFECT ON ECONOMIC JUSTIFICATION OF COST GROWTH—NASA ANNOUNCEMENT *
1985 TUG AND SPACE STATION
581 FLIGHTS
(Billions — 1971 Dollars)

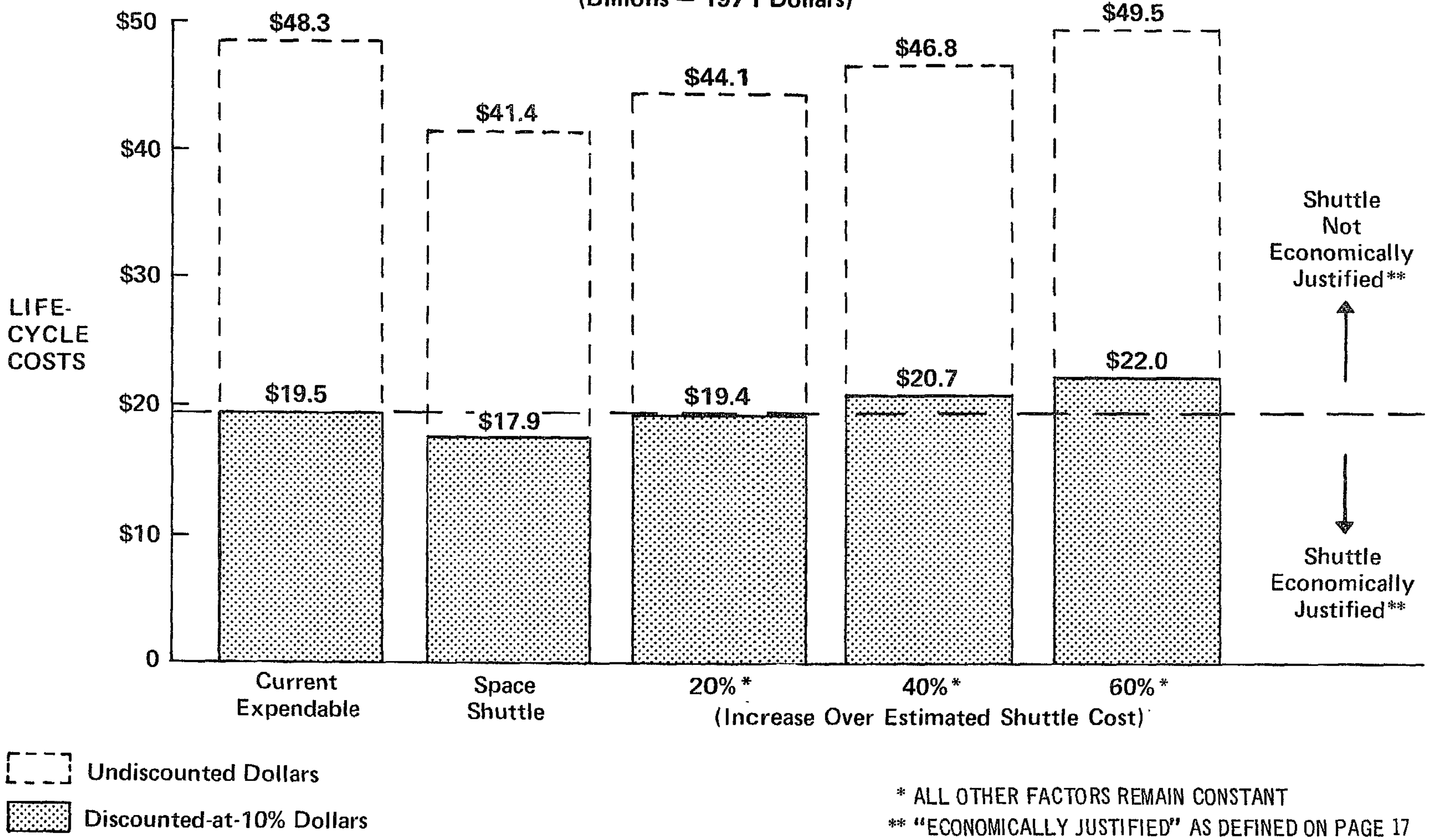

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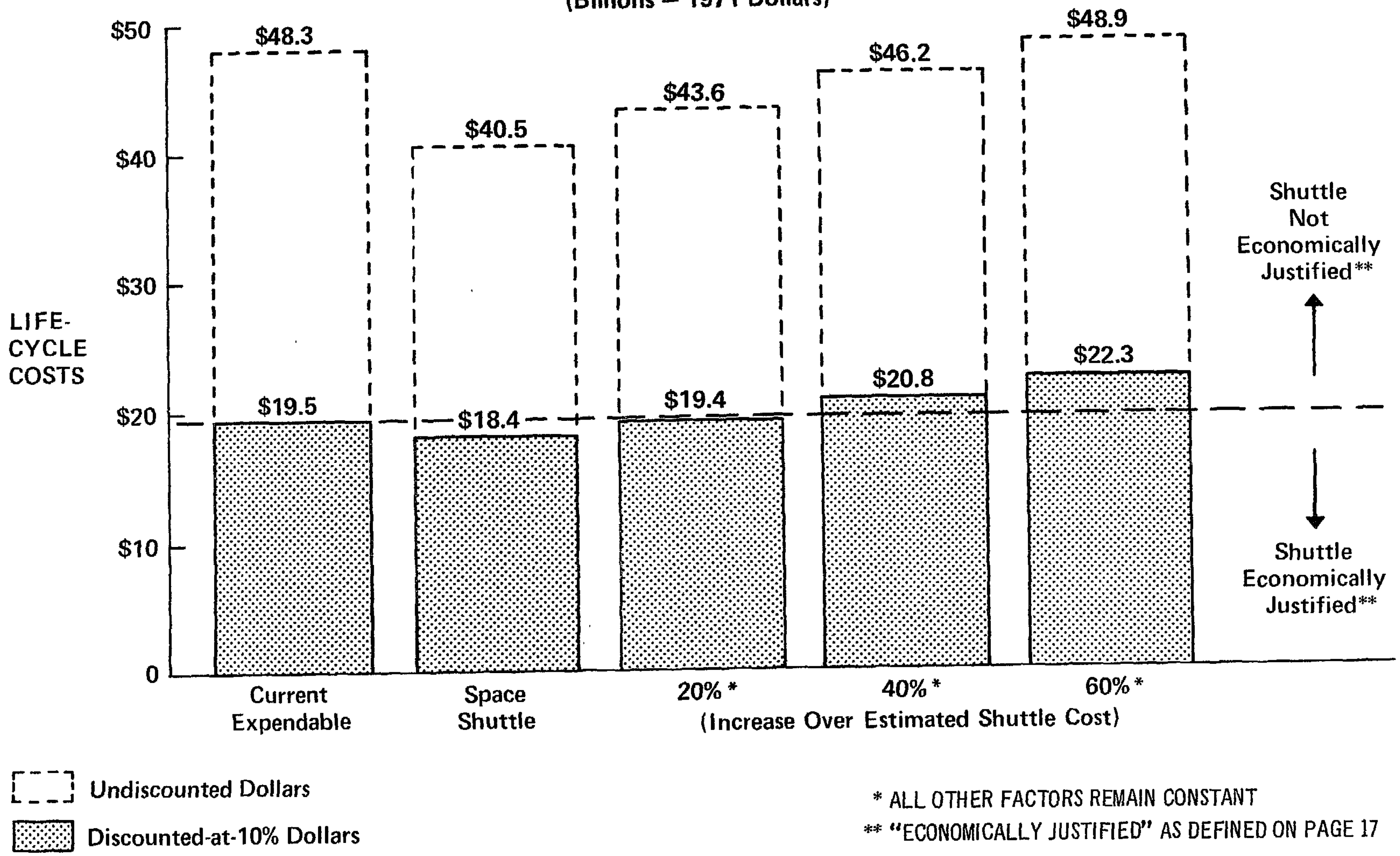
Figure 8

LIQUID BOOSTER SHUTTLE
EFFECT ON ECONOMIC JUSTIFICATION OF COST GROWTH–NASA ANNOUNCEMENT*
1985 TUG AND SPACE STATION
581 FLIGHTS
(Billions – 1971 Dollars)



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CHAPTER 7

COST PER LAUNCH

Estimates of the average cost per launch are critical determinants of the shuttle's economic justification. This chapter reviews the effects of variations in the cost per launch on the shuttle's economic justification.

This critical area was selected for review because of (1) the cited importance of the reduced cost per launch to the shuttle's economic justification and (2) the uncertainty of current estimates. Uncertainty stems from the nature of problems faced by the shuttle designers and the as yet unproven approaches and techniques incorporated in the shuttle development plans. Problems faced by shuttle designers that could cause changes in the cost per launch include, but are not necessarily limited to, the requirement for (1) reusability of the orbiter's rocket engines, (2) reusability of the booster rocket engines, and (3) refurbishment of the orbiter.

The shuttle's actual average cost per launch will not be known until the system reaches operational status. Consequently these costs cannot be estimated with certainty. On the other hand the information available from Mathematica's economic studies can be used to calculate the level of growth in the cost per launch that can be tolerated without changing the shuttle to an economically unjustified status.

Figures 9 and 10 show that if either the solid booster shuttle or the liquid booster shuttle experiences a growth of more than 75 percent in the cost per launch, assuming no growth in other parts of the total space program cost for the shuttle system, it will no longer be economically justified.

Figure 9

SOLID BOOSTER SHUTTLE
EFFECT ON ECONOMIC JUSTIFICATION OF GROWTH IN AVERAGE COST PER LAUNCH*
514 FLIGHTS
(Billions — 1970 Dollars)

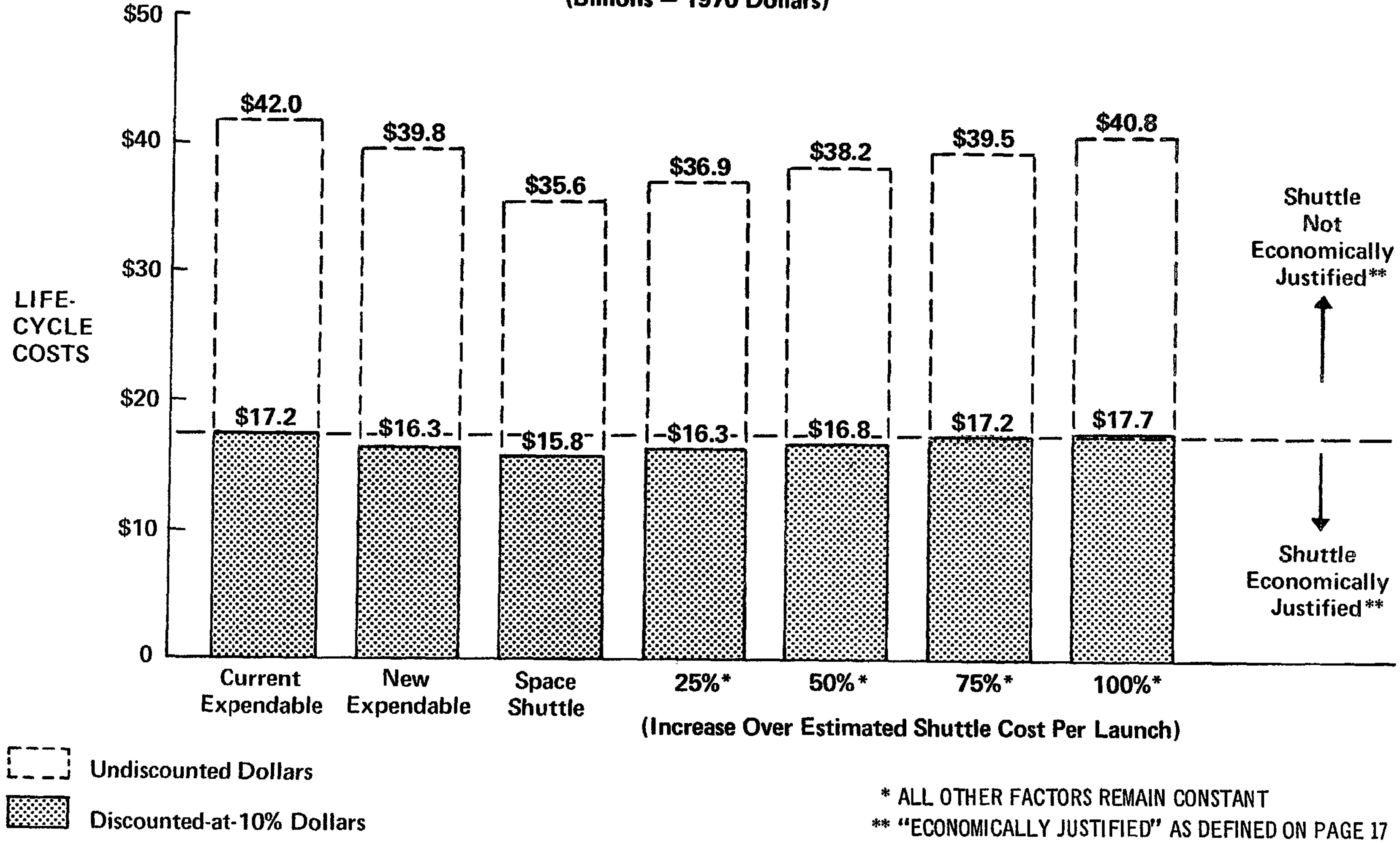

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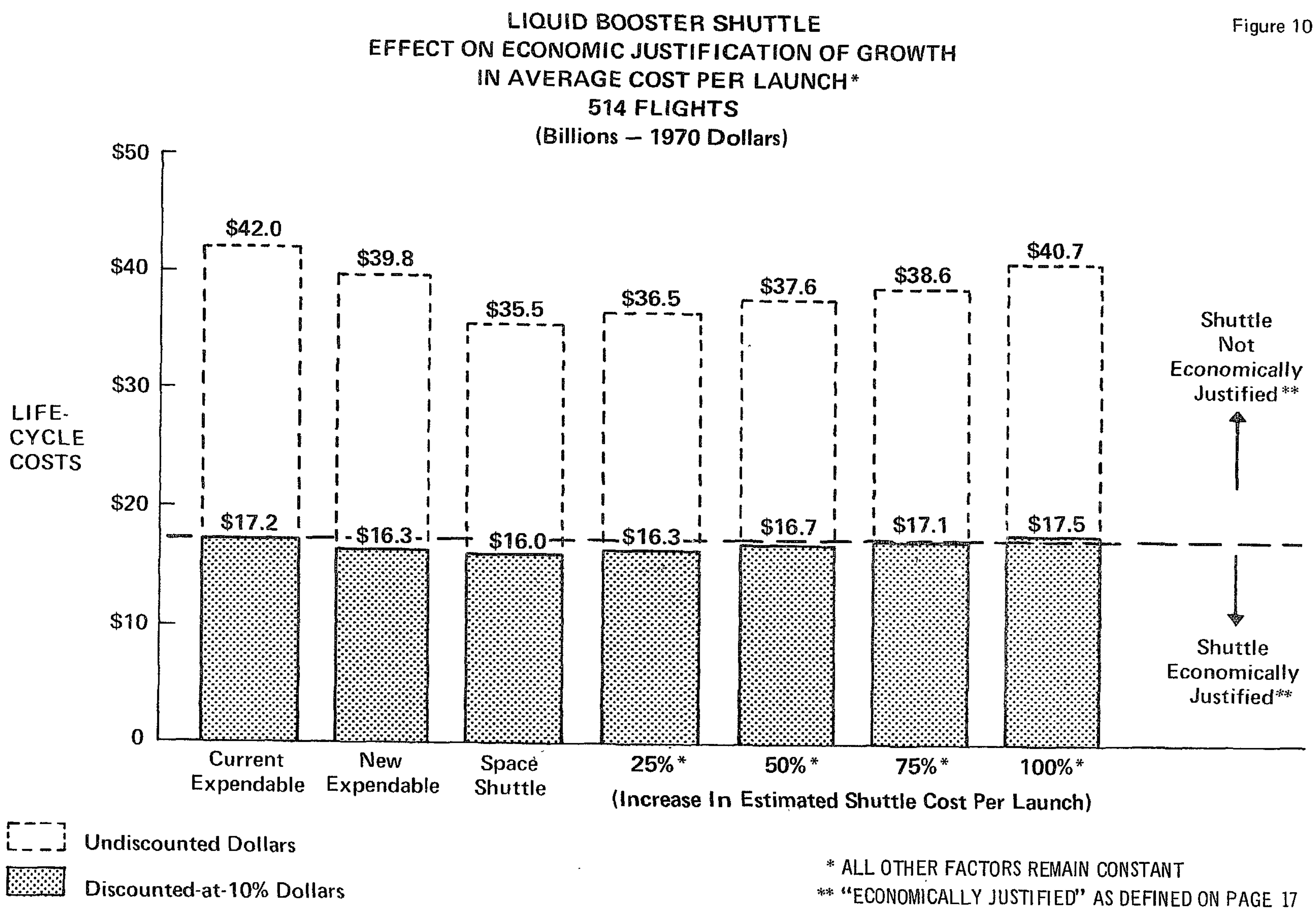
Figure 10



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CHAPTER 8

PAYLOAD RETRIEVAL AND REFURBISHMENT

One of the cost-saving features of the space shuttle is expected to be its capability to retrieve and repair satellite payloads. The present use of expendable launch vehicles does not allow revisits to the satellite package after it is placed in orbit. If the payload fails to function or needs repair or refurbishment, there is no economical method of retrieving it. The space shuttle should enable revisiting the satellite to make repairs or bringing the satellite back to earth to refurbish its vital operating components. Since payloads are expensive, reusing and refurbishing them can result in cost savings.

Lockheed, under contract to NASA and participating in the development of data for analysis by Mathematica, provided data for The Aerospace Corporation showing that significant savings in payloads could result from refurbishing the operating component of specific payloads. The results of Lockheed's and The Aerospace Corporation's work on payloads to be carried by the space shuttle indicated that the payload refurbishment cost would be about 40 percent of the payload procurement cost.

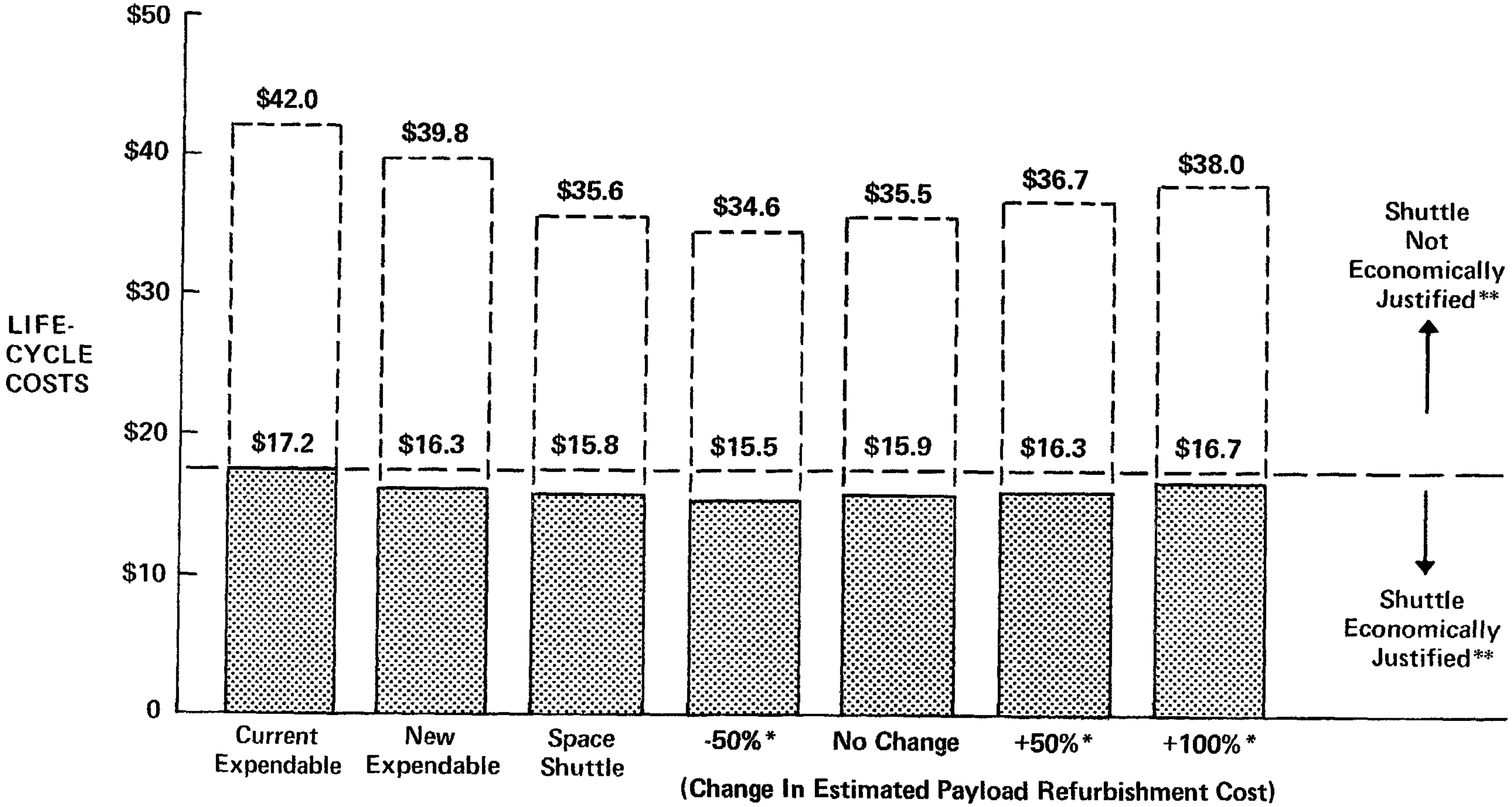
On the basis of the methods used by The Aerospace Corporation in arriving at a payload cost estimate for the shuttle, we varied estimated payload costs for the shuttle by assuming that payload refurbishment costs could be as large as 100 percent or as small as 50 percent of the payload refurbishment cost used by The Aerospace Corporation and incorporated in Mathematica's analysis.

The reason for special emphasis on payload refurbishment and reuse is that it represents approximately three-quarters of the savings in expected payload costs due to using a space shuttle instead of an expendable vehicle. We were advised by several contractors that, since payloads never had been returned or refurbished, the actual result of such an effort might be higher or lower savings because of unforeseen factors in handling the payloads.

Figures 11 and 12 show that increases of more than 100 percent do not affect the economic justification of the Space Shuttle Program, provided that all other factors remain unchanged. We found that increases in refurbishment costs must exceed about 150 percent before the economic justification is affected.

Figure 11

SOLID BOOSTER SHUTTLE
EFFECT ON ECONOMIC JUSTIFICATION OF CHANGES IN PAYLOAD REFURBISHMENT COST *
(Billions – 1970 Dollars)



Undiscounted Dollars

Discounted-at-10% Dollars

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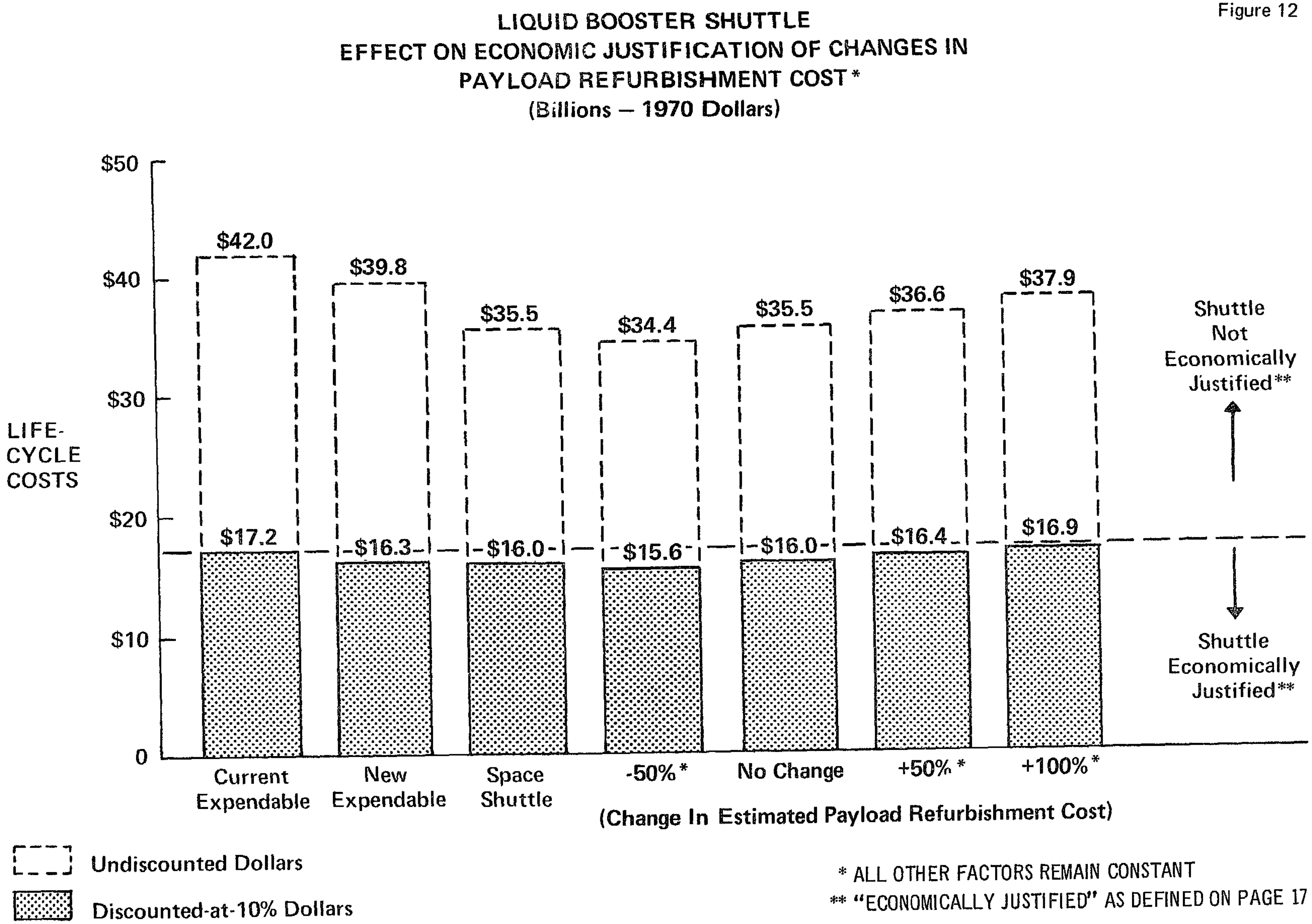
Figure 12



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CHAPTER 9

RANGE OF CONTRACTOR ESTIMATES

During the phase B extension studies, NASA directed the hardware contractors to study configurations of the space shuttle other than the two-stage fully reusable configuration. These contractors developed designs and estimated the costs to develop, procure, and operate each of the various shuttle configurations. In most cases these estimates were incorporated in Mathematica's analysis and published in the January 31, 1972, report.

Generally each contractor established a unique design for each shuttle configuration considered. The uniqueness of the designs stemmed from different approaches to various design problems. The different approaches, in turn, reflected the data base available to the contractor, as well as the unique backgrounds, experiences, philosophies, and judgments of the contractor's design and management personnel. For similar reasons, different contractors produced different cost estimates for the same shuttle configuration.

Our review of these contractors' reports showed that many of the differences in estimates exceeded $1 billion. In reviewing the size of these differences, we assessed the significance of the ranges of contractor-based estimates to the economic justification of the shuttle. In assessing the estimates we used the high, low, and representative total space program cost estimates for the two configurations described in chapter 3--the solid booster shuttle and the liquid booster shuttle--that Mathematica furnished to us at our request.

The results of our assessment for the solid booster shuttle and the liquid booster shuttle are shown in figures 13 and 14, respectively. The solid booster shuttle would remain economically justified even if the high contractor estimate proves to be the most accurate. When the total space program cost for the liquid booster shuttle in discounted 1970 dollars is compared with the costs for the current expendable and new expendable systems in discounted dollars, the shuttle is not economically justified if the high contractor estimate proves to be the most accurate.

It should be noted that, because of time limitations, our review was confined to the estimates submitted by the contractors. Each contractor very likely developed several estimates in arriving at the one submitted to NASA. Consequently the high contractor estimate furnished to us by Mathematica was not necessarily the highest estimate of the contractors.

Figure 13

SOLID BOOSTER SHUTTLE
EFFECT ON ECONOMIC JUSTIFICATION OF RANGE OF CONTRACTOR ESTIMATES*
(Billions — 1970 Dollars)

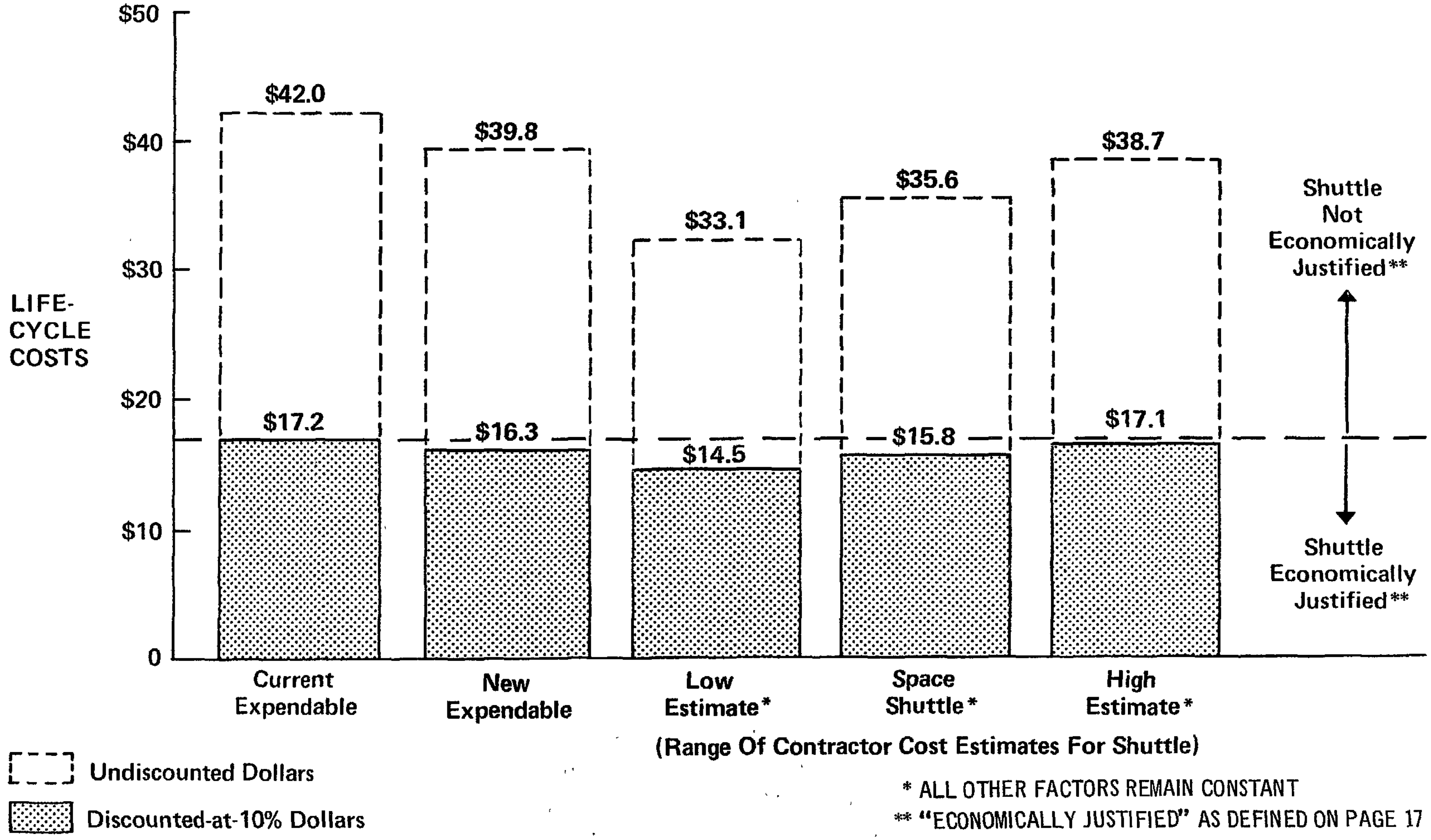

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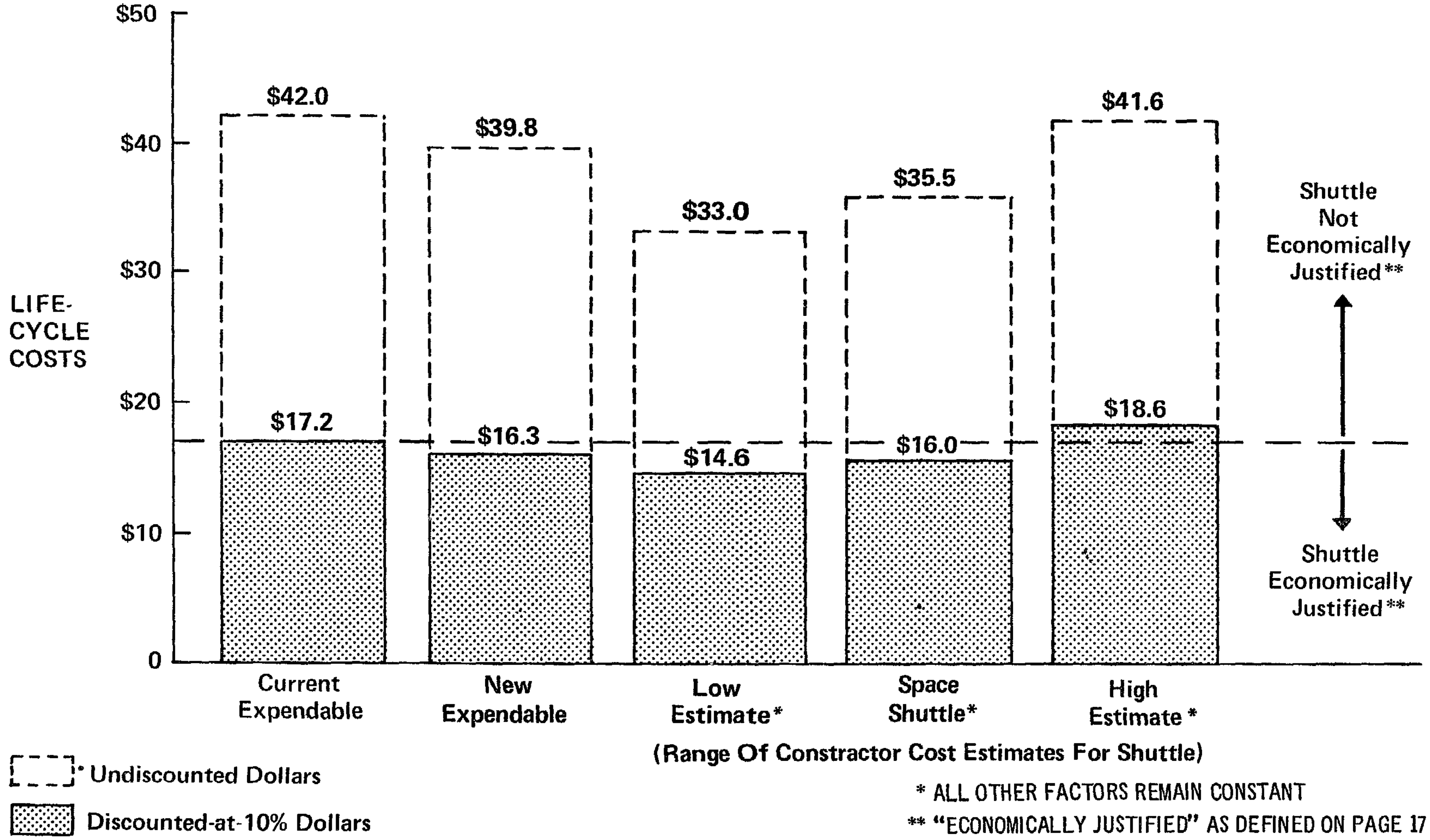
Figure 14

LIQUID BOOSTER SHUTTLE
EFFECT ON ECONOMIC JUSTIFICATION OF RANGE OF CONTRACTOR ESTIMATES*
(Billions — 1970 Dollars)



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United States Senate

COMMITTEE ON BANKING, HOUSING AND URBAN AFFAIRS
WASHINGTON, D.C. 20510

February 17, 1972

Mr. Elmer B. Staats
Comptroller General
General Accounting Office
441 G Street N.W.
Washington, D.C.

BEST DOCUMENT AVAILABLE

Dear Mr. Staats:

As you know, the National Aeronautics and Space Administration is planning a new Space Shuttle program, which was announced on January 5, 1972. This program will involve an expenditure of $5.5 billion for research, development, test and engineering, together with 20 percent overrun allowance, and $0.3 billion for launch facilities. This Shuttle will be a two-stage vehicle--consisting of a booster and an orbiter. Each booster will cost $50 million, and at this point, the booster's reuse capability is not defined. Each orbiter, which NASA claims can be used 100 times, will cost an estimated $250 million.

NASA claims that each shuttle flight will cost less than $10 million and that the cost of placing a pound of payload in orbit can be reduced to less than $100. Thus, it is argued that the Space Shuttle will be a cost effective vehicle for the space program.

Obviously, the Senate is confronted with a situation wherein prospective economics becomes the basis for a new space transportation system. However, there appear to be many technological unknowns in this new venture and a wide margin of uncertainly in cost estimates. I would therefore deeply appreciate it if your office would undertake a review and analysis of the cost-benefit analyses used by NASA in support of these Shuttle estimates.

In this connection, I would like your review to include, but not necessarily be limited to, the following:

(1) Identification of supporting analyses for the NASA estimates,

(2) Identification of the processes whereby these estimates were conducted, the organizations involved, and any supporting studies or other work involved in the processes,

(3) Identification of significant assumptions and other critical study elements which influence the estimates of shuttle economics,

(4) Analysis of these studies and their critical elements and analysis of the range of possible effects on shuttle economics forecast by these estimates.

I would like the results in the form of a document showing the range of possible effects on the shuttle economic estimates and a description of the other work described in this request. In view of the urgency of the Space authorization, I would like the members of your staff assigned to this work to maintain a day-to-day working relationship with members of my staff, particularly Mr. Steven Engelberg, and others to be designated.

Sincerely,

Walter F. Mondale

Walter F. Mondale

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

May 24, 1972

OFFICE OF THE ADMINISTRATOR

Honorable Elmer B. Staats
Comptroller General of
the United States
Washington, D. C. 20548

Dear Mr. Staats:

As requested by your office, I am writing to comment on the latest revision of the proposed GAO report to Congress on the cost-benefit analyses used in support of the space shuttle program.

Discussions between NASA and GAO staff have now resolved all major issues with the GAO analysis. We find no major fault with the revised draft incorporating the revisions discussed by our staffs on May 23.

I would like to make two comments to clarify NASA's position on important aspects of the report:

1. The criterion of 10% return on investment was used by NASA and Mathematica as a conservative base point for analysis, not as a decision criterion for proceeding with the space shuttle program. As pointed out on page 3-48 of Volume 1 of the Mathematica Report, "the 10% rate of discount is among the highest rate used for the evaluation of public investment projects in large scale research and development programs." The basic result of the NASA and Mathematica studies, now confirmed by the GAO analyses, is most accurately summarized by the statement that the shuttle program now proposed is a good investment <u>even</u> if a 10% rate of return is assumed to be required.[1]

2. It should be emphasized that neither NASA nor Mathematica have stated that the economic analysis is the only justification for the space shuttle. We have repeatedly testified that economics is only one aspect of the justification for the space shuttle program. Among the other points we have made are these:

[1] See GAO note, p. 52 .

> The shuttle will provide quick and routine access to space and eliminate the constraints imposed by the present mode of space operations which is characterized by high risk, long lead times, and complex systems. The shuttle has the capability to conduct manned and unmanned experiments in a single mission which will make possible an integrated manned and unmanned space program. It will serve a large number of defense applications. The low risk access to space possible with the shuttle will increase commercial interest in exploiting space in a wide variety of beneficial applications. It will also encourage substantially increased international cooperation in space work. In addition, the shuttle will provide a quick reaction capability for space rescue. Finally, the space shuttle program provides the means for a continuing U.S. program in manned space flight after the Apollo and Skylab flights. It means that the U.S. will not abandon the field of manned space flight to the Soviet Union.

For these and other reasons which are in the national interest, NASA's position is that development of the shuttle would be justified even if we had not been able to demonstrate at this time that it will have a substantial economic return.

Sincerely,

James C. Fletcher
Administrator

GAO note: Since GAO did not deal with NASA's March 1972 estimated costs for the now-proposed Space Shuttle Program, GAO has not concluded that the program is or is not a good investment. (See pp. 11 and 34.)

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
George M. Low (acting)	Sept. 1970	Apr. 1971
Thomas O. Paine	Oct. 1968	Sept. 1970
DEPUTY ADMINISTRATOR:		
George M. Low	Dec. 1969	Present
ASSOCIATE ADMINISTRATOR:		
Homer E. Newell	Oct. 1967	Present
ASSOCIATE ADMINISTRATOR FOR MANNED SPACE FLIGHT:		
Dale D. Myers	Jan. 1970	Present
Charles W. Mathews (acting)	Dec. 1969	Jan. 1970
George E. Mueller	Sept. 1963	Dec. 1969
DIRECTOR, SHUTTLE PROGRAM:		
Charles J. Donlan (acting)	Nov. 1970	Present

U.S. GAO, Wash., D.C.

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