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EXECUTIVE SUMMARY

ECONOMIC ANALYSIS OF THE SPACE SHUTTLE SYSTEM

EXECUTIVE SUMMARY

Study directed by

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for the

National Aeronautics and Space Administration
under Contract NASW - 2081

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a.

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Dr. Klaus P. Heiss, Director of Advanced Technology Economics and Dr. Oskar Morgenstern, Chairman of the Board of MATHEMATICA, Inc. have been fully responsible for the overall conception, approach and implementation of the economic analysis of the Space Shuttle System.

The Space Shuttle Study Group included also the following members:

Dr. Kan Young, who contributed Chapter 7.0 on macro and micro-economic considerations affecting the Space Shuttle System decision.

Edward Greenblat, who contributed Chapter 8.0 and was responsible for the running of the benefit-cost evaluation programs developed by the Space Shuttle Study Group.

J. Preston Layton and his technical work group who contributed Chapters 4.0 and 5.0, the technical description of satellite payloads as well as space transportation vehicles.

Martin Wagner, who contributed Chapter 6.0 of this report on launch vehicle and payload costs.

The economic advisory group included also Dr. David Bradford, Dr. William Baumol and Dr. Roland Shephard.

The report also benefitted from the advice and guidance of Dr. Courtland D. Perkins, a member of our Technical Advisory Group.

O U T L I N E

EXECUTIVE SUMMARY

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0.1 CONCLUSIONS

The major conclusions of the Economic Analysis of the Space Shuttle System are:

- THE DEVELOPMENT OF A SPACE SHUTTLE SYSTEM IS ECONOMICALLY FEASIBLE ASSUMING A LEVEL OF SPACE ACTIVITY EQUAL TO THE AVERAGE OF THE UNITED STATES UNMANNED PROGRAM OF THE LAST EIGHT YEARS.

- A THRUST ASSISTED ORBITER SHUTTLE (TAOS) WITH EXTERNAL HYDROGEN/OXYGEN TANKS IS THE ECONOMICALLY PREFERRED CHOICE AMONG THE MANY SPACE SHUTTLE CONFIGURATIONS SO FAR INVESTIGATED. EARLY EXAMPLES OF SUCH CONCEPTS ARE RATO OF MCDONNELL DOUGLAS, TAHO OF GRUMMAN-BOEING, AND SIMILAR CONCEPTS STUDIED BY NORTH AMERICAN ROCKWELL AND LMSC - LOCKHEED; THESE CONCEPTS ARE NOW COMMONLY KNOWN AS ROCKET ASSISTED ORBITERS (RAO).

- THE CHOICE OF THRUST ASSIST FOR THE ORBITER SHUTTLE IS STILL OPEN. THE MAIN ECONOMIC ALTERNATIVES ARE PRESSURE FED BOOSTERS AND SOLID ROCKET MOTORS, EITHER USING PARALLEL BURN. A THIRD ECONOMIC ALTERNATIVE TO THESE VERSIONS IS TO USE SERIES BURN BOOSTERS.

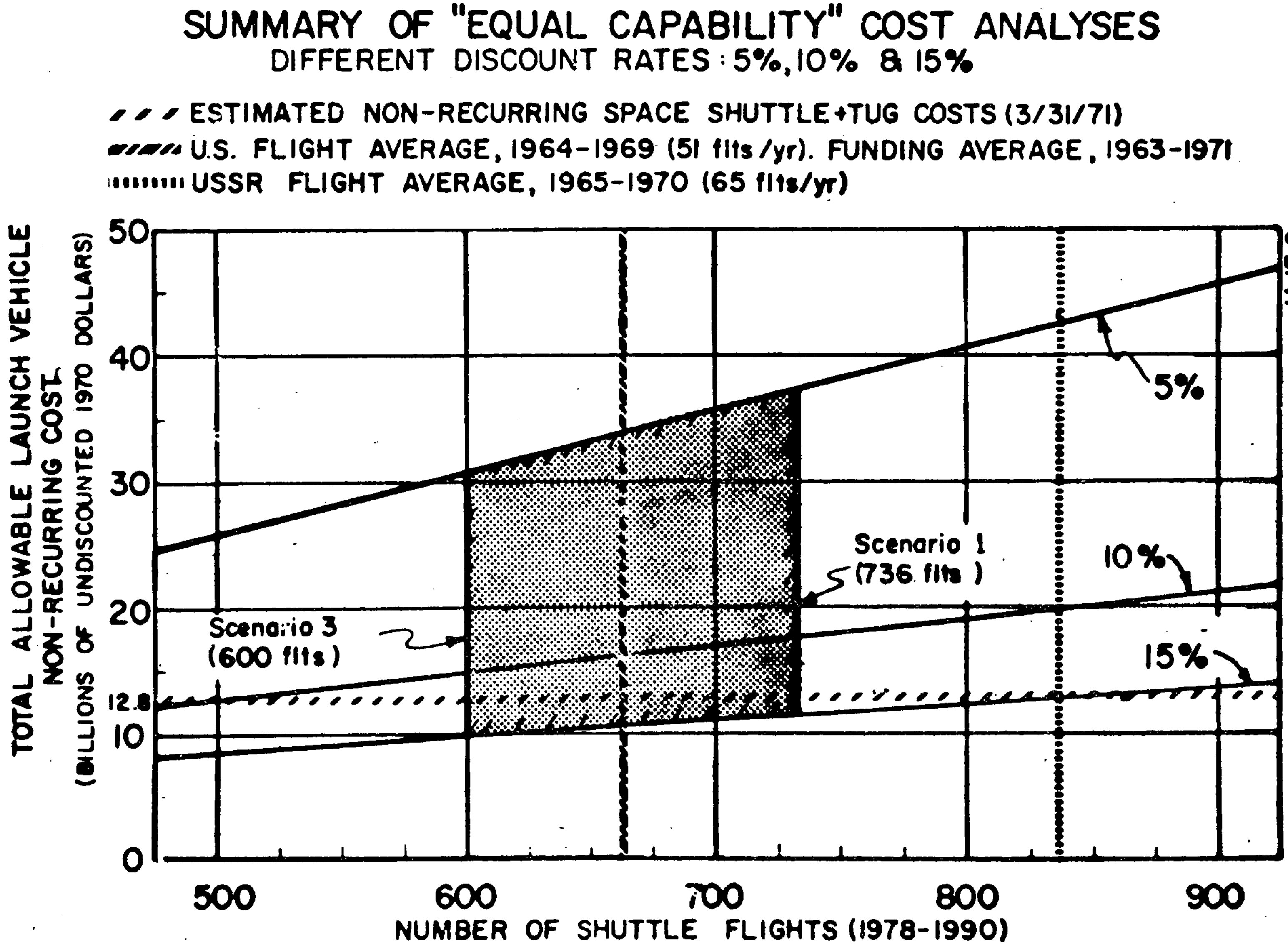
These conclusions are based on the following results of the economic analysis:

0.2 THE ECONOMIC WORTH OF A SPACE SHUTTLE SYSTEM

0.2.1 Results of the May 31, 1971 Analysis

The major findings of the economic analysis of new Space Transportation Systems reported on May 31, 1971, which were prepared for the National Aeronautics and Space Administration, are concerned with the analysis of the economic value of a reusable Space Transportation System without any particular concern as to which, among the many alternative Space Shuttle Systems would, in the end, be identified as the most economic system.

Figure 0.1 shows the summary of the major results of the May 31, 1971 analysis. In this analysis we report only the results of the "Equal Capability" Analyses, the most conservative approach to evaluate new technologies. "Equal Budget" analyses were also performed and those calculations give even more favorable economic results (see also May 31, 1971 analysis). On the horizontal axis the numbers of Space Shuttle flights between 1978 and 1990 are shown as ranging between 450 and 900 flights for that period. On the vertical axis the allowable non-recurring cost for the development of the launch vehicle -- that is, the Space Shuttle as well as the Space Tug and the required launch sites -- are shown in billions of undiscounted 1970 dollars. The benefit lines shown in this figure show how the allowable non-recurring costs -- that is, the benefits to be associated with a fully reusable Space Transportation System -- increase as the flight level expected for the 1980's increases between 450 and 900 flights. Overall, this is very much a function of the particular rate of discount (or social rate of interest) chosen and applied to the analysis. Three summaries are shown in Figure 0.1: the results of 5%, 10% and 15% social rates of discount respectively. We may wish to use them interchangeably. Since all the costs as well as the calculated cost savings were expressed in constant dollars, the interest rates applied are real interest rates which do not include elements of inflation. As shown at a 10% rate of interest, the allowable non-recurring cost would vary from about $12.8 billion (about 500 Space Shuttle flights in the 1980's), up to $20 billion at a flight level of about 850 flights for the same period. The shaded vertical



Results of May 31, 1971 Economic Study

Figure 0.1

lines in Figure 0.1 show, first, the average U. S. flight level in terms of Shuttle flights between 1964 and 1969 (61 flights per year) and reflect also the funding average between the years 1963 and 1971. Also shown are the average USSR flights for the period 1965 to 1970 (65 flights per year). Furthermore, the baseline mission model of 736 flights, at that time, is shown on the right side of the darkly shaded area where the left boundary of that area is defined by a reduced mission model of around 600 flights for Space Program 3 in that analysis. Since then, we have used in our present analysis a reduced baseline mission model of 514 flights with a potential overall level of 624 space flights. Thus, in the last six months, the analysis of the Space Shuttle System has been extended downwards to cover substantially the region between 450 and 600 flights. Also shown in Figure 0.1 are the then estimated non-recurring costs of $12.8 billion for a two-stage fully reusable Space Shuttle System* as well as the Space Tug and the required installations. We show the estimated economic potential of a reusable Space Transportation System in terms of allowable non-recurring costs as a function of several economic variables, among them the expected space activity level, the social rate of discount, and the type of cost-effectiveness analysis. The major findings of that effort are:

The major economic potential identified for Space Transportation Systems in the 1980's is the lowering of space program costs due to the reuse, refurbishment, and updating of satellite payloads. The fully reusable, two-stage Shuttle is the major system considered in the May 31, 1971 report, but not the only system to achieve reuse, refurbishment and updating of payloads. Payloads were assumed to be refurbished on the ground, with refurbishment costs varying between 30% and 40%. The launch costs of the Space Shuttle and Space Tug needed to recover and place the refurbished payloads are also allowed for. We strongly recommended in May that other systems be studied to determine the extent and the cost at which they can achieve reuse, refurbishment, and updating of payloads.

*The selected Space Shuttle System is no longer a two-stage fully reusable system and has substantially reduced non-recurring costs [see section 0.2].

The cost reductions identified originate in three distinct areas:

(a) The research, development, test and evaluation (RDT&E) phase of new payloads (satellites);

(b) The construction and operating costs of payloads (satellites) for different space missions;

(c) The cost of launching payloads into orbit.

The projected non-recurring cost associated with developing the Space Shuttle and Tug as configured in May, 1971, (a two-stage system) is shown by the economic analysis to be covered by the identified benefits provided the United States intends to operate a space program with the number of flights equal to the unmanned space program activities of the United States in the 1960's. The direct costs (payload and transportation) of space activity carried out by a Space Shuttle System are expected to be about one-half of the direct costs of the current expendable transportation system.

Manned space flight options -- for example, a manned lunar option -- are also analyzed. They show that a Space Shuttle System offers economic advantages also in terms of transportation costs for some large lunar and planetary (or defense) space flight options for the 1980's. These advantages were not considered when formulating the basic conclusions of the economic study, due to the great uncertainty of these options being adopted by the United States.

The choice of the social discount rate has a major influence on the economics of a new Space Transportation System. Differences in the rate applied to the analysis outweigh many other important issues usually raised -- and analyzed -- in the context of large scale RDT&E projects, including uncertainties in the cost data. As shown in this report, the social rate of discount influences not only the overall worth of a new Space Transportation System, but also the choice of specific technical configurations in deciding among alternative technical approaches to bring about a reusable Space Transportation System.

The May 31, 1971 report concludes that the economic justification of a reusable Space Transportation System is not tied to the question of manned versus unmanned space flight. Space programs used and analyzed are in line with the activity and funding levels of the unmanned United States space program of the 1960's (NASA, DoD, and commercial users included). If a substantial number of manned space flights were to be undertaken in the 1980's, a Space Shuttle System would also contribute significantly to lowering the costs of such missions and activities.

The May 31, 1971 report analyzes the economically allowable non-recurring cost of a reusable Space Transportation System. It is the task of the present report to identify the economically best reusable Space Transportation System among all the possible required alternatives.

A major point of the May 31st report is: any investment can only be justified by its goals. This applies to business as well as to government, hence also to NASA. A new, reusable Space Transportation System should only be introduced if it can be shown, conclusively, what it is to be used for and that the intended uses are meaningful to those who have to appropriate the funds, and to those from whom the funds are raised, as well as to the various government agencies that undertake space activities. The space goals can be political (rivalry with the space programs of other countries), military (to meet military space efforts of other countries who use the potential of space to meet needs of national security), scientific (for example, astronomy), or commercial (for example, earth resources applications). All these goals will, of course, be mixed into one national space program, representing to various degrees a joint demand for space transportation with a varying mix of payloads.

0.2.2 Updated Economic Results On The Economic Worth of A Space Shuttle System

Since May 31, 1971 our efforts concentrated on two major questions: first, to what extent is the overall economic worth of a Space Shuttle System modified by new inputs given to our study; and, second, which of the many alternative Space Shuttle configurations is the most economical.

The new inputs reflect a substantially modified NASA and DoD Baseline Mission Model for the 1980's, and make a new assessment of payload effects for different missions; very importantly, new alternative Space Shuttle Systems that still promised the achievement of most of the objectives of the Space Shuttle program but at considerably reduced non-recurring costs in the 1970's, were considered.

Table 0.1 shows the estimated complete direct life-cycle costs for a NASA and DoD U. S. space program from 1979 to 1990 (twelve years) of 514 Space Shuttle flights, or an average of 43 Space Shuttle flights per year, in this period. This space program is based on the NASA Baseline Mission Model, including scientific and application missions as well as some manned space flight activity, and a modified DoD mission model.

As can be seen from Table 0.1, the same facts hold for the basis of the economic analysis of the Space Shuttle System as in the May 31, 1971 Report:

(1) The Space Shuttle System has substantially higher research, development and investment costs (non-recurring costs) associated with it than any of the current expendable or new expendable systems. This remains true, although the non-recurring costs of the Thrust Assisted Orbiter Shuttle (TAOS) System are substantially lower than the corresponding fully reusable two-stage Shuttle System costs of May, 1971.

(2) The TAOS Space Shuttle System promises reductions in the recurring launch costs of Space Transportation.

(3) The Space Shuttle System promises a reduction in the costs of satellite payloads through reuse, refurbishment, in-orbit checkout of payloads, and possible updating and maintenance of payloads in orbit or on the ground.

It is the combined reduction in launch costs and payload costs that underly the economic justifications of the TAOS Space Shuttle System. These life-cycle costs are the starting point and the basis of our economic analysis. A wide variety of alternative Space Shuttle Systems was investigated by us with a wide variety of technical changes when compared with the May, 1971 Space Shuttle configuration.

TABLE 0.1: SPACE TRANSPORTATION SYSTEMS COST SUMMARY [1]

(Millions of Undiscounted 1970 Dollars)

Modified NASA and DoD Baseline
514 Space Shuttle Flights (1979-1990)

	Current Expendable	New Expendable	TAOS Space Shuttle and Tug
EXPECTED LAUNCH VEHICLE COSTS			
Non-Recurring Costs (FY1972-87)	1,620	2,000	7,450
Recurring Costs (FY1977-1990)	10,600	8,760	4,800
Total Launch Costs	12,000	11,000	12,000
EXPECTED PAYLOAD COSTS (SATELLITES)			
RDT&E (FY1975-1990)	11,000	10,600	9,880
Recurring Costs (FY1976-1990)	18,800	18,400	12,700
Total Payload Costs	30,000	29,000	23,000
EXPECTED TOTAL SPACE PROGRAM COSTS	42,000	40,000	35,000

(1) Source: Adapted from Aerospace Corporation and Contractor Data

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On each of these changes a substantial set of alternative calculations was made, in keeping with the analyses and methodology already developed.

The results of the updated economic analysis are shown in the next three figures. In Figure 0.2 the estimated non-recurring costs of alternative Space Shuttle Systems are shown on the horizontal axis. These non-recurring costs include the full non-recurring costs of the Space Shuttle System with at least the same capabilities as those given by the expendable Space Transportation System. Where the economic analysis of a space program indicated the continued use of expendable rockets -- e.g., Scout Rockets -- then these system costs have been included as Space Shuttle System costs. Similarly, in the time of the Space Shuttle System phase-in -- to replace expendable Space Transportation Systems -- the cost of expendable systems, as required, is also included as a Space Shuttle cost. Most important, the non-recurring costs of the Space Tug, which gives the Space Shuttle System the capability to deploy and bring back payloads from all earth orbits when economically justified, are fully included. Finally, the non-recurring costs, as used in our analysis, also include the costs of two launch sites, (ETR and WTR). It is on the basis of these non-recurring costs that the economic evaluation of the Space Shuttle System has been carried out.

The estimated non-recurring costs also include fleet investment. An estimated five Space Shuttles will be required to fulfill the NASA and DoD Baseline Mission Models for the 1980's. Fleet investment includes the orbiter procurement cost for all configurations considered, but reusable booster costs have been amortized as a recurring cost except for the manned flyback booster case.

Not shown in Figure 0.2 are the RDT&E and investment costs to the First Manned Orbited Flight (FMOF) of the Thrust Assisted Orbiter Shuttle (TAOS), estimated now by NASA at $5.5 billion. The estimates of alternative Space Shuttle Systems in Figure 0.2 are grouped into two classes: first, the modified two-stage reusable Space Shuttle Systems that were investigated in the past months as alternatives to the two-stage fully reusable Space Shuttle System of May 31, 1971. These systems all have associated

SPACE SHUTTLE AND TUG

ESTIMATED TOTAL NON-RECURRING COST (BILLIONS OF 1970 DOLLARS)

RDT & E AND INVESTMENT (5 VEHICLES EACH)

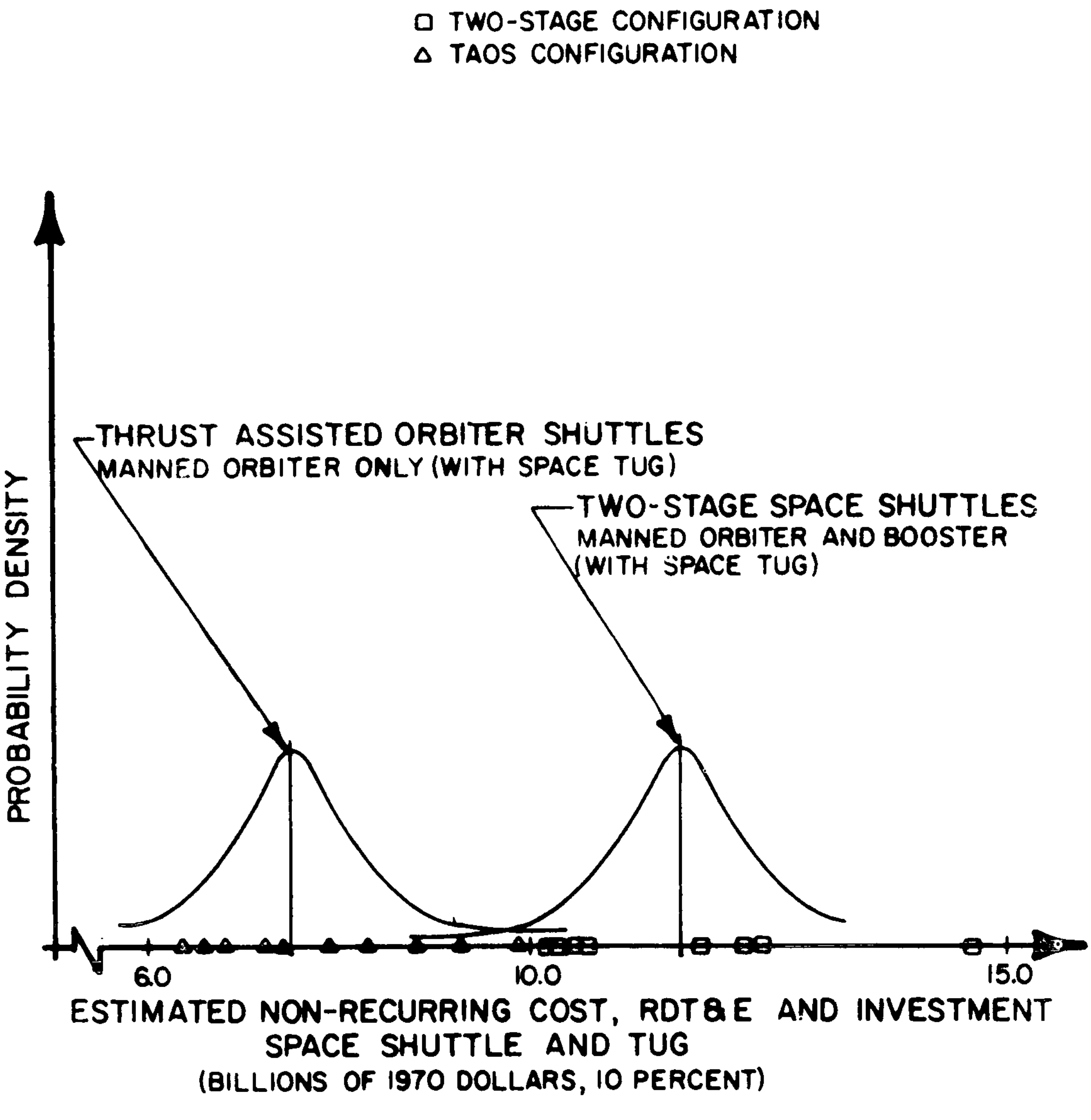


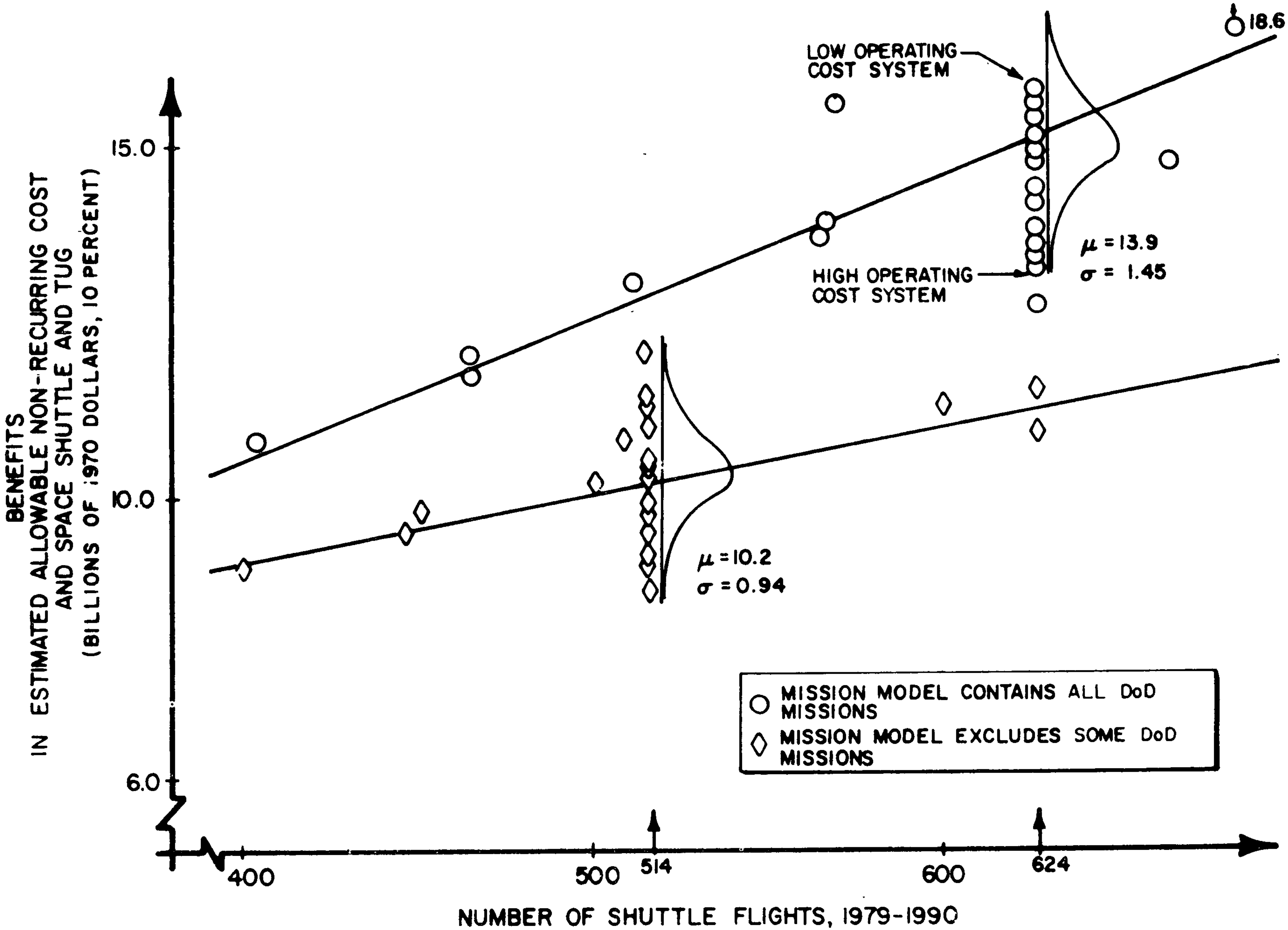
Figure 0.2

with them lower non-recurring costs than the estimate for the original fully reusable Space Shuttle System. Considerable variation existed with regard to the non-recurring costs of these modified two-stage (manned booster) systems. In addition, therefore, we show the mean of these estimates as well as the standard deviation (σ) of the non-recurring cost estimates of these systems. As shown in Figure 0.2, the mean of the non-recurring costs of such modified two-stage Space Shuttle Systems is $11.5 billion, the standard deviation is $1.44 billion.

Similarly, also shown in Figure 0.2 are estimated total non-recurring costs of Thrust Assisted Orbiter Space Shuttle Systems (TAOS) that include a wide variety of technical choices, all having in common that only the orbiter is manned, with external hydrogen/oxygen tanks and all are assisted at take-off by either solid rocket motors or pressure fed rocket systems. The mean of the non-recurring cost estimates of such systems is $7.5 billion. These include about $1.6 billion for the non-recurring costs of the Space Tug and the additional required launch site. They also include a fleet of 5 Space Shuttles, each estimated at about $300 million. When Space Tug and WTR costs are excluded ($1.6 billion), as well as 3 Space Shuttle vehicles (about $900 million), then the estimated non-recurring costs in the 1970's (comparable, roughly, to FMOF costs) are estimated to be $5.0 billion (1970 dollars). The standard deviation of this estimate if $900 million, again in 1970 dollars.

Using these alternative Space Shuttle Systems, a comprehensive set of economic analyses was performed along the lines of the May 31, 1971 report to determine the economic benefits of a Space Shuttle System. In Figure 0.3 the results of the equal capability cost-effectiveness analysis are shown, at a 10 percent social rate of discount, directly comparable to the results of May 31, 1971 as shown in Figure 0.1. The benefits are expressed in Allowable Non-Recurring Costs, thus making the benefits shown directly comparable to the estimated non-recurring costs of Figure 0.2.

Major variations were introduced in the space program activities of the 1980's, concentrating on the lower role of expected space activities of the 1980's and beyond. While in the May 31st analysis the area of interest -- based on historical, unmanned activities of the United States (and the Soviet



The Economic Benefits of a Space Shuttle System

Figure 0.3

Union) -- was confined to between 500 and 900 Space Shuttle flights in the 1978 to 1990 period, the present analysis was confined to look at the range of Space Shuttle flights between 400 and 650 Space Shuttle flights, with major variations in the analysis at 514 and 624 flights.

Two separate benefit lines were arrived at and are shown in Figure 0.3: first, the analysis concentrating around 514 Space Shuttle flights shows the economic results with the exclusion of some DoD missions that are particularly suited for Space Shuttle operations; second, the analysis concentrating at around 624 Space Shuttle flights takes the same NASA mission model, now, however, including on the DoD side the missions omitted in the first analysis.

With regard to the lower benefit line, we conclude that at 514 flights in the 1979-1990 period, the estimated benefits of a Space Shuttle System are $10.2 billion in 1970 dollars with a variance of $940 million -- expressed in allowable non-recurring costs. The economic "break even" point is reached at an annual space activity level of about 30 Space Shuttle flights, carrying satellite payloads. This annual level of NASA and DoD space activity in the 1980's and beyond will justify the development of the TAOS Space Shuttle at a social rate of discount of 10 percent.

When, on the other side, Space Shuttle related DoD missions are included, the economic analysis shows, at 624 Space Shuttle flights in the 1979 to 1990 period, an estimated benefit of $13.9 billion of allowable non-recurring costs, with a standard deviation of ± $1.45 billion. As activity levels are increased or decreased around these space programs, the expected benefits of a Space Shuttle System increase or decrease as shown by the two benefit lines in Figure 0.3. The TAOS Space Shuttle System will "break even" at an annual activity level of about 25 Space Shuttle flights, carrying satellite payloads, when the "624" mission model is taken as representative of U. S. space activities in DoD and NASA for the 1980's.

Again, we want to emphasize that these results reflect the benefits of a Space Shuttle System when applying a 10 percent real social rate of discount to the complete economic analysis.

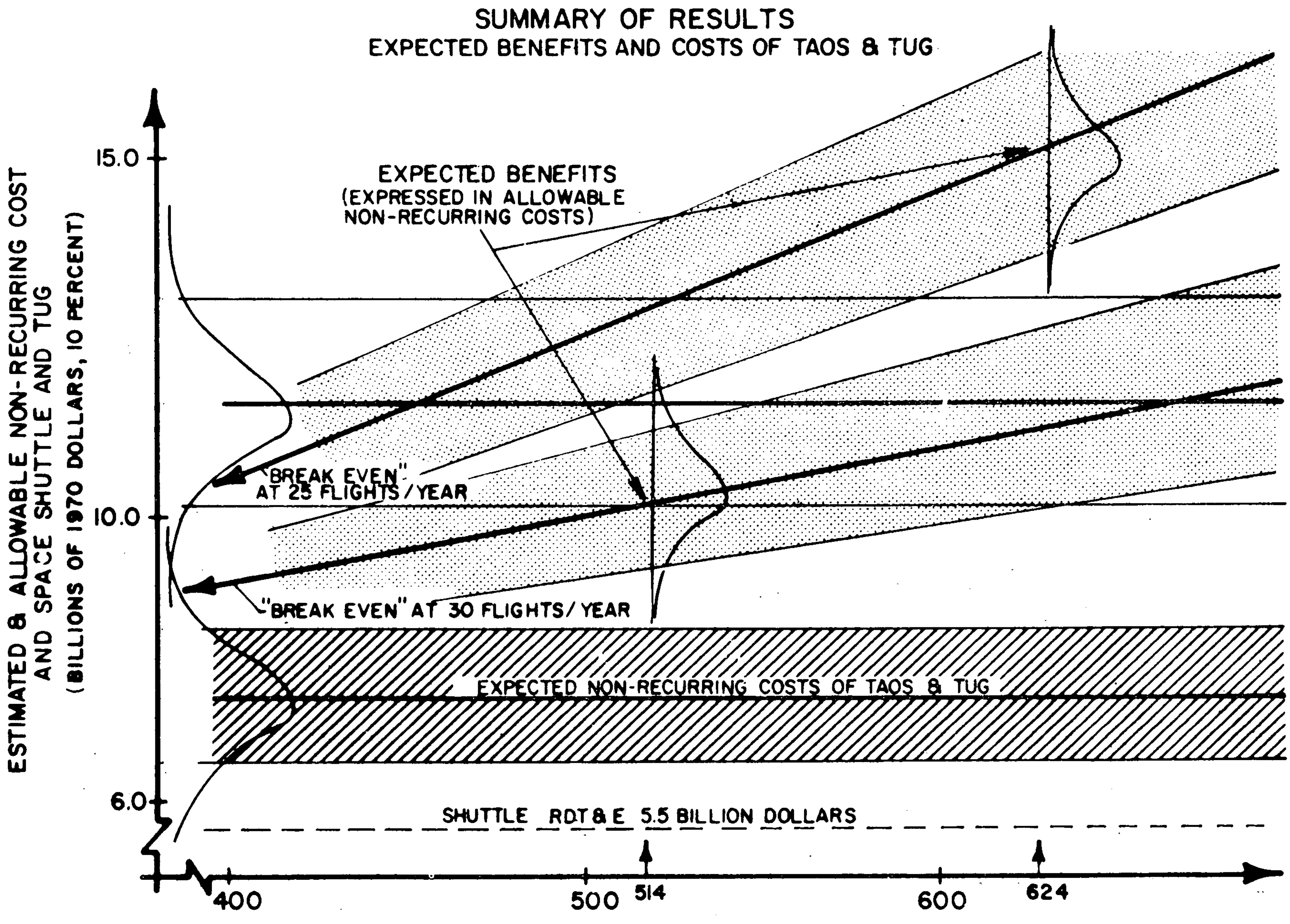
By combining Figures 0.2 and 0.3, we can directly judge the results of the economic analysis of a Space Shuttle System.

In Figure 0.4, we show on the vertical axis the estimated non-recurring costs -- as developed in Figure 0.2 -- and also the benefits of a Space Shuttle System in terms of "allowable non-recurring costs" as developed in Figure 0.3. The estimated non-recurring costs of the TAOS Space Shuttle Systems are emphasized and the expected standard deviation of these costs is shown by the shaded area around the non-recurring cost estimate of TAOS. Similarly, the benefit lines as developed in Figure 0.3 are shown; the standard deviation around these estimates is indicated again by the shaded areas.

From the results as shown in Figure 0.4, WE CONCLUDE THAT THE DEVELOPMENT OF A TAOS SPACE SHUTTLE SYSTEM IS ECONOMICALLY JUSTIFIED, within a level of space activities between 300 and 360 Shuttle flights in the 1979-1990 period, or about 25 to 30 Space Shuttle flights per year, well within the U. S. Space Program including NASA and DoD. If the NASA and DoD mission models are taken at face value (624 Space Shuttle flights in the 1979-1990 period), <u>the estimated benefits of a Space Shuttle System are estimated to be $13.9 billion</u> with a standard deviation of ± $1.45 billion expressed in 1970 dollars (at a 10% social rate of discount). If parts of the expected U. S. Space Program are substantially modified (514 Space Shuttle flight level in the 1979-1990 period), <u>the estimated benefits of a Space Shuttle System are $10.2 billion</u>, with a standard deviation of $940 million (at a 10% social rate of discount).

<u>The estimated non-recurring costs</u> directly comparable to the benefits expressed in "allowable" non-recurring costs of a <u>TAOS Space Shuttle System are $7.5 billion with a standard deviation of $960 million</u>.

Since the complete economic evaluation of the Space Shuttle System as summarized here REFLECTS THE RESULTS WHEN USING A 10 PERCENT REAL SOCIAL RATE OF DISCOUNT, THE ECONOMIC RESULTS IN SUPPORT OF THE TAOS SPACE SHUTTLE DEVELOPMENT HAVE TO BE REGARDED AS VERY STRONG IN THE CONTEXT OF UNITED STATES NATIONAL PRIORITIES.



Expedted Benefits and Costs of a TAOS Space Shuttle System

Figure 0.4

0.3 THE MOST ECONOMIC SPACE SHUTTLE CONFIGURATION: TAOS

As shown in Figure 0.2, there exists a great variety of alternative Space Shuttle configurations that have been studied in the past months and years to achieve the ultimate goal of a reusable Space Transportation System. If all of the Space Shuttle Systems had the same recurring costs (roughly the cost per flight) and differed only in the expected non-recurring costs, as shown in Figure 0.2, then the economic problem of choice among the proposed systems would be straightforward: find the system with the lowest non-recurring costs (RDT&E and investment).

However, the economic task is not that simple: most of the reductions in non-recurring costs are achieved by increasing, in one way or another, the operating costs of the Space Shuttle System in the 1980's and beyond. It is the economic tradeoff between non-recurring cost savings in the 1970's versus expected increases in operating costs in the 1980's and beyond that becomes the subject of economic analysis when determining the most economic Space Shuttle configuration. It is only through such an analysis that a single system or family of systems can be identified with confidence among the wide variety of alternative choices. This was done extensively by our group.

The economic methodology of determining the most economic Space Shuttle System has been put forth in detail in this report. This effort will have to take into account a variety of economic factors. Foremost among these are (1) the objectives to be achieved by an investment like the Space Shuttle System, (2) the identification of cost-effective Space Shuttle configurations, (3) the identification, among the cost-effective configurations, of a single most economic Space Shuttle System which again will depend on (a) the activity level to be expected in the 1980's and beyond, (b) the social rate of interest to be applied to the investment decision and, (c) the anticipated payload effects of the Space Shuttle System in the area of reducing payload costs, and making possible the reuse, refurbishment and updating of payloads. The estimates of the economic benefits are also dependent on the type of cost-effectiveness analysis used within the range of equal capability and equal budget analyses. Most important are the objectives within which the analysis is carried out. We, therefore, state these here explicitly.

0.3.1 The Objectives of a Reusable Space Transportation System (STS)

In the economic analysis of this report the principal objectives of a Space Shuttle System are considered to be:

(a) A new capability of meeting all now foreseeable space missions in NASA, DoD and elsewhere, including manned space flight capabilities. Thus, whenever a proposed system cannot meet all requirements, the costs of the required expendable systems are fully included as part of that Space Shuttle System.

(b) Reduction of space program costs (manned, unmanned, NASA, DoD, commercial users) over the present expendable Space Transportation costs through reuse, refurbishment, maintenance, and updating of payloads. The Space Tug is therefore included as an integral part of a reusable Space Transportation System.

(c) Reduction of Space Transportation costs for all missions (low energy, high energy, manned).

(d) Option of later transition to a fully reusable system.

The above four objectives were considered to be the principal motivations for the investment in a reusable Space Transportation System. Additional objectives supporting the major objectives were considered to be:

(e) A low non-recurring cost to meet funding constraints.

(f) Assurance of a low cost per launch. Launch costs of up to about $10 million are justifiable when payload costs and effects are considered.

It is with these objectives in mind that the results of this report hold. Had the objectives been different, for example, to maintain a manned space flight capability only, or to undertake a limited technology program in support of future Space Transportation only, then a different economic analysis would have to be made, since the benefits of the Space Shuttle development -- the promised capabilities -- are analyzed here within the context of overall Space Transportation capability.

0.3.2 Space Transportation Systems Considered

Over the last two years, but particularly in the effort of the past six months, many alternative Space Shuttle concepts have been considered. It is difficult to follow and appreciate all the different ideas proposed to achieve the objectives listed in the previous section. Several basically different approaches were investigated, among them two-stage fully reusable systems, two-stage systems with some external (expendable) tankage, manned orbiters with a variety of unmanned boosters, single orbiters with parallel burn and rocket assists, single stage to orbit concepts, stage and one-half concepts, and others. When variations of technical options within each of these approaches are considered, then literally hundreds of different Space Shuttle Systems have been studied by NASA, the Phase B Study contractors and other interested parties. It can be affirmed that seldom if ever before has a single investment program of the scope and size as the Space Shuttle System been studied in such detail -- both technical and economic -- as to alternative approaches to achieve the objectives listed. The configurations listed and discussed in the subsequent pages are already the result of an extensive technical and economic elimination process. Some of these systems are described in detail in this report. Nevertheless, large economic differences still exist between these configurations.

This study examines in detail the economics of the following alternative Space Transportation Systems for use in the decade of the 1980's:

A. The Current Expendable System

The system envisages continuing use of the types of expendable launch vehicles presently in the United States inventory.

B. The New Expendable System

As its name implies, this envisages use of a new family of expendable vehicles designed to have better (economic) performances than the Current Expendable vehicles. Where economically justified, payloads were redesigned to take advantage of the New Expendable System performances.

C. Space Shuttle System

Systems considered within this category differ in concept from the previous systems in implying reusable rather than expendable launch vehicles. Two major elements are employed in each of these: a Space Shuttle which operates between the earth's surface and earth orbits of at least 185 kilometers; and a Space Tug which can be transported within the Space Shuttle and which can operate from the relatively low orbit of the Space Shuttle to high earth orbits such as the synchronous equatorial orbit (35, 500 kilometers). Only the combined Space Shuttle and Tug systems provide a reusable launch system able to place payloads into all widely used earth orbits, and also able to recover payloads from these orbits. The capabilities, performances and operations of the Space Tug were assumed as given and fixed for purposes of this study, which concentrates on identifying the most economic Space Shuttle among the alternative configurations. The following systems were analyzed extensively across a wide variation of expected mission models and levels of demand for Space Transportation in the 1980's:

a. The two-stage fully reusable Space Shuttle. The baseline used also in the evaluation of the May 31, 1971 report aimed at determining the economic potential of a reusable Space Transportation System.

b. Two-stage Space Shuttle Systems with external hydrogen tanks on the orbiter.

c. Two-stage (F-1) Flyback Space Shuttle System also known as the Reusable SIC. The orbiter used in this version is the present baseline orbiter (with external hydrogen and oxygen tanks, a 60 x 15 payload bay); the ultimate capability of this system was considered to be 40K pounds to polar orbit of 185 by 185 kilometers.

d. Series Burn Pressure Fed Booster (SPFB) Shuttle System, with the present baseline orbiter.

e. Series Burn Solid Rocket Motor Boosters (SSRM) Shuttle System, with the present baseline orbiter.

f. (Twin) Pressure Fed Booster (TPFB) Shuttle Systems, with the present baseline orbiter and parallel burn at takeoff (TAOS).

g. (Twin) Solid Rocket Motor Boosters (TSRM) with the present baseline orbiter with parallel burn at takeoff (TAOS).

h. Identical Vehical Space Shuttle System, with two identical orbiters and three drop tanks sandwiched between them.

Each of these systems has associated with it a considerable amount of non-recurring costs, (research and development costs as well as initial fleet investment costs), and substantially different cost per flight of the systems varying from $4.5 million per launch to over $15 million per launch. The total non-recurring costs, including the cost of the Space Tug and two launch sites varies from a low of $6.9 billion to a high of $14 billion (see also Figure 0.2).

D. A Space Glider Combined with a New Expendable Space Transportation System

The Space Gliders considered had payload bays of 60 x 15 feet and 40 x 12 feet; they would be launched on expendable vehicles. Costs per flight of these systems are in excess of $30 million per launch.

In addition to the above configurations, other variations in the Space Shuttle were also considered as alternatives. One such alternative is a 40 x 12 payload bay with 30K pounds of equatorial launch capability for the Space Shuttle System.

The cost estimates and breakdowns for the alternative Space Shuttle configurations are given, in detail, in Chapters 6 and 8 of the report.

In Figures 0.5 and 0.7 the major alternative Space Shuttle configurations are shown as identified and recommended by the Phase B study contractors in their reports of September 1, 1971 (Figure 0.5), November 3, 1971 (Figure 0.6) and December 15, 1971 (Figure 0.7). The non-recurring costs of the alternative Space Shuttle configurations are shown on the vertical axis of each of these figures, while the contractor estimated costs per flight of each alternative configuration are shown on the horizontal axis of each of these figures, all expressed in constant dollars.

In Figure 0.8, all of the systems are shown that were studied and proposed in the past six months. Among these the most economic Space Shuttle configuration has to be identified.

RECURRING COSTS (PER FLIGHT) vs NON-RECURRING COSTS OF ALTERNATE CONFIGURATIONS
SEPTEMBER 1, 1971 DATA

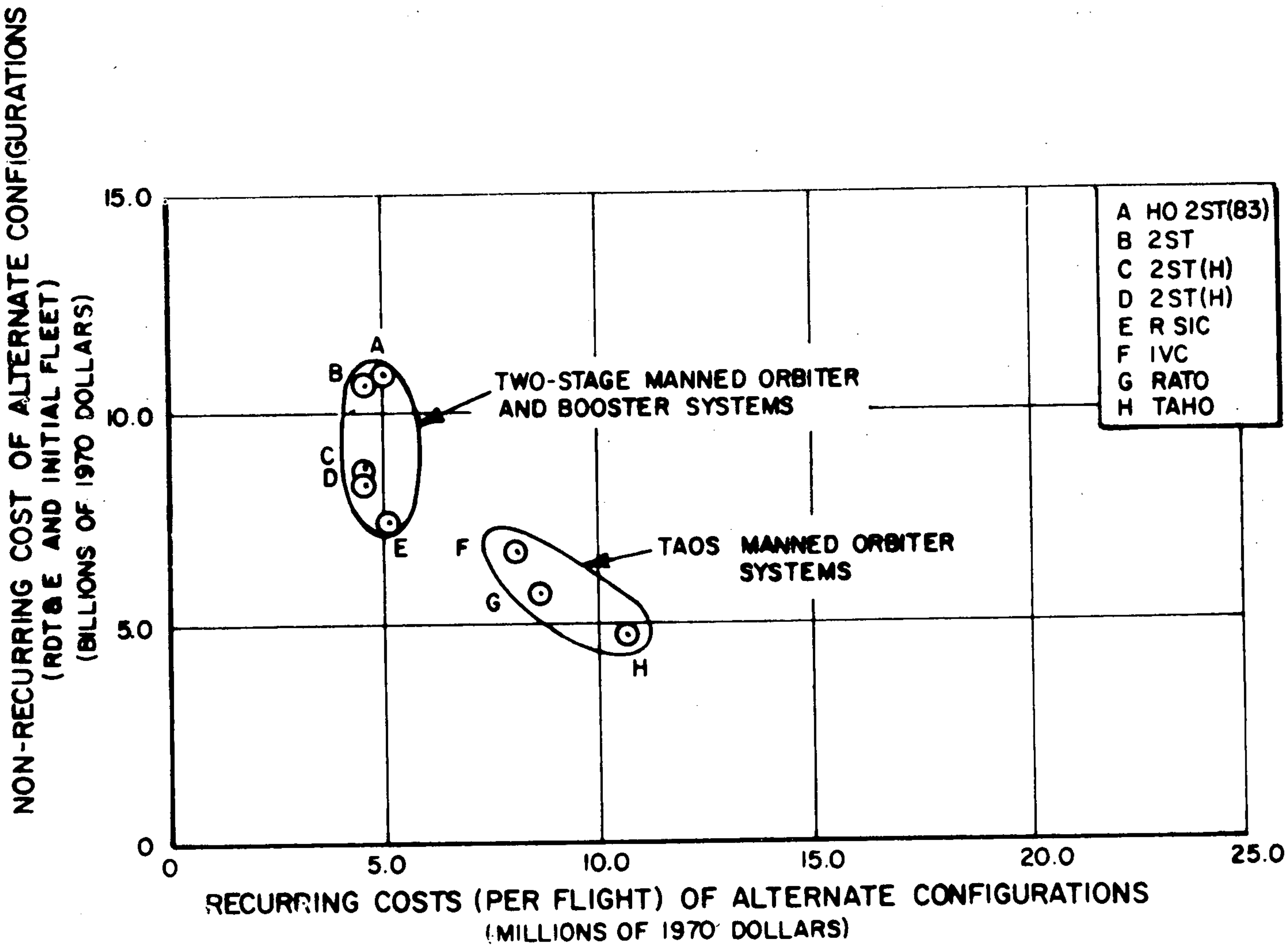


Figure 0.5

RECURRING COSTS (PER FLIGHT) vs NON-RECURRING COSTS OF ALTERNATE CONFIGURATIONS

NOVEMBER 3, 1971 DATA

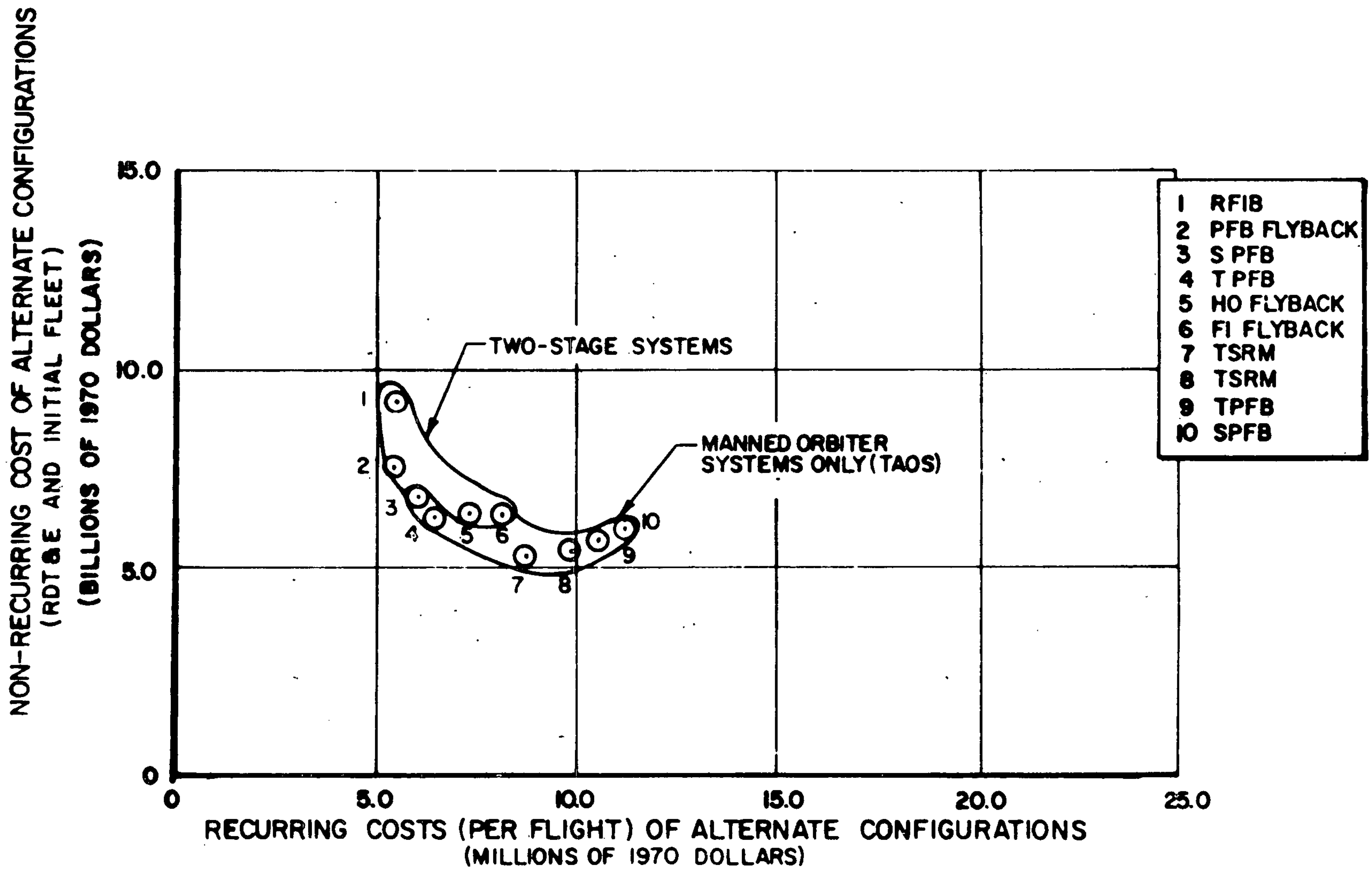


Figure 0.6

RECURRING COSTS (PER FLIGHT) vs NON-RECURRING COSTS OF ALTERNATE CONFIGURATIONS

DECEMBER 15, 1971 DATA

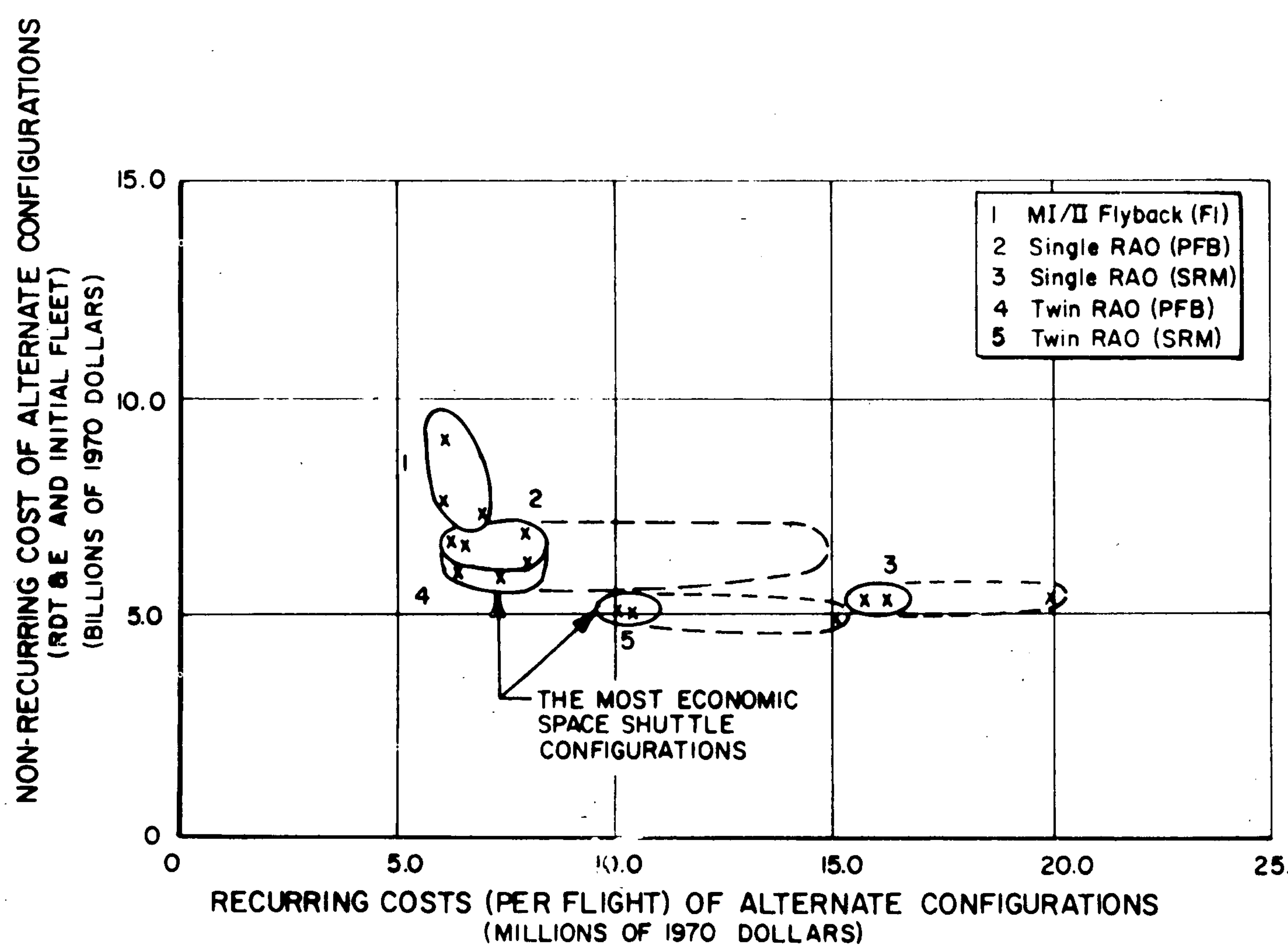


Figure 0.7

0.3.3 Results of the Economic Analysis on Alternative Space Shuttle Systems

The methodology for the determination of cost-effective systems, the meaning and significance of the economic tradeoff line, as well as the theoretic identification of the most economic systems among cost-effective systems is described in the report. Here the results are represented in convenient diagrammatic form in the next figures.

In Figure 0.8 we show two important results: first, among the different concepts investigated and reported on by NASA and Industry there emerge the following families of systems as cost-effective: the original two-stage fully reusable Space Shuttle System at an estimated non-recurring cost of $12.8 billion and the lowest expected cost per flight of $4.6 million, a family of cost estimates associated with F-1 Booster technology, also known as the Reusable SIC, and shown by the shaded area in Figure 0.8 reflecting December 15 variations in industry estimates; a family of cost estimates associated with series burn and parallel burn pressure fed Space Shuttle Systems, all having in common the new baseline (manned) orbiter and unmanned recoverable pressure fed booster systems; a family of cost estimates associated with Solid Rocket Motor boosters and the new baseline orbiter, using parallel burn operations (i.e., orbiter engines are ignited at takeoff); and a family of cost estimates for series burn solid rocket motor boosters, again using the new baseline orbiter. Also shown are all the other cost estimates since September 1, 1971 of alternate Space Shuttle configurations. And not quite accurately shown, due to the high cost per launch, is the Space Glider concept discussed by different agencies and NASA with a cost per flight of $30 million or more and a non-recurring cost of between $2.8 and $4.1 billion. Within the economic analysis and the objectives of the Space Shuttle program stated in the previous section, the Space Glider is a cost-effective system, but clearly not the most economic system among the alternative devices as the further economic analysis will show.

The black-shaded areas in Figure 0.8 show, with emphasis, the likely cost estimates for the two most interesting alternative Space Shuttle Systems, the "twin pressure fed parallel burn booster" Space Shuttle and the "twin SRM, parallel burn" Space Shuttle concepts, emphasizing the

COST-EFFECTIVE SPACE SHUTTLE SYSTEMS DEFINED BY EXPECTED NON-RECURRING & RECURRING COST ESTIMATES

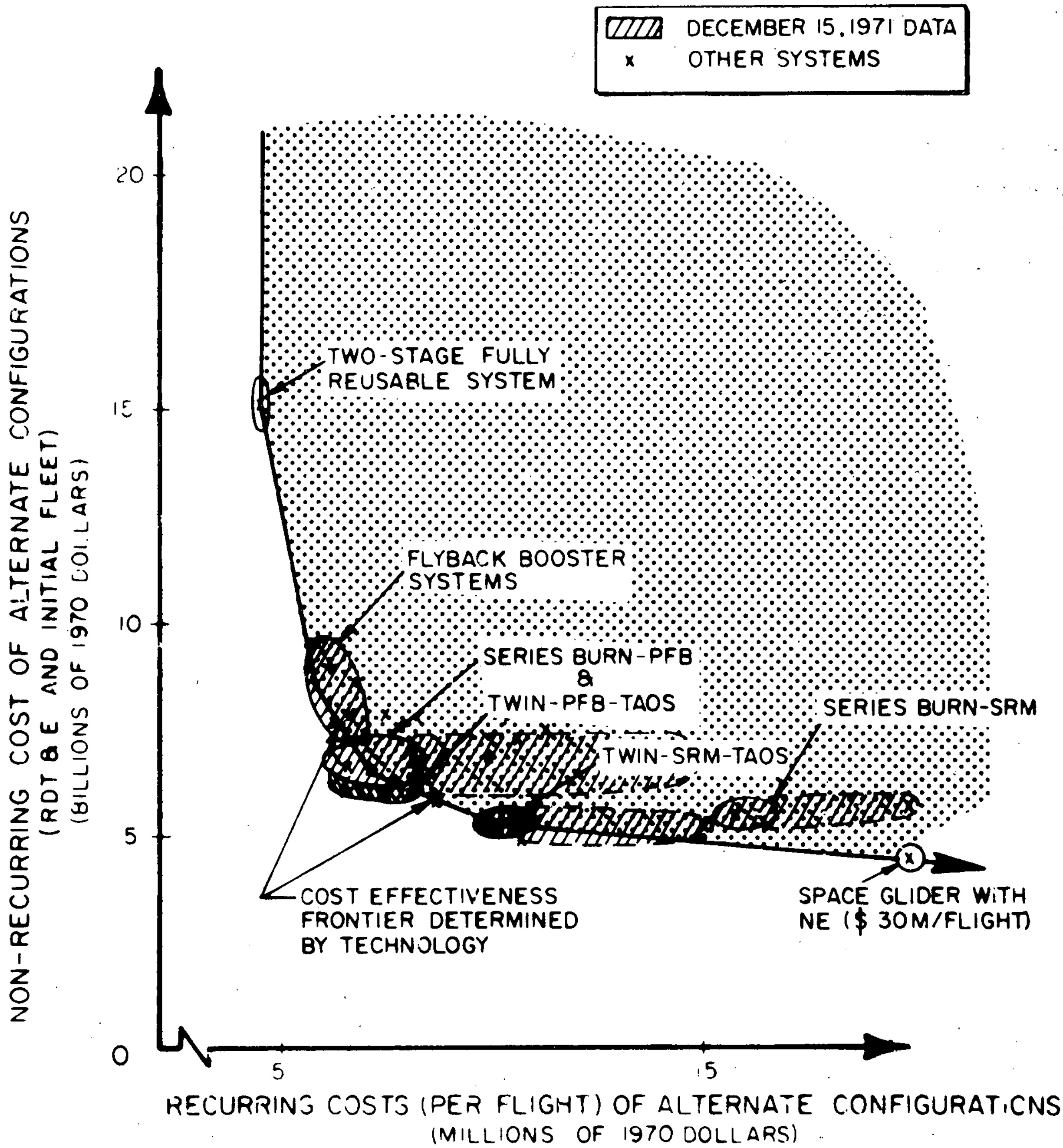


Figure 0.8

most recent and frequently quoted recurring and non-recurring cost estimates for these systems in industry. Closely associated, economically, with the "twin parallel burn PFB" Space Shuttle are the alternative, series burn pressure fed booster systems, as shown in Figure 0.8.

Finally, also shown in Figure 0.8 is the cost-effectiveness frontier as defined by these alternative technological choices: systems above and to the right of this cost-effectiveness frontier are all possible and feasible; many of these have been studied in Phase B of the Space Shuttle study effort, and some of these are indicated in Figure 0.8. The existence of systems to the left and below the cost-effectiveness frontier as shown in Figure 0.8 can, by now, be excluded with some confidence; their existence would imply that, within the range of the defined objectives of a Space Shuttle program lower non-recurring <u>and</u> recurring cost combinations were feasible; although the existence of such systems can never be excluded with complete certainty by anybody, it seems highly unlikely that such opportunities were missed in the effort of the past months and years (within the present state of technology and know-how).

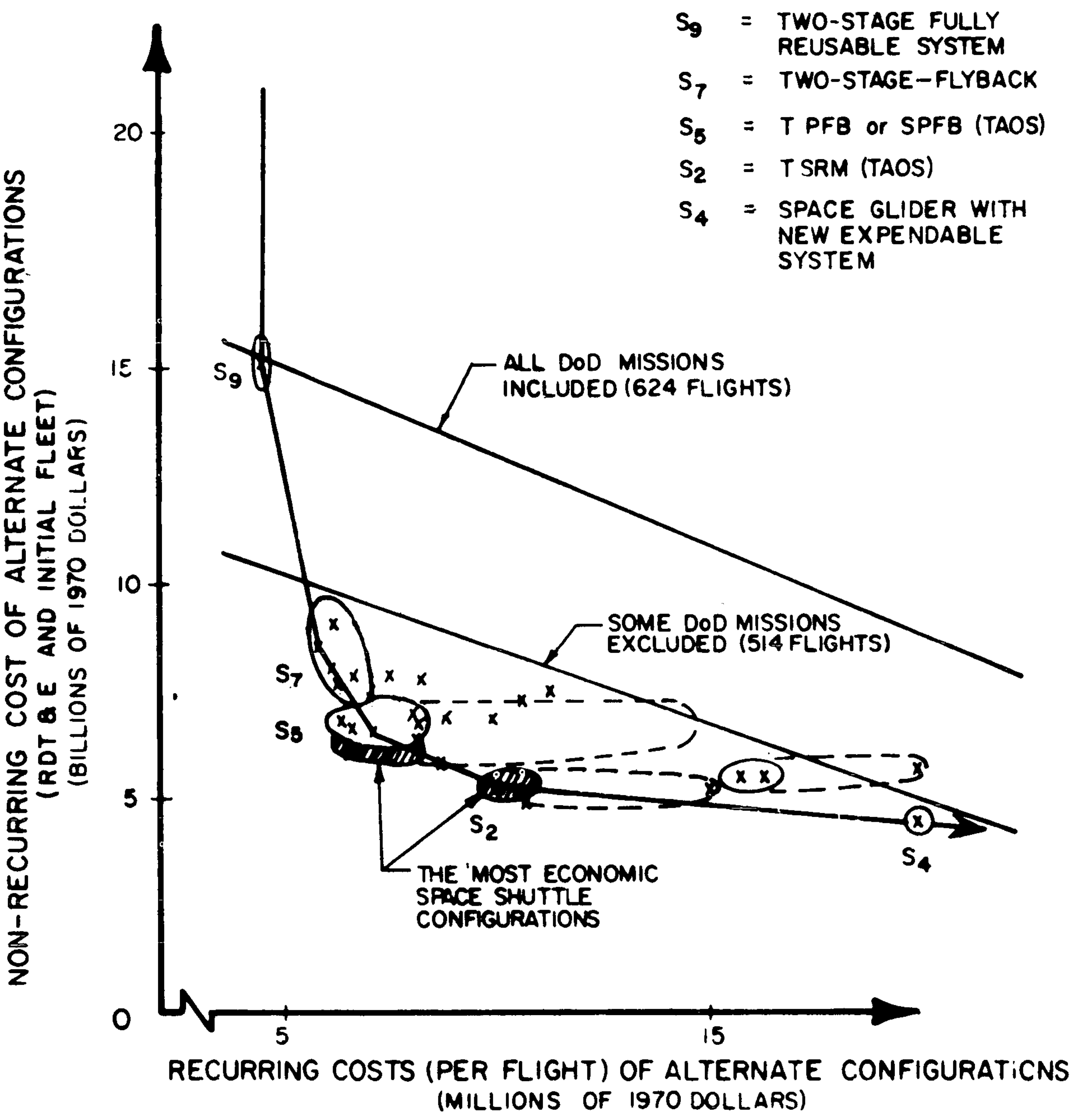
The economic analysis was carried out within the cost estimates -- and their uncertainty estimates as shown in Figure 0.8. Figures 0.9, 0.10 and 0.11 summarize the results of the economic analysis: within the expected activity levels of space programs in the 1980's, a reasonable variation in the social opportunity cost of investment funds in the 1970's and a considerable variation in the expected payload effects due to repair, reuse, refurbishment and updating of payloads the "SRM-PARALLEL BURN BOOSTER", and the "PRESSURE FED-PARALLEL BURN BOOSTER" CONCEPTS (TAOS) EMERGE CLEARLY AS THE MOST ECONOMIC SPACE SHUTTLE ALTERNATIVES, with the "SERIES BURN PRESSURE FED BOOSTER" SPACE SHUTTLE AS A POSSIBLE THIRD ALTERNATIVE CHOICE.

In coming to this conclusion, the "Economic Tradeoff Function," measuring the tradeoff between non-recurring cost variations in the 1970's versus recurring cost changes in the 1980's and beyond, is of decisive importance. The Economic Tradeoff Function is defined and calculated in the report. Figures 0.9 to 0.11 show the results of these calculations combined with the non-recurring and recurring cost estimates of Figure 0.8.

In Figure 0.9, the position and slopes of the Economic Tradeoff Function is shown as it varies with different activity levels in the 1979-1990 period at a 10 percent social rate of discount. Systems above the Economic Tradeoff Function are not economic when compared to an Expendable Space Transportation System in the 1980's; systems below and to the left of the Economic Tradeoff Function are, economically, better than an Expendable Space Transportation System in the 1980's at a 10 percent social rate of discount. The three activity levels shown for the 1979 to 1990 period correspond to three basic space program alternatives that were used by us in the economic analysis, with considerable further variations (see Chapters 6 and 8 of the report): the NASA and DoD Baseline Mission Model for 1979-1990 (624 Space Shuttle flights), the modified NASA and DoD Mission Model (514 Space Shuttle flights, modified in the DoD part under exclusion of some missions particularly suited for Space Shuttle operations) and the former (May 31, 1971 report) NASA and DoD Baseline Mission Model (about 736 Space Shuttle flights). With each of these activity levels the slope of the Economic Tradeoff Function does not change significantly over the range of interest. THE MOST ECONOMIC SPACE SHUTTLE SYSTEM IS THEN THE SYSTEM ALONG THE COST-EFFECTIVENESS FRONTIER WHERE THE ECONOMIC TRADEOFF FUNCTION IS TANGENT TO THE COST-EFFECTIVENESS FRONTIER; it is the Space Shuttle System most distant from the Economic Tradeoff Function, when measured orthogonally to that function. In this case, both TAOS systems (TPFB and TSRM) are equally preferred over any of the other systems proposed; with higher activity levels the advantage of the TPFB-TAOS system increases, as the slope of the Economic Tradeoff Function increases slightly, and at activity levels below 624 Space Shuttle flights the advantage of the TSRM-TAOS system increases. In each case the series burn PFB system is a third best alternative.

In Figure 0.10, three alternative Economic Tradeoff Functions are shown (for a 514 flight space program from 1979 to 1990) for three different social rates of discount: a 5 percent rate, a 10 percent rate and a 15 percent rate. At a 5 percent social rate of interest and accepting the non-recurring and recurring cost estimates as given by industry, the TPFB-TAOS is the most economic choice among all the technical alternatives. It

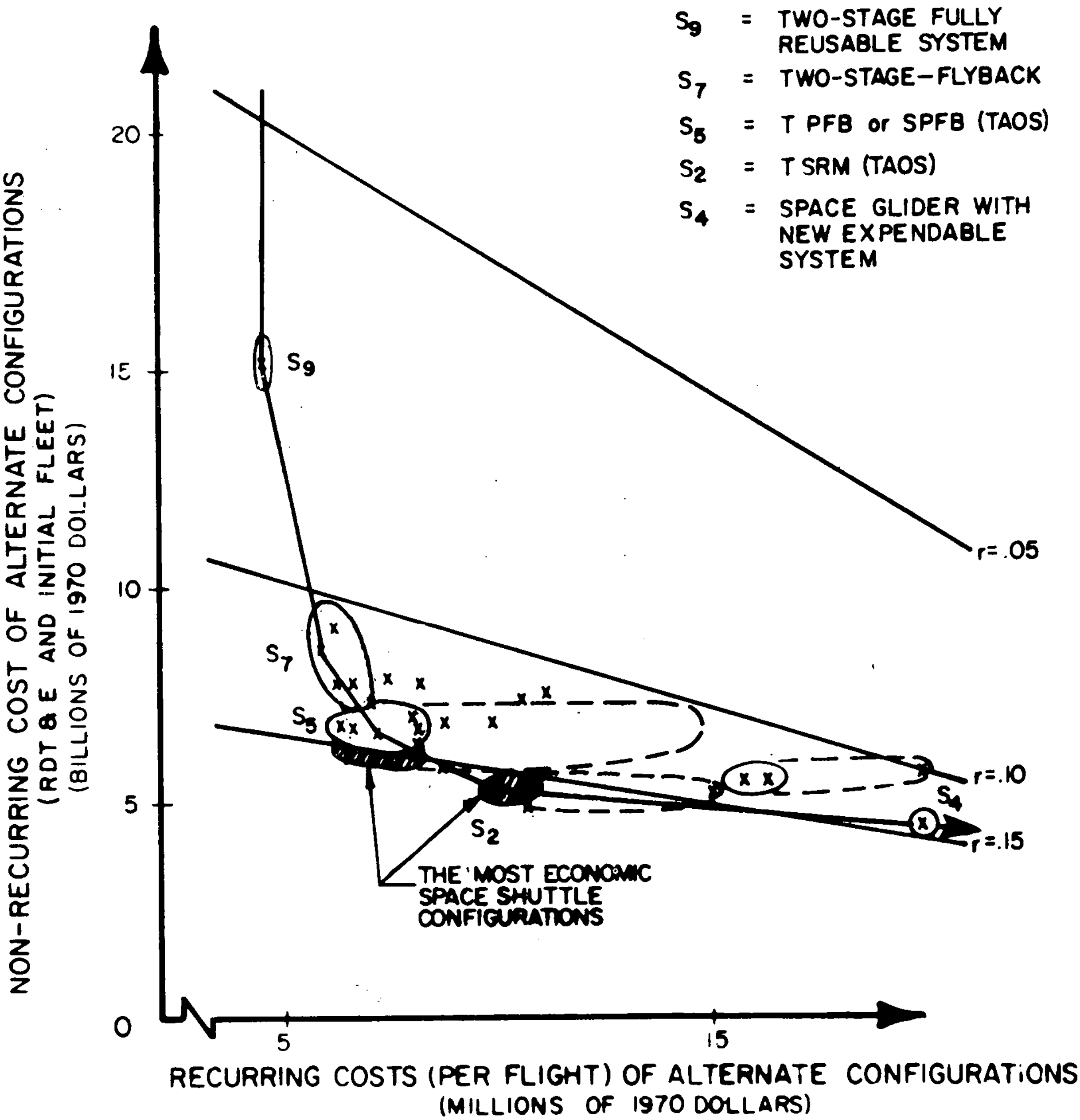
COST-EFFECTIVE SPACE SHUTTLE CONFIGURATIONS



Economic Trade-off Function for Space Shuttle System with 514 Shuttle Flight Space Program (1979-1990) and 624 Shuttle Flight Space Program

Figure 0.9

COST-EFFECTIVE SPACE SHUTTLE CONFIGURATIONS



Economic Trade-off Function for Space Shuttle System when Social Rate of Discount is Varied from 10% to 5% and 15% (514 Shuttle Flight Space Program)

Figure 0.10

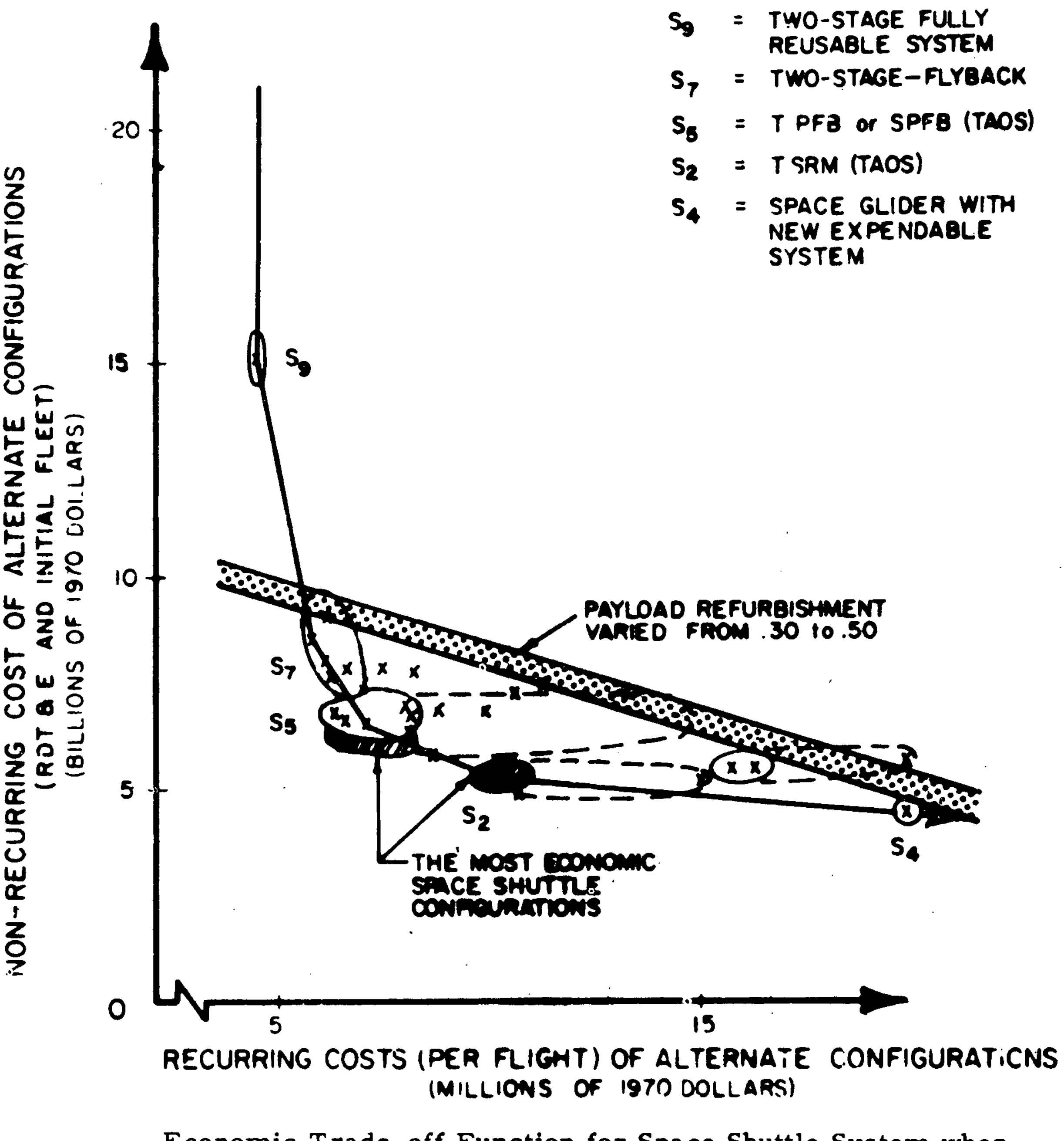
means that at the relatively low social opportunity costs for investment funds (as expressed by the 5 percent rate) it may be indicated to spend the additional funds on more advanced booster programs in the form of pressure fed reusable systems with the promise of a lowering in the cost per flight in the operating phase of the Space Shuttle System. (Again, the point of tangency determines the most economic Space Shuttle System along the cost-effectiveness frontier.

At a 10 percent rate of social interest, recommended by the Office of Management and Budget, the TSRM-TAOS and TPFB-TAOS are about equally preferred to all other systems with a slight economic advantage of the TSRM-TAOS; both lie close enough to the slope of the Economic Tradeoff Function that one cannot be preferred to the other based solely on economic criteria. The TPFB-TAOS involves higher risks but promises lower operation costs. The TSRM-TAOS involves lower risks and non-recurring costs but possibly higher costs per flight. At a 15 percent social rate of discount, that is with high social opportunity costs for investment funds in the 1970's, clearly the TSRM-TAOS system emerges as the preferred Space Shuttle configuration and possibly the only system, the development of which is justified on economic grounds.

Finally, in Figure 0.11, alternative Economic Tradeoff Functions are shown, as the payload refurbishment and updating costs are varied from 30 percent of satellite unit costs to 50 percent of satellite unit costs, the band of variation within which alternate payload refurbishment costs were estimated by LMSC (Lockheed) and Aerospace Corporation as part of this economic study. The Economic Tradeoff Functions all reflect a 10 percent social rate of discount and an activity level of 514 Space Shuttle flights in the 1979 to 1990 period. As shown in Figure 0.11, again, the TSRM-TAOS and the TPFB-TAOS emerge as the preferred economic systems over any other Space Shuttle configuration.

Thus, the results of the economic analysis indicate, that the "Parallel Burn Solid Rocket Motor Booster" Space Shuttle System (TSRM-TAOS) and the "Parallel Burn Pressure Fed Booster" Space Shuttle systems are economically the best Space Shuttle choices. Insofar as the "series burn

COST-EFFECTIVE SPACE SHUTTLE CONFIGURATIONS



Economic Trade-off Function for Space Shuttle System when Payload Reuse and Refurbishment Costs are Varied from 30% to 50% (expected: 39%)

Figure 0.11

pressure fed booster" Space Shuttle offers nearly the same advantages as the TPFB-TAOS, it has to be considered as a third viable economic choice among the many alternative system configurations. At very high social opportunity costs for investment funds, the TSRM-TAOS is the clearly preferred choice, at lower social opportunity costs for investment funds, the TPFB-TAOS is preferred.

Insofar as a Space Shuttle development program can be defined, the economic choice facing NASA seems to be between the development of the Parallel Burn Solid Rocket Motor TAOS or a TPSB-TAOS with the TSRM-TAOS as a technical fall back position, at some additional cost. A mixed development strategy by NASA may be the best development choice, and particularly if a fixed funding limit were imposed on the Space Shuttle development in the 1970's. Yet insufficient detailed information was available to us to make any such recommendation between these two choices.

The TAOS concepts forego the development of manned booster stages in the Shuttle System. With the use of thrust assist of either solid rocket motors or pressure fed systems -- which can be made in part reusable for low staging velocities -- the TAOS concept promises a reduction in the non-recurring costs (RDT&E and initial fleet investment, Space Tug included) from about $10 billion or more (two stage systems, including reusable SIC's) to about $7 billion or less, with an acceptable recurring cost increase in the operating phase of the TAOS systems. The decision between the twin pressure fed and the series burn pressure fed TAOS Space Shuttle System is basically a tradeoff function between the higher non-recurring costs as well as higher risks in the development of the series burn pressure fed booster as against the lower non-recurring cost, lower risk, but possibly higher recurring cost per launch of twin pressure fed systems.

The detailed economic justifications of the TAOS concepts -- when compared to any two-stage reusable system are:

1. The non-recurring costs of TAOS are estimated by industry to be $7 billion or less over the period to 1979 or to 1984-1985 depending on the objectives and choices of NASA.

2. The risks of the TAOS development are in balance lower but still substantial. Intact abort with external hydrogen/oxygen tanks is feasible; lagging performance in the engine area can be made up by added external tank capability. A large reusable manned booster is not needed.

3. The TAOS's that were analyzed promised the same capability as the original two-stage Shuttle, including a 40,000 pound lift capability into polar orbit and a 60 x 15 feet payload bay.

4. The TAOS can carry the Space Tug and capture high energy missions from 1979 on.

5. The most economic TAOS would use the advanced orbiter engines immediately. Our calculations indicate that among the alternative TAOS configurations an early full operational capability and high performance engines on the orbiter are economically most advantageous and feasible within budget constraints of $1 billion peak funding or less. (Also see next section).

6. The TAOS avoids the immediate need to decide on a large reusable booster and allows postponement of that decision without blocking later transition to a fully reusable system, if and when desired. Thereby, a TAOS eliminates or lowers the risk and potential cost overruns in booster development.

7. The TAOS would use "parallel burn" concepts which, if feasible, may change the reusable booster decision. Of course, a TAOS orbiter with a series burn pressure fed booster is also possible.

8. Technological progress may make the expendable parts of the TAOS system (involving mainly tank costs, and thrust assisted rocket costs) less expensive thus further aiding TAOS concepts when compared to two-stage concepts or fully expendable concepts.

9. The TAOS funding schedule makes an early Space Tug development possible. The Space Tug is an integral part of the Space Shuttle System and may be developed by Europe.

10. The TAOS assures NASA the major objectives stated previously of a reusable Space Transportation System.

0.4 FUNDING CONSTRAINTS: THE DEVELOPMENT OF THE SPACE SHUTTLE SYSTEM AND THE PROJECTED BUDGET FOR NASA

The space programs analyzed in both the May 31, 1971 report as well as in this report are well within the budgetary limitations of the U.S. space program of NASA and the Department of Defense in the 1960's for the unmanned space program as well as some reasonable, conservative extensions of these activities for the 1980's. The particular mission model provided by NASA, which includes a set of missions for the Office of Space Science, the Office of Manned Space Flight, and the Office of Applications of NASA, as well as for the Department of Defense, are described later in this report as well as in the work of Aerospace Corporation in support of the present study. As in the earlier May 31st report, wide variations were applied to the mission model and programs supplied to us by NASA and the Aerospace Corporation. In all, close to 200 different mission models were examined over the past six months.

Underlying the conclusions of this analysis are first, funding requirements for a thrust assisted shuttle with an Initial Operating Capability (IOC) date of 1979 as identified in the selection of the most economic Space Shuttle System, and second, the mission model of 514 Space Shuttle flights in the 1980's including NASA, the DoD, as well as commercial applications. For each of the major alternative systems, that is, the competing expendable systems versus the most economic Space Shuttle System, i.e., the thrust assisted orbiter shuttle, a detailed analysis of the life cycle costs of each of the systems was undertaken. Tables 0.2, 0.3, and 0.4 describe the detailed life cycle cost summary data for the period of 1972 to 1990 (fiscal years) for the current expendable, the new expendable and the thrust assisted orbiter shuttle transportation systems. The thrust assisted orbiter shuttle system considered was a typical system among the TAOS systems identified earlier.

In each of these tables, annual total costs of a given typical Space Transportation System are divided into non-recurring costs and recurring costs. Both of these costs are then sub-divided into launch vehicle and pay-

Table 0.2

LIFE CYCLE COST SUMMARY DATA
SCENARIO 32 - TYPICAL TAOS AND TUG, 1979 IOC
CURRENT EXPENDABLE SYSTEM
(MILLIONS OF UNDISCOUNTED 1970 DOLLARS)

FISCAL YEAR	NON-RECURRING COSTS LAUNCH VEHICLE RDT&E	NON-RECURRING COSTS LAUNCH VEHICLE INVEST.	NON-RECURRING COSTS PAYLOAD RDT&E	RECURRING COSTS LAUNCH	RECURRING COSTS PAYLOAD	TOTAL
1971	0	0	0	0	0	0
1972	0	0	0	0	0	0
1973	0	0	0	0	0	0
1974	0	0	0	0	0	0
1975	50	0	38	0	0	88
1976	160	10	114	0	1	285
1977	290	62	450	114	303	1219
1978	250	105	1018	302	989	2644
1979	140	145	1163	643	1221	3312
1980	60	135	1193	896	1320	3804
1981	5	125	1364	912	1456	3862
1982	5	75	1264	899	1700	3945
1983	0	0	1273	882	1698	3853
1984	0	0	929	948	1796	3673
1985	0	0	632	954	1592	3178
1986	0	0	476	1020	1872	3168
1987	0	0	418	1008	1716	3142
1988	0	0	365	982	1781	3128
1989	0	0	242	743	1282	2267
1990	0	0	64	292	327	683
TOTAL	960	657	11003	10595	18834	42049

Table 0.3

LIFE CYCLE COST SUMMARY DATA
SCENARIO 32 - TYPICAL TAOS AND TUG, 1979 IOC
NEW EXPENDABLE SYSTEM
(MILLIONS OF UNDISCOUNTED 1970 DOLLARS)

FISCAL YEAR	NON-RECURRING COSTS LAUNCH VEHICLE RDT&E	NON-RECURRING COSTS LAUNCH VEHICLE INVEST.	NON-RECURRING COSTS PAYLOAD RDT&E	RECURRING COSTS LAUNCH	RECURRING COSTS PAYLOAD	TOTAL
1971	0	0	0	0	0	0
1972	0	0	0	0	0	0
1973	0	0	0	0	0	0
1974	0	0	0	0	0	0
1975	60	0	38	0	0	98
1976	190	10	114	0	1	315
1977	355	80	441	81	308	1265
1978	315	194	978	240	883	2610
1979	195	193	1121	460	1163	3132
1980	60	135	1133	605	1311	3244
1981	5	125	1285	812	1423	3650
1982	5	75	1212	758	1639	3689
1983	0	0	1241	751	1649	3641
1984	0	0	905	806	1750	3461
1985	0	0	606	799	1580	2985
1986	0	0	455	837	1656	2948
1987	0	0	409	856	1684	2949
1988	0	0	362	834	1739	2935
1989	0	0	242	653	1261	2156
1990	0	0	64	269	328	661
TOTAL	1185	812	10606	8761	18375	39739

D

Table 0.4

LIFE CYCLE COST SUMMARY DATA
SCENARIO 32 - TYPICAL TAOS AND TUG, 1979 IOC
SPACE SHUTTLE SYSTEM
(MILLIONS OF UNDISCOUNTED 1970 DOLLARS)

FISCAL YEAR	NON-RECURRING COSTS LAUNCH VEHICLE RDT&E INVEST.	NON-RECURRING COSTS PAYLOAD RDT&E	RECURRING COSTS LAUNCH	RECURRING COSTS PAYLOAD	TOTAL
1972	17	0	0	0	17
1973	230	0	0	0	230
1974	504	0	0	0	504
1975	756	28	0	0	784
1976	978	90	0	0	1068
1977	973	411	93	252	1729
1978	939	944	294	814	2991
1979	740	1049	358	976	3122
1980	631	1048	299	1128	3106
1981	466	1136	260	960	2822
1982	420	1089	279	1021	2809
1983	344	1104	269	1057	2774
1984	211	841	234	1195	2481
1985	127	558	315	1028	2028
1986	90	422	414	859	1785
1987	27	400	495	952	1874
1988	0	362	495	1038	1895
1989	0	241	495	989	1725
1990	0	66	495	419	980
TOTAL	7453	9879	4795	12687	34724

load costs. Furthermore, for non-recurring launch vehicle costs of expendable systems, the RDT&E costs and the investment costs are identified separately. For the current expendable and new expendable systems reported in Tables 0.2 and 0.3, the RDT&E costs, the investment costs for the launch vehicles were identified separately year by year for a 1979-1990 space program. The research and development costs basically concerned the development of a space program to maintain the option of manned space flight in the 1980's. The investment costs are the costs associated with producing the necessary vehicles for launch operations in the 1980's. The actual launch costs are shown under the recurring costs. In obtaining these cost estimates the payload costs for NASA (the Office of Space Science, the Office of Applications, the Office of Manned Space Flight) as well as the DoD and commercial applications were separately identified and costed. Notice that the estimated costs provided in the tables are based on a particular space program known as the reduced baseline mission model with 514 flights, covering the period 1979-1990. The costs of all space missions for the period before 1978 have not been included. Since the new Space Shuttle System is not expected to be available before 1979, these earlier missions would have to be accomplished by an expendable system regardless of whether a new Space Shuttle System is to be developed or not.

The current expendable system exemplified a typical space program along the lines of present knowledge and reflects the potential of space applications in the 1980's. The cost data of such a system are presented in Table 0.2. In our cost effectiveness analysis, the other systems were required to compete against this known technology. The major systems considered are a new expendable launch system, that includes major modifications and adaptations of payloads to better provide for the needs of space transportation in the 1980's, and the Space Shuttle System, in this case particularly, the TAOS. Table 0.3 shows the comparable life cycle costs, non-recurring costs as well as recurring cost data for the new expendable transportation system which basically represent an extended Titan III system adopted for both lower payloads as well as very large payload launch requirements. Finally, in Table 0.4, the cost data of a thrust assisted orbiter shuttle system (TAOS) are provided. It must be pointed out that many alternative space programs were also analyzed on a mission by mission and a launch by launch basis, each implying different budget levels and activity levels for the 1980's. We believe that these tables represent a likely, and possibly, somewhat conservative, outlook for the space activities in the 1980's.

In Figure 0.12 the annual launch and payload costs of the new expendable system and the Space Shuttle System are shown for the period from 1972 to 1990 for a typical space program of the period 1979 to 1990. As one can see from Figure 0.12, a considerable part of the space program costs for the space program after 1979 has to occur with either system before the IOC date of 1979. This is due to the fact that payloads to be flown from 1979 on have to be developed and built in part before that time with a usual lead time of between 3 and 5 years for individual payload programs. Similarly, the necessary launch site as well as new expendable or shuttle payload fleets have to be developed. It is therefore only the shaded area representing the budget difference between the new expendable system and the Space Shuttle System in the period before 1979 that shows the potential net budget impact of the Space Shuttle decision on the NASA budget requirements in 1970 dollars. On the other side, the shaded area of the 1980's shows the net cost difference that a Space Shuttle System would imply for a national space program in the United States along the activity lines outlined in a 514 flight program. It is the expected cost savings in the 1980's and beyond that have to justify the net investment cost outlay implied by a Space Shuttle System, in this case the TAOS system of the 1970's. The overall economic margin within which such a decision will have to be made was fully reported in the May 31, 1971 report.

However, by inspection of Figure 0.12, it is also apparent that all the costs shown are only related to a space program after 1979. Between 1972 and 1979 a continuing space program of NASA is of course planned and will take its course within very limited and very restricted budget considerations. The overall question was, as formulated in the May 31, 1971 report, whether the additional expenditures, or "hump" problem of the Space Shuttle decision could be important with regard to the NASA budget. As a result of this effort, we have undertaken an analysis of the net impact of a Space

Table 0.5

TOTAL FUNDING REQUIREMENTS UNDER ALTERNATIVE STS, AND DIFFERENCES FOR 1979 - 1990 U. S. SPACE PROGRAM (NASA AND DOD) (MILLIONS OF UNDISCOUNTED 1970 DOLLARS)

	Space Shuttle	Current Expendable		New Expendable	
	Budget	Budget	Difference = SH-CE	Budget	Difference = SH-NE
1972	17	0	+ 17	0	+ 17
1973	230	0	+ 230	0	+ 230
1974	504	0	+ 504	0	+ 504
1975	784	88	+ 696	98	+ 686
1976	1068	285	+ 783	315	+ 753
1977	1729	1219	+ 510	1265	+ 464
1978	2991	2644	+ 347	2610	+ 381
		IOC DATE OF SPACE SHUTTLE SYSTEM			
1979	3122	3312	- 190	3132	- 10
1980	3106	3604	- 498	3244	- 138
1981	2822	3862	-1040	3650	- 828
1982	2809	3943	-1134	3689	- 880
1983	2774	3853	-1079	3641	- 867
1984	2481	3673	-1192	3461	- 980
1985	2028	3178	-1150	2985	- 957
1986	1785	3168	-1383	2948	-1163
1987	1874	3142	-1268	2949	-1075
1988	1895	3128	-1233	2935	- 947
1989	1725	2267	- 542	2156	- 431
1990	980	683	+ 297*	661	+ 319*
TOTAL	34,724	42,049		39,739	

* The costs shown in this table refer to the complete life cycle costs of a 1979 to 1990 Space Program. From 1988 to 1990 this program comes to an end. In 1990 no payloads are refurbished or updated, nor are new payloads developed (for 1990!), thus showing again an advantage for expendable systems. Of course, if we have a Space Program also in the 1990's, the advantage of the Space Shuttle would continue to hold.

SPACE PROGRAM COSTS FOR 1979-1990 OPERATIONS
WITH AND WITHOUT SPACE SHUTTLE DEVELOPMENT
(TAOS-CONFIGURATION, REDUCED MISSION MODEL-514)

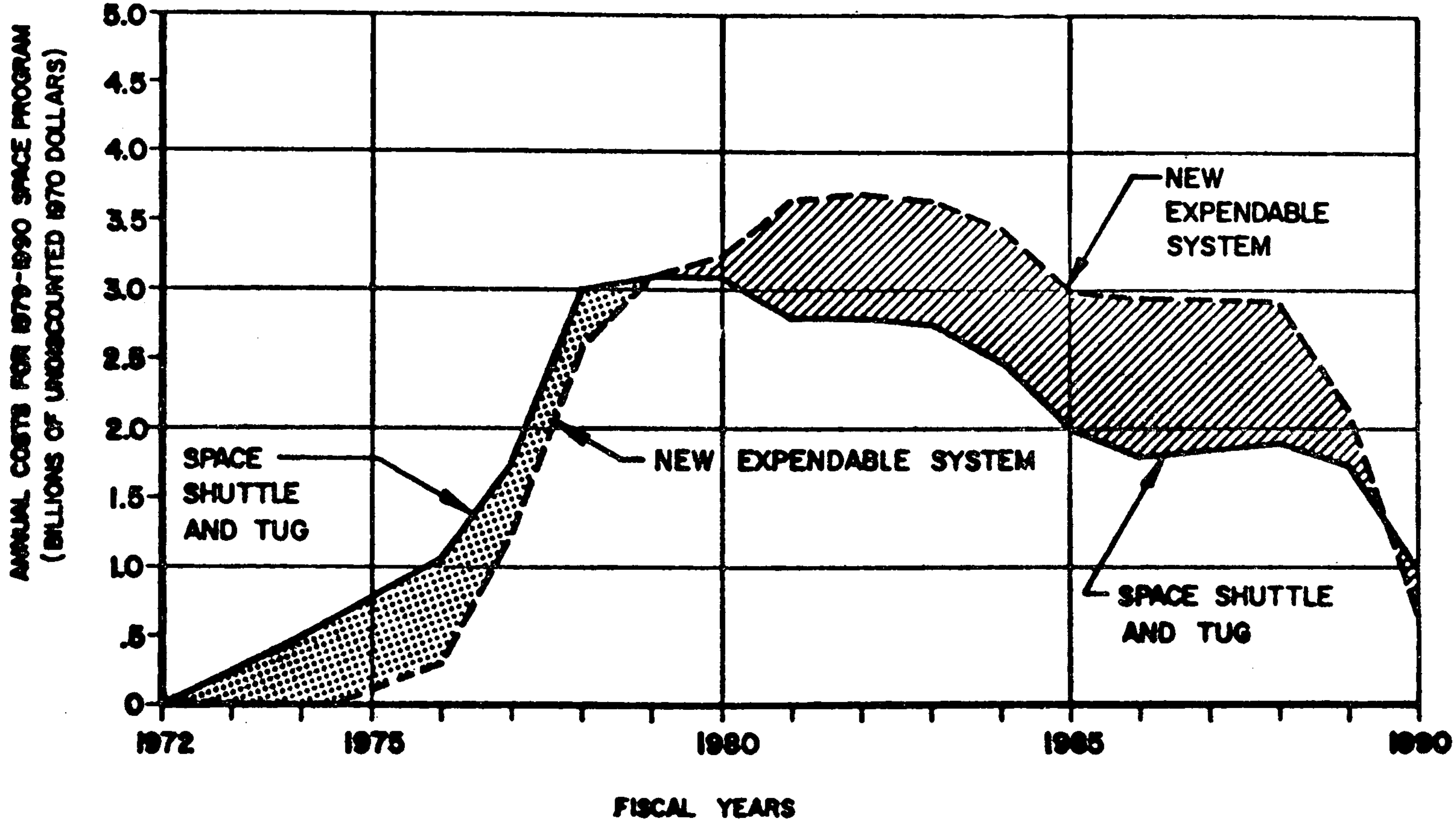


Figure 0.12

NET SPACE PROGRAM COST DIFFERENCES FOR 1979-1990 OPERATIONS
SPACE SHUTTLE SYSTEM Vs NEW EXPENDABLE SYSTEM
(TAOS-CONFIGURATION, REDUCED MISSION MODEL-514)

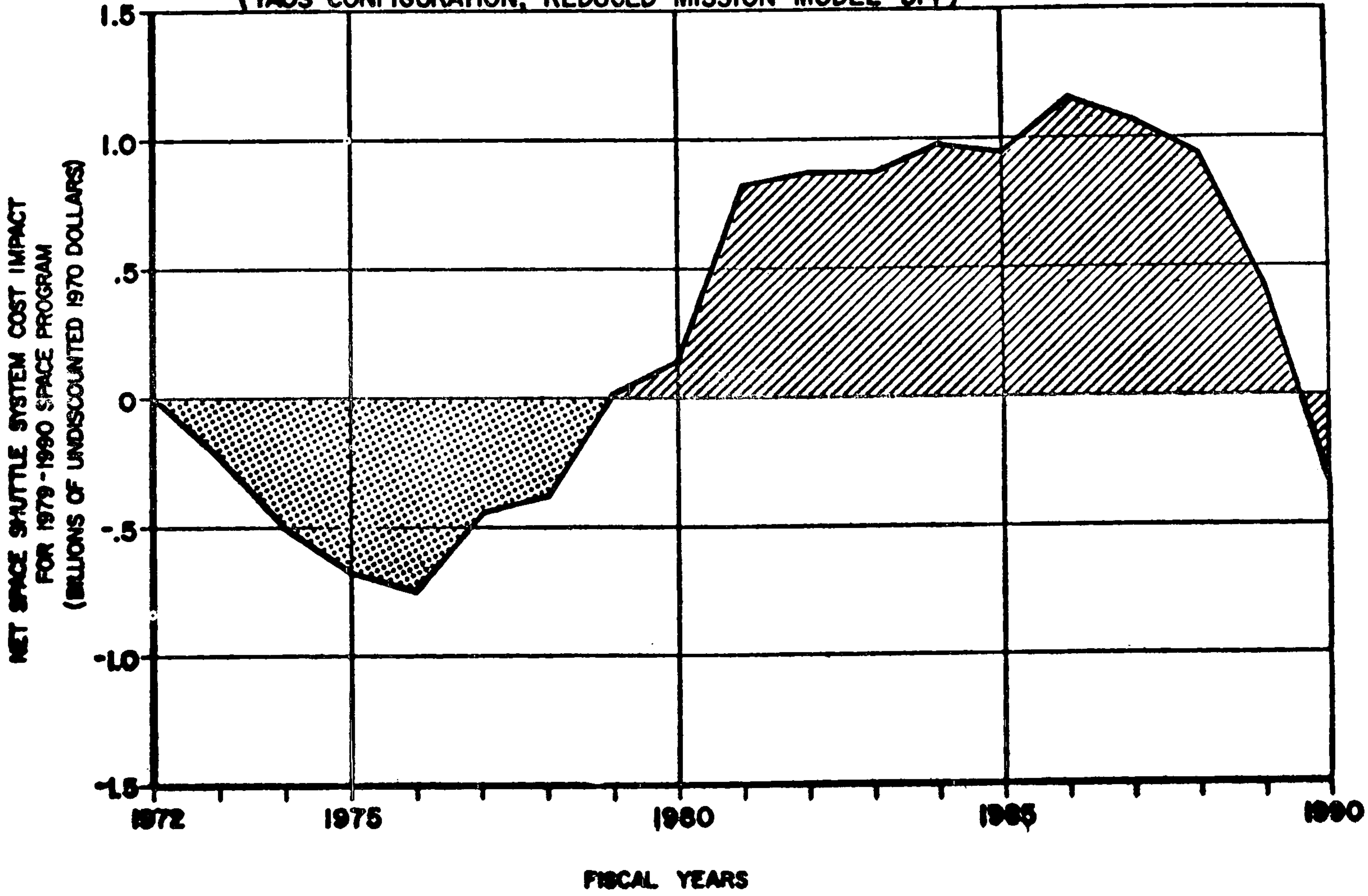


Figure 0.13

Shuttle decision. In Table 0.5 the cost differences between a Space Shuttle System and a new expendable transportation system are shown from the years from 1972 to 1990, in terms of millions of 1970 dollars. In Figure 0.13 the net cost differences between the Shuttle System and the new expendable system are shown again for the years 1972 to 1990. We take into account that considerable expenditures, mainly associated with the development of new payloads, are also associated with the new expendable or a current expendable system for a space program starting in 1979 and lasting until 1990. A fully operational space program (launch vehicles, payloads and operations) from 1979 to 1990 implies substantial expenditures before 1979 and a gradual tapering off of expenditures for the period 1988 to 1990, as shown in Figure 0.12. This tapering off of costs and benefits around 1990 makes the data for these years somewhat misleading. The true expenditures in these later years would be at about the same level as the mid 1980's, but most of them would be associated with flight programs in the 1990's and can therefore not be included in 1979 to 1980 Space Program costs and benefits. The overall net cost impact between a Space Shuttle System and an expendable system is considerably less than the overall development cost and investment cost of the Space Shuttle alone would indicate. It is this net cost impact that is really associated with the option of developing or not developing a Space Shuttle System and not the absolute costs of the Space Shuttle System as shown in the life-cycle cost of Table 0.4. Notice that cost streams as shown in Tables 0.2 to 0.5 as well as Figures 0.12 and 0.13 do not include any allowance for space expenditures in the 1970's that are related to the space program of the 1970's.

In order to assess the impact that a Space Shuttle investment might have in addition to the potential NASA expenditures for the 1970's, we attempt a completely new approach in order to determine or project what the likely NASA budget might be in the 1970's. As reported already in the May 31, 1971 report, there are many factors that affect the budget of an agency like NASA and that determine the amount of space activities that a nation like the United States can carry on. The past NASA budget and the development of the trends of the appropriations for its individual offices are only some of the many variables that influence such a decision and outlook. There are several other very important economic variables that also determine the overall level of NASA budget projections and of the national space activities in the United States. Among these, general economic conditions and, in particular, the overall level of federal purchases of goods and services as well as monetary conditions (e. g., the rate of inflation) have important, though indirect, effects on the ultimate budget that NASA may expect. In addition, there are political decisions (as for example the decision to land a man on the moon in the 1960's) and institutional considerations. Nevertheless, in the report we tried to develop a macro-economic explanation of the expected NASA budget if only economic conditions were to determine the NASA budget in the 1970's, taking into account the past history of the NASA budget in the 1960's.

To a large extent, the formulation of a long-range program, like that of NASA's space program, must necessarily rely on our knowledge of the two-way relationship between the national economy in general and space activity in particular. Furthermore, whether a particular long-range space program can be successful depends largely on our ability to gain such knowledge and to apply it to obtain reliable forecasts of economic conditions and space activity. If plentiful resources are available, space activities can be expected to increase. If on the other side, the demand for national resources is high when compared to their availability due to the existence of many other national priorities, the general level of space activity can be expected to be less than under the first hypothesis. It must be realized however, that an economic analysis would naturally have certain limitations since it does necessarily involve numerous simplifications.

Despite these limitations, we hope to have demonstrated that macro-econometric approaches to projecting national space expenditures can provide useful information for a rational long-range planning of space exploration. In order to project expected space expenditures, as a function of economic conditions in the 1970's, a macro-econometric model has been formulated. Emphasis has been placed on the possible influence of economic conditions of the level of the space budget. Furthermore, we have also attempted to show how the future economic conditions may be affected by different fiscal and monetary policies. By investigating the possible relationship between the level of the space budget and economic conditions, which to some extent may be affected by governmental fiscal and monetary policies, we hope to have demonstrated that a suitably formulated micro-econometric model can be useful for investment decisions in long-range planning for various agencies of the federal government such as NASA.

The macro-econometric model implemented in the present report is a dynamic system of 28 equations which includes 8 equations for the government sector dealing with both receipts and expenditures. In addition, this system of equations includes not only the relationships of production, consumption, and investment activities, but also the relationship of wage and interest determination and personal income as well as corporate profit. The econometric model with the parameters estimated from annual observations from 1929 to 1941 and 1947 to 1964 was evaluated by comparing several alternative simulations with the observed values from the period 1965 to 1970 and found to be reasonably satisfactory. In particular, the simulation results of the government sector were found to be significantly superior to those of trend extrapolation of a more conventional single equation model. Following the evaluation of the model, several alternative simulations were made for the period 1971 to 1980. Both short term and long term projections as well as the implications of alternative fiscal and monetary policies appear to be quite reasonable.

Finally, the alternative simulations for the period 1971 to 1980, representing expansionary, neutral, and restrictive policies, respectively, were then used to project the future space expenditure. In order to achieve this purpose, we demonstrated that the level of current space expenditure may be explained not only by the level of past space expenditure but also by the level of government spending in general and other economic conditions such as the rate of inflation. Based on such an additional empirical relationship obtained from the annual observations of 1958 to 1969 together with alternative simulations of the econometric model, several alternative projections of the level of space expenditure were provided for the period 1971-1980. It is found that under the expansionary policy with relatively high rates of inflation the projected level of space expenditure is generally lower than that of the alternative restrictive policy. According to the neutral policy, the level of space expenditure is expected to rise gradually from $3. 3 billion in 1971 to $4. 1 billion in 1980 (in terms of 1970 constant dollars). According to the expansionary and restrictive policies, the level of space expenditure is projected to rise from $3. 2 billion in 1971 to $3. 7 billion and $4. 6 billion respectively in 1980 (again, in terms of 1970 constant dollars). Among the alternative projections, the results of the most conservative projection (in 1970 dollars) from 1972 to 1980 are shown in column 1 of Table 0. 6. As seen from these projections, the budget of NASA would not vary substantially around an average of $3 billion in the 1970 period with initial projections of slightly below $3 billion using 1970 dollars ($2. 91 for 1973 and $2. 88 for 1974). We once again stress that this restricts itself to economic factors. However, the inclusion of several possible economic futures will hopefully account for political considerations implicitly.

In analyzing the impact that a Space Shuttle System would have on such a projected NASA budget level, two alternate extreme approaches are possible within which the decision would have to lie: first, the total net cost impact of a Space Shuttle development may be added to the projected NASA budget, considering the previous projections as the levels that one could anticipate without such a major decision like the Space Shuttle System development. Column 2 of Table 0. 6 shows the cost difference of the Shuttle over the new expendable development in the 1970 period for the space program between 1979 and 1990 as shown in the previous tables. This column, when added to column 1, gives the maximum expected NASA expenditures in column 3 of Table 0. 6. This would be the maximum expected budget even with a Space Shuttle development of the type of a Thrust Assisted Orbiter Shuttle (TAOS) analyzed and identified in the previous sections. As shown, any of the projected budgets for the 1970 period would not exceed $3. 77 billion. Of course, the closer one gets to the year 1979 the more of the total NASA budget will be taken up by activities that go to the planning, preparation and initiation of programs beyond 1979 as shown in the previous tables. On the other side one could also take the other extreme view regarding the projected space expenditures shown in column 1 of Table 0.6 as the absolute maximum that NASA can expect with or without a Space Shuttle System. In this case, the net cost impact of the Space Shuttle would have to be subtracted from the projected space budget as shown in column 1 in order to arrive at the remaining resources that NASA will have after an affirmative decision on the Space Shuttle is made. The remaining budget for other operations, therefore, is shown in column 4 of Table 0.6. It also implies the margin that NASA is giving up for the period before 1979 with a development of a Thrust Assisted Orbiter Shuttle. Again, a substantial part of this budget will be taken up in the later years of the 1970's for activities and missions that have to do with space programs in the period of 1979 and beyond. The net impact of the Space Shuttle decision, however, is again only the net cost difference between the Space Shuttle and the new expendable system since both of these try to meet equal capabilities as projected for the 1980's.

The economic projections of the NASA budget as well as the mission model used to analyze the Space Shuttle decision lend themselves to surprisingly strong conclusions. Since the mission model analyzed for the 1980's was done with activities of the 1960's of the unmanned space program as a baseline, one would have expected some agreement among the projected space budget activities of NASA and the activities in the 1980's. Yet the close agreement and relative stability of the NASA budget for the 1970's which were arrived at on an econometric statistical basis and the 1980's budget under the new expendable system which were arrived at by a mission by mission and launch by launch planning basis lend very strong support to the economic conclusions drawn here. Figure 0.14 shows on one side for the 1972 to 1980 period the projected budget level under the new expendable system of space transportation and the activity and mission models as given to us from the space program of the United States for use in this analysis.

Of course, many external factors will influence the overall level of the NASA budget in the 1970's as well as the level of U.S. space activities of the United States in the 1960's. If a decision is made to go ahead with a substantial manned program for the exploration of the moon or the planets in the 1980's, then these manned space flight activities would have to be

Table 0.6

IMPACT OF SPACE SHUTTLE DEVELOPMENT ON
NASA BUDGET OR ACTIVITIES
1972 - 1980
(IN BILLIONS OF UNDISCOUNTED 1970 DOLLARS)

FY	Projected Space Expenditures, (1970 dollars) (1)	Difference SH/NE (2)	Maximum Expected NASA Exp. (3) (1) plus (2)	Budget of Rest of NASA if (1) is max. (4) (1) minus (2)	Projected Inflation Rates
1972	$ 3.20	$ .02	$ 3.22	$ 3.18	3.22 %
1973	2.91	.23	3.14	2.68	3.46
1974	2.88	.50	3.38	2.38	3.56
1975	2.91	.69	3.60	2.22	3.55
1976	3.02	.75	3.77	2.27	3.48
1977	3.10	.46	3.56	2.64	3.56
1978	3.30	.38	3.68	2.92	3.44
1979	3.48	-.01	3.47	3.48	3.51
1980	3.70	-.14	3.56	3.70	3.48

MACRO-ECONOMETRIC BUDGET PROJECTIONS, 1972-1980

Vs

LEVEL OF SPACE ACTIVITY IMPLIED BY 514-FLIGHT MISSION MODEL

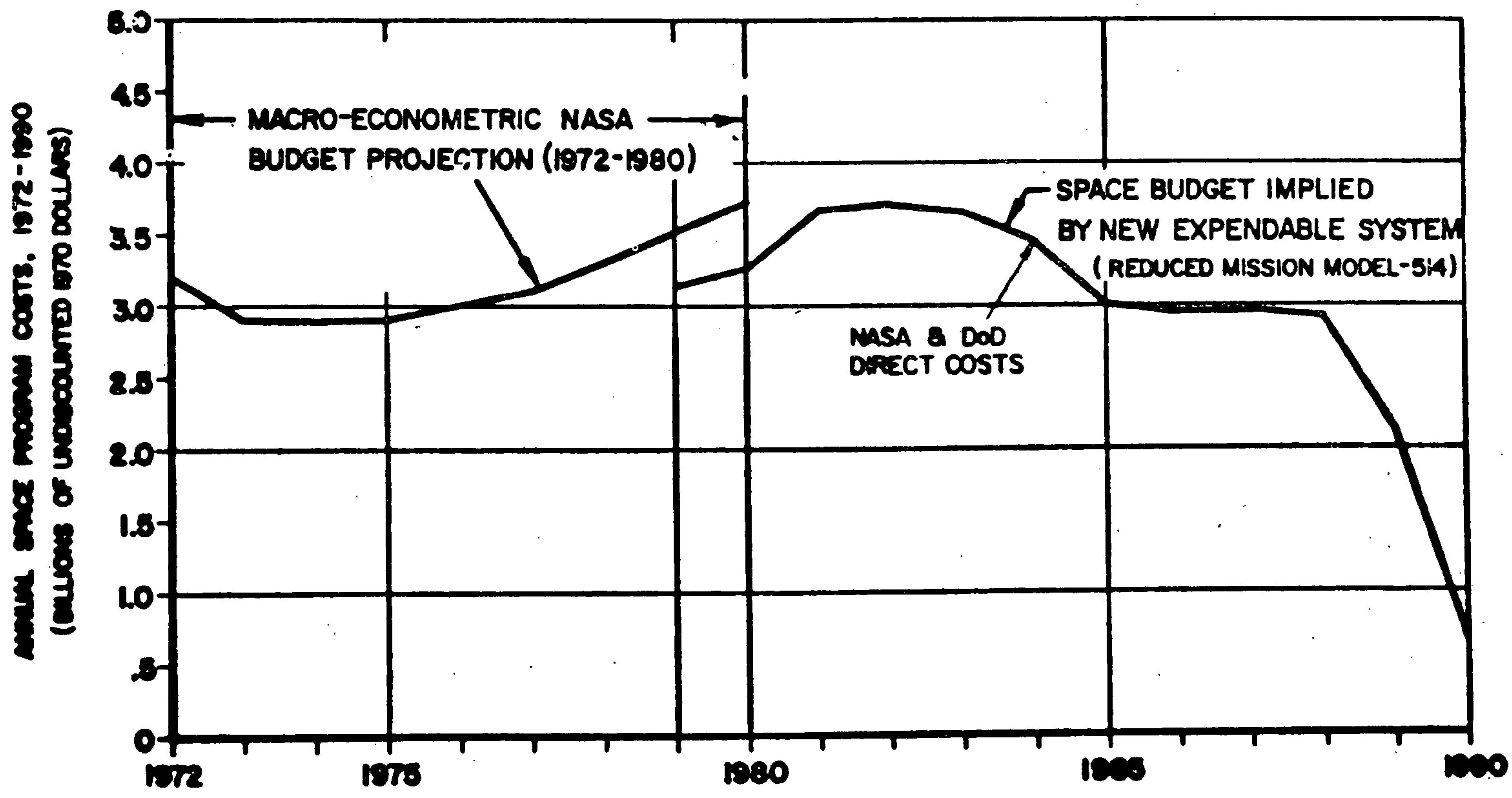


Figure 0.14

added to the projected alternative space budgets (Shuttle versus New Expendable) for the 1980's as shown in Figure 0.14. Similarly, other factors could influence the projected U.S. space activities in the 1980's either through new technological developments, international developments, or a decision to forego any manned space flight. Within these projected alternatives, we regard the space budget shown in Figure 0.14 to be conservative.

If alternative one in the previous discussion of the impact of the Space Shuttle were taken as the baseline, i.e., the net impact is added to the original projections of NASA budget, then Figure 0.15 clearly shows such a consequence. The figure shows first, the projected space budget for the period from 1972 to 1990; second, the net impact by adding the differences of the Space Shuttle System over the new expendable cost system for the period of 1972; and third, the part of the NASA budget taken up, in the 1970's, by the Space Shuttle System and payload development required for the space program for the period 1979 to 1990. As shown in Figure 0.15 through 0.18, <u>a decision to build the thrust assisted orbiter shuttle in the 1970's would not impact dramatically on the overall level of space expenditures, as was previously the case with the two-stage Space Shuttle System analyzed in the May 31, 1971 report</u>. In Figure 0.16, the total of the funds taken up in the 1972 to 1980 period by the Space Shuttle development as well as the payloads for the 1979 to 1990 period are shown separately. In no case do the anticipated program costs in both the launch vehicle developments as well as payload cost developments exceed the econometrically projected space budget for NASA in this period.

If the other view were taken, that is, the economic projections of the NASA budget are the <u>maximum</u> funds that NASA can expect within the present environment of the United States economy, a hypothesis not at all unreasonable, then the net cost impact of the Space Shuttle decision on the NASA budget is shown by Figures 0.17 and 0.18. The total net cost difference is subtracted from the projected space budgets of NASA for the period of 1972 to 1980. Again, the dotted line in Figure 0.18 shows the total funding that the Space Shuttle as well as the development of the payloads for the 1979 to 1990 period would take up out of this total. Again, a compatibility is found

C

IMPACT OF TAOS SHUTTLE DEVELOPMENT WHEN NET COST DIFFERENCE IS ADDED TO PROJECTED NASA BUDGET FOR 1972-1980 PERIOD — 1970 DOLLARS

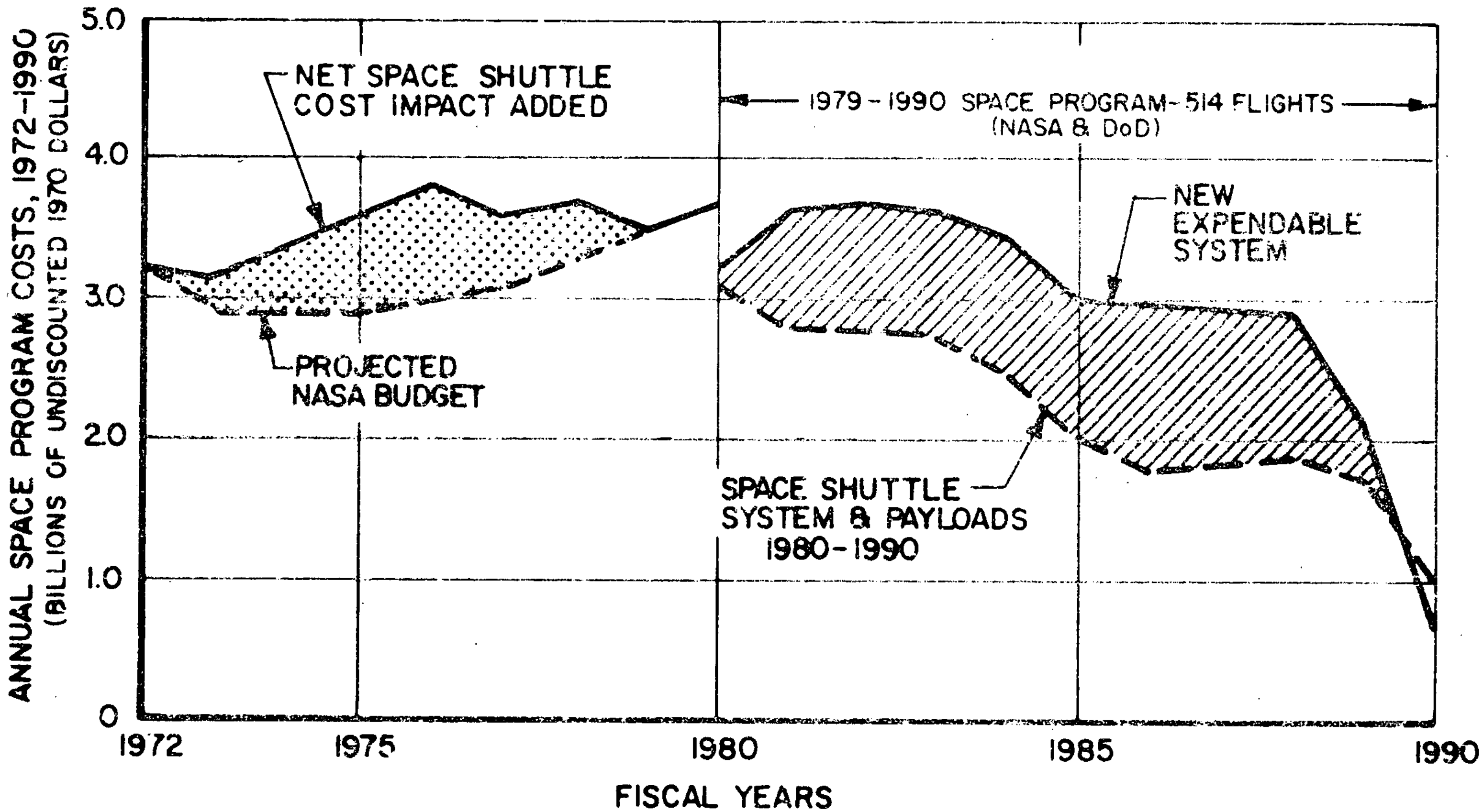


Figure 0.15

IMPACT OF TAOS SHUTTLE DEVELOPMENT WHEN NET COST DIFFERENCE IS ADDED TO PROJECTED NASA BUDGET FOR 1972-1980 PERIOD— 1970 DOLLARS

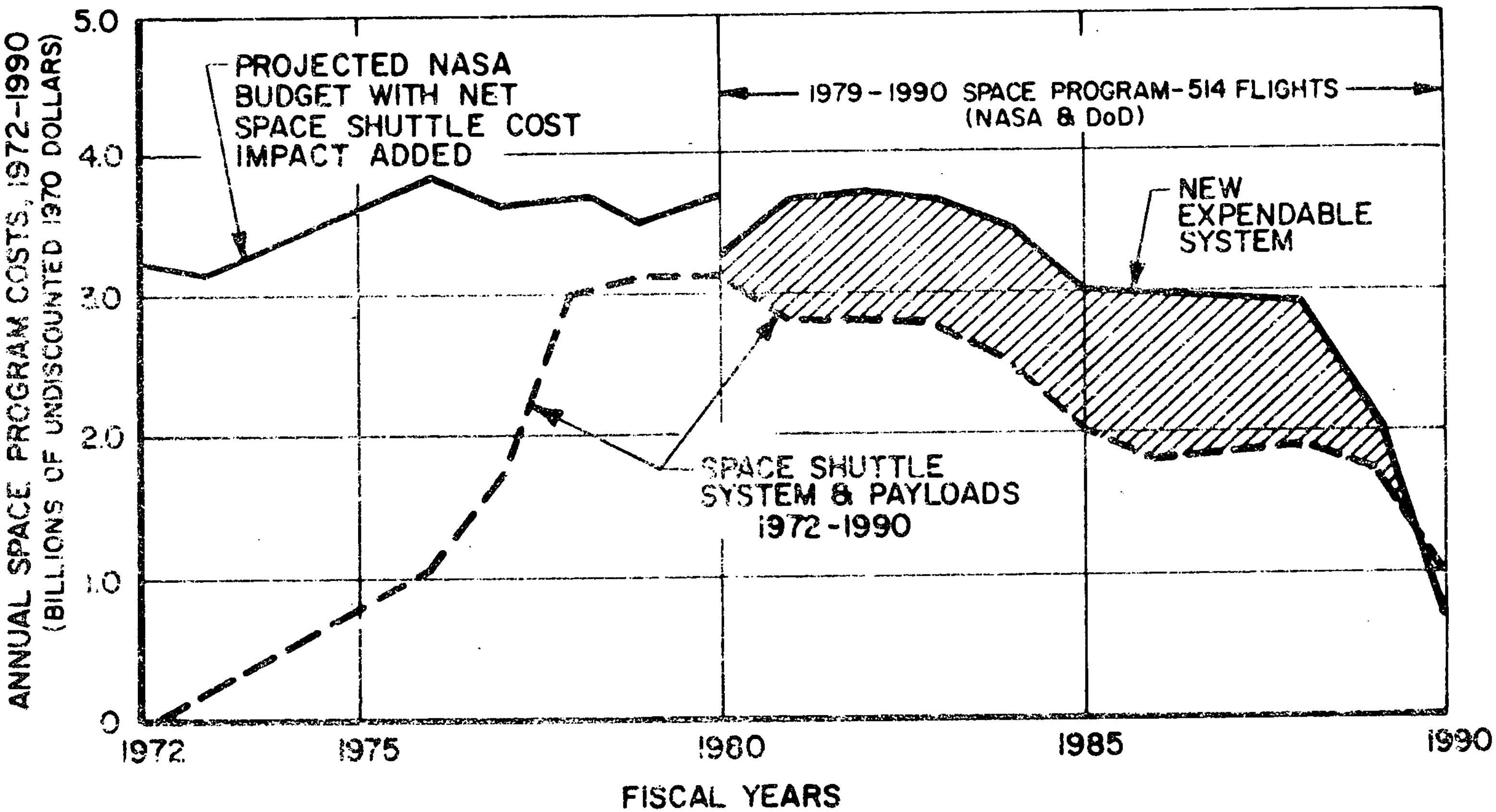


Figure 0.16

IMPACT OF TAOS SHUTTLE DEVELOPMENT WHEN NET COST DIFFERENCE IS FINANCED WITHIN PROJECTED NASA BUDGET FOR 1972-1980 PERIOD-1970 DOLLARS

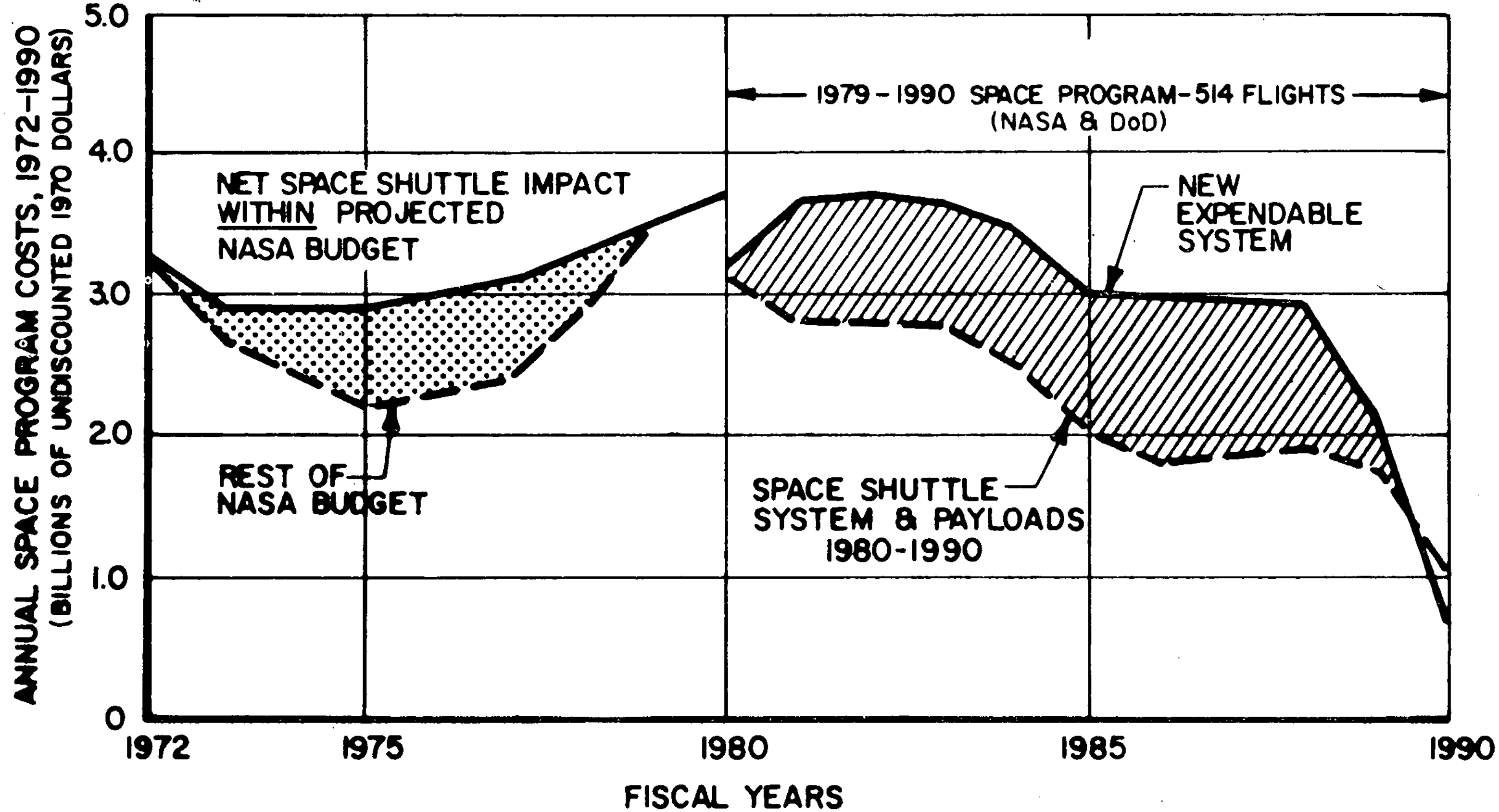


Figure 0.17

IMPACT OF TAOS SHUTTLE DEVELOPMENT WHEN NET COST DIFFERENCE IS FINANCED WITHIN PROJECTED NASA BUDGET FOR 1972-1980 PERIOD—1970 DOLLARS

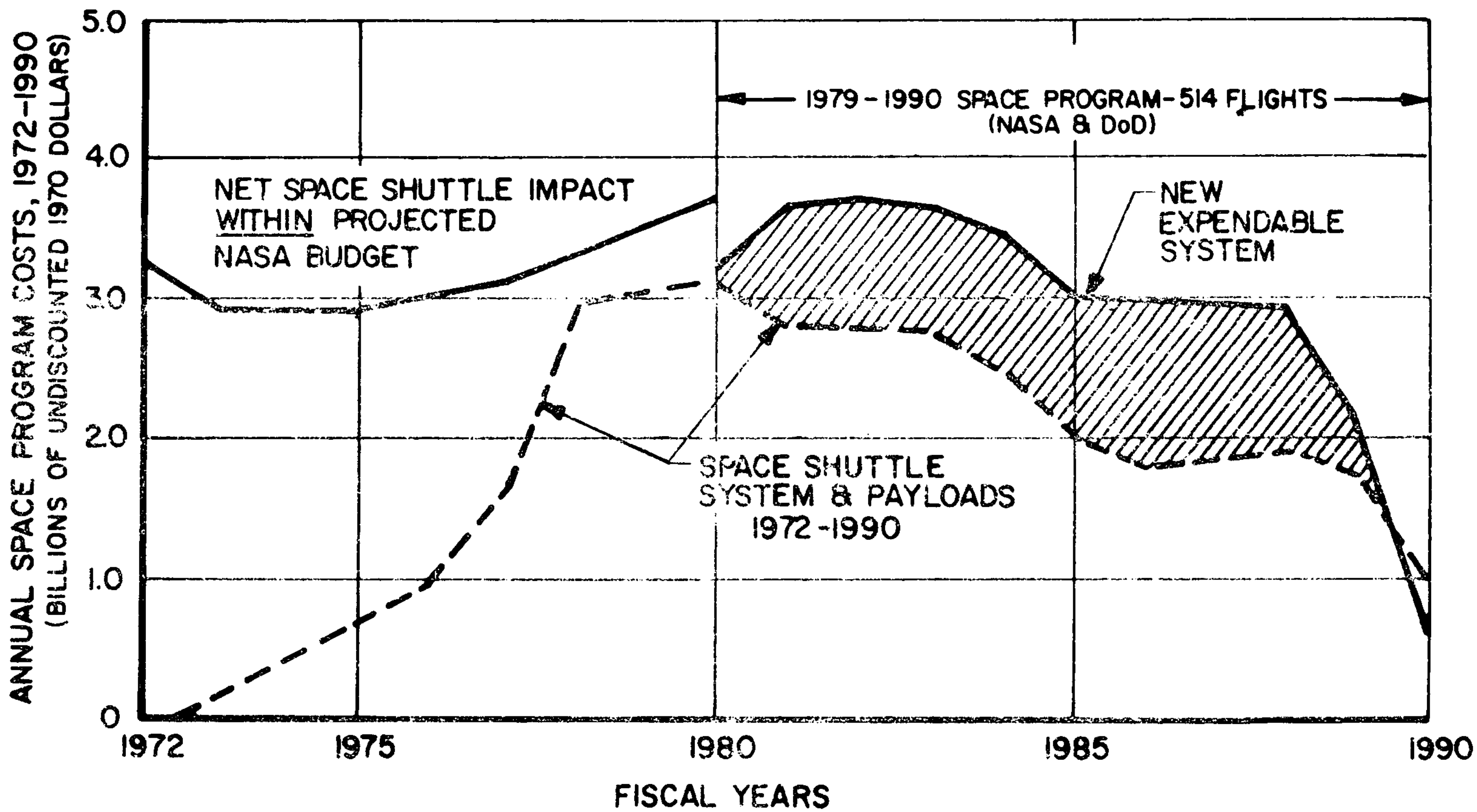


Figure 0.18

between the econometric projections of the possible NASA budget in the 1970's as well as the detailed cost estimates for the Space Shuttle System and the required payload development for the 1979-1990 period. All the other activities of NASA, of course, would have to be financed out of the remainder between the total projected NASA budget and the total Space Shuttle development funds as shown in Figure 0.18. In each case, that is either Figures 0.15, 0.16, 0.17 or 0.18, the projected budget for the 1980's is shown for the New Expendable System and the Space Shuttle System assuming an equal capability approach. The difference, i.e., the direct cost savings expected from a Space Shuttle development is shown by the shaded area. It is the cost savings that justify the added outlays and expenditures in the 1970 period for the Space Shuttle development.

While in the May 31, 1971 report, the total non-recurring cost of a Space Shuttle System development of $12.8 billion or more was a considerable problem with regard to the NASA budget required in the 1970's, it now seems that <u>a development of a TAOS Space Shuttle System, including a Space Tug and the required launch sites, may well be within reasonably projected budgets for space activities in the 1970's and 1980's</u>.

Thus, the crucial questions that remain are:

First, what are the expected levels of space activities in the 1980's beyond or possibly below those projected in the present mission models for NASA (The Office of Space Science, the Office of Applications, the Office of Manned Space Flight), the Department of Defense, commercial applications and potential foreign demand for United States space transportation services. It is ultimately these objectives as exemplified by past as well as future expected space activities that go to justify the development of a new, reusable Space Transportation System. If the activity level in the 1980's or beyond were to increase substantially, the development of a fully reusable Space Transportation System (i.e., using a reusable Flyback booster) in the 1980's or 1990's may be justified, again on a cost-effectiveness or benefit-cost basis.

Second, the choice of the most economic booster assist remains open. Among the alternate configurations identified to lie within the region of the most economic Space Shuttle configurations, there remain uncertainties as to the most economic booster that should go with the development of the orbiter. The choice seems now to lie between three alternate, substantially different systems, all of which should not influence the basic orbiter decision: (1) a (Twin) Parallel Burn Solid Rocket Motor Booster System, (2) a (Twin) Parallel Burn Pressure Fed Booster System, (3) a Series Burn Pressure Fed Booster. Overall, it seems that a minimum non-recurring cost program and minimum technological risk program for the 1970's will favor a Solid Rocket Motor thrust assisted orbiter shuttle system. On the other side, pressure fed systems of either the twin pressure fed type or the series burn pressure fed boosters may be justified if the technological risks as well as the higher non-recurring costs are justified by confidence in the estimated lower costs per flight and higher activity levels in the 1980's. Thus, the ultimate decision among these boosters is an economic tradeoff decision among non-recurring costs, development risk, activity level, and the level of the social rate of discount (the opportunity cost of economic funds) in the 1970's and 1980's.

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