

NASA CR-143705

~~N75-22191~~

ECONOMIC ANALYSIS OF NEW
SPACE TRANSPORTATION SYSTEMS

EXECUTIVE
SUMMARY

MAY 31, 1971

Prepared for the

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
UNDER CONTRACT NASW-2081

By

MATHEMATICA, INC.

P.O. Box 92

PRINCETON, NEW JERSEY 08540

O U T L I N E
E X E C U T I V E S U M M A R Y

	<u>Page No.</u>
ACKNOWLEDGEMENTS	i
LIST OF FIGURES	ii
LIST OF TABLES	iv
0.1 INTRODUCTION	0-1
0.2 STATEMENT OF THE ECONOMIC PROBLEM	0-8
0.3 ECONOMIC PRINCIPLES APPLIED IN THE ANALYSIS	0-16
0.3.1 Cost Effectiveness Analyses	0-16
0.3.2 The Measurement of Induced Benefits from Incremental Space Activities	0-19
0.3.3 The Social Rate of Discount	0-22
0.3.4 The Uselife of the Space Transportation System RDT&E Investments	0-26
0.3.5 Other Economic Parameters: Program Start, Gestation Period and the Initial Operational Capability	0-26
0.3.6 The Incremental Costs of Space Flights in the 1980's of Different Space Transportation Systems	0-27
0.3.7 Risk and Uncertainty	0-31
0.4 SUMMARY OF THE QUANTITATIVE RESULTS OF THE ECONOMIC ANALYSES	0-34
0.5 CONCLUSIONS	0-60

ACKNOWLEDGEMENTS

The Report on Economic Analysis of New Space Transportation Systems has been prepared for the National Aeronautics and Space Administration under Contract NASW-2081 dated June 4, 1970 by MATHEMATICA, INC. The study is being directed by Drs. Oskar Morgenstern and Klaus P. Heiss. The following persons are associated responsibly: David Bivins, Edward Greenblat, J. Preston Layton, Courtland D. Perkins, Uwe Reinhardt, Miklos Remenyi, Joseph Traybar and Kan Young.

The NASA monitor is Mr. Robert N. Lindley, Director, Engineering and Operations, Office of Manned Space Flight. His informed interest and warm concern are gratefully acknowledged. Thanks are extended to other NASA and contractor personnel who have contributed to this work.

Last, but not least, this report owes much to the dedication of Margaret Wirth, the project secretary, who directed and participated greatly in the typing and editing of this work.

LIST OF FIGURES

Figures

0.1	The Role of Economic Analysis in the Evaluation of Public Projects	0-3
0.2	Flow of Inputs to the Economic Analysis	0-5
0.3	STS Recurring vs. Non-Recurring Launch Cost Trade-Offs at Given Discount Rate	0-11
0.4	Space Program Costs (1978-1990 Operations)--Scenario 1	0-14
0.5a	Equal Capability Analysis, NASA, DoD and Other Users	0-18
0.5b	Equal Budget Analysis, NASA, DoD and Other Users	0-18
0.6	The Measurement of Induced Benefits from Incremental Space Activities	0-20
0.7	Sensitivity of Net Present Project Value to the Discount Rate	0-24
0.8	Average and Incremental Launch Costs of the Space Shuttle	0-30
0.9	"Equal Capability" Cost Analyses (10% Discount Rate)	0-36
0.10	"Equal Budget" Cost Analyses (10% Discount Rate)	0-43
0.11	"Equal Capability" Cost Analyses (No Net Mass Effect, 10% Discount Rate)	0-45
0.12	"Equal Capability" Cost Analyses (15% Discount Rate)	0-48
0.13	"Equal Capability" Cost Analyses (5% Discount Rate)	0-49
0.14	Summary of Different Cost Effect Analyses (10% Discount Rate)	0-50
0.15	"Equal Capability" Cost Analyses with Lunar Option 1 Added	0-52

0.16	Summary of "Equal Capability" Cost Analyses--Different Discount Rates: 5%, 10% & 15%	0-53
0.17	Space Program Costs (1978-1990 Operations)--Scenario 3	0-55
0.18	Space Program Costs (1978-1990 Operations)--Scenario 23	0-56
0.19	Space Program Costs (1978-1990 Operations)--Scenario 24	0-57
0.20	Space Program Costs (1978-1990 Operations)--Scenario 25	0-58
0.21	Space Program Costs (1978-1990 Operations)--Scenario 26	0-59

LIST OF TABLES

Table

0.1	Space Transportation Systems--Life Cycle Cost Summary	0-9
0.2	Life Cycle Cost Summary Data--Scenario 1	0-15
0.3	Launch Vehicle Cost Classification for Economic Analysis	0-28

0.1 INTRODUCTION

This Executive Summary is an abstract of MATHEMATICA's report, Economic Analysis of New Space Transportation Systems of 31 May 1971, which was carried out in accordance with the provisions of Contract NASW-2081.

The study conducted by MATHEMATICA examines the economic merits of three alternative Space Transportation Systems¹ for use in the decade of the 1980's:

- The Current Expendable System. The system envisages continuing use of the types of expendable launch vehicles in the United States inventory at present.
- The New Expendable System. As its name implies, this envisages use of a new family of expendable vehicles, designed to have better (economic) performance than the current expendable vehicles.
- The Space Shuttle and Tug System (a new Space Transportation System). This system differs in concept from the previous systems in employing reusable rather than expendable launch vehicles. Two major elements are employed: a Space Shuttle which operates between the Earth's surface and Earth orbits of altitudes between 185 and 1,110 kilometers (100 and 600 nautical miles); a Space Tug, which can be transported within the Space Shuttle and which can operate from the relatively low orbits of the Space Shuttle to high Earth orbits such

¹ A Glossary of Terms is included in the Report.

as the synchronous equatorial orbit (35,500 km or 19,230 n.m. altitude). The combined Space Shuttle and Tug System provides a fully reusable launch system able to place payloads into all widely used Earth orbits, and to return payloads to Earth from these orbits.

The costs associated with reaching an Initial Operational Capability (IOC) with these three systems vary widely. The two expendable systems represent modest investments by space program standards, but the recurring costs of operation under them would remain relatively high. The Space Shuttle and Tug System requires a substantial investment, but would substantially reduce the recurring costs of operation. The impacts of the three systems on the costs of the space program of the 1980's also vary widely. MATHEMATICA has analyzed economic benefits and costs of the different systems. The findings, as well as the economic principles applied, are summarized herein.

Figure 0.1 shows the logic of the overall economic analysis performed by MATHEMATICA and the context within which this analysis should be seen as affecting the Space Shuttle decision. MATHEMATICA submits that within this framework a consistent and detailed economic analysis of the fully reusable Space Shuttle has been made. As Figure 0.1 shows, there are other than economic factors that influence a decision of the scope and character of the Space Shuttle; they have to do with political criteria, the ranking of technological preferences, national priorities and other non-economic criteria. The economic analysis is but one important element to be considered in the approach to the decisions relating to the development and use of a new Space Transportation System.

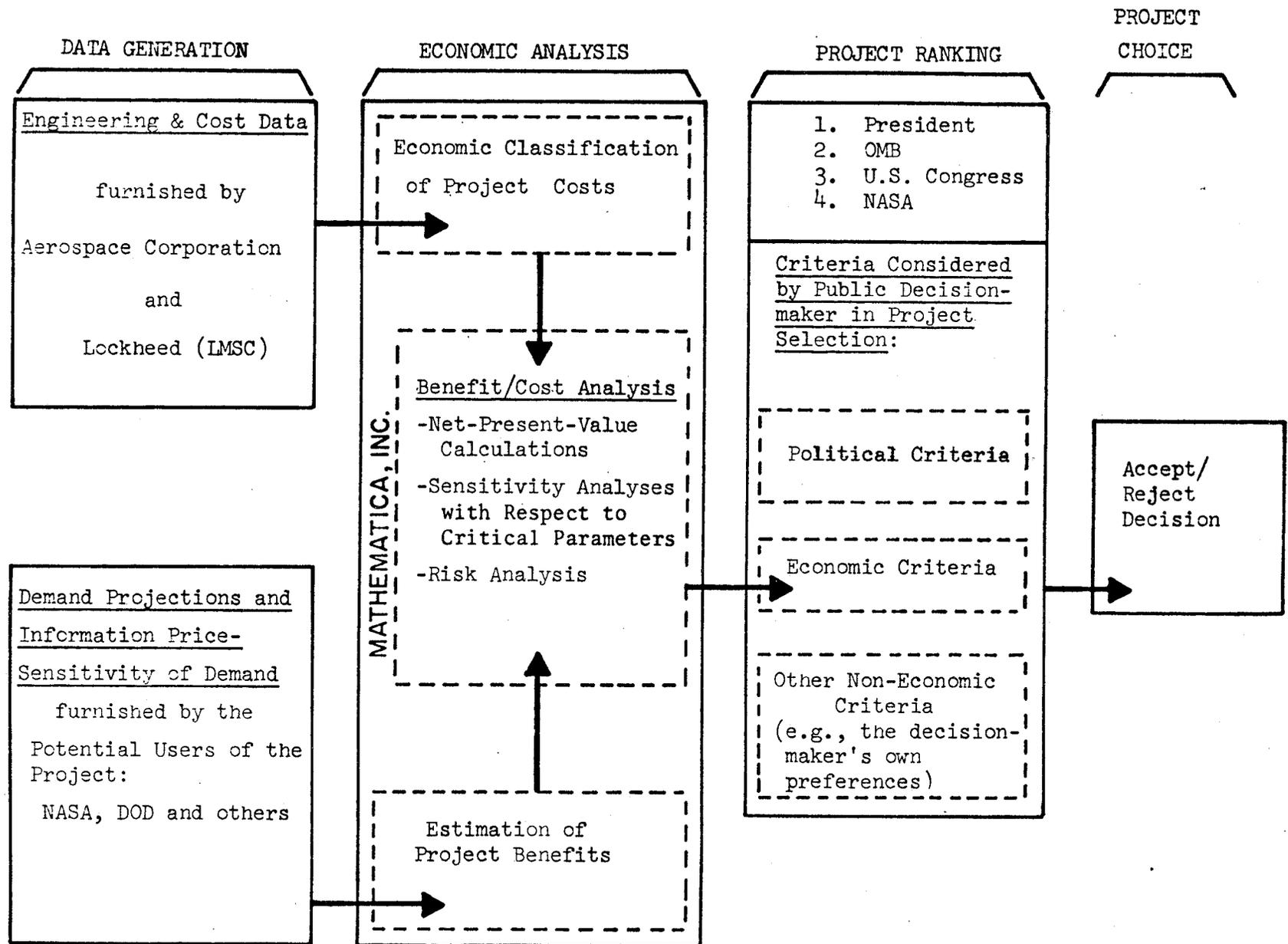


Figure 0.1 The Role of Economic Analysis in the Evaluation of Public Projects

The study conducted by MATHEMATICA makes major use of the results of the studies performed by two other contractors, LMSC (Lockheed Missiles and Space Company) and Aerospace Corporation, as well as facts, plans and assumptions provided by NASA and the Department of Defense. Figure 0.2 shows the flow of inputs to the economic analysis performed by MATHEMATICA.

The contributions of LMSC consisted primarily of estimates of sample payload costs for the expendable and the reusable Space Transportation Systems for the period 1978 - 1990, based on extensive payload preliminary designs. LMSC first performed an analysis of expected payload costs based on historical experience to determine whether cost reductions could be achieved. To accomplish this LMSC selected four typical satellites and estimated their expected research, development, test and evaluation (RDT&E) costs, first unit costs and operating costs for each of the three Space Transportation Systems considered. Then these four satellites were looked at in great detail at a subsystem level and redesigned to correspond to the three major classes of satellites anticipated for the 1980's space traffic. Aerospace Corporation then used the results of the LMSC effort as a basis to generalize the payload effects across the Baseline mission model supplied by NASA, which incorporates traffic of NASA, the Department of Defense and other users. Aerospace Corporation then provided MATHEMATICA with the life cycle cost streams from 1971 to 1990--RDT&E costs included--for the Current Expendable launch vehicles and payloads, the New Expendable launch vehicle family and payloads, and the fully reusable Space Shuttle Transportation System based on a two-stage Space Shuttle and reusable Space Tug configuration.

In recognition of the problems of accurately predicting the rate of space activity more than a decade in the future, MATHEMATICA introduced many variations of the Baseline model which

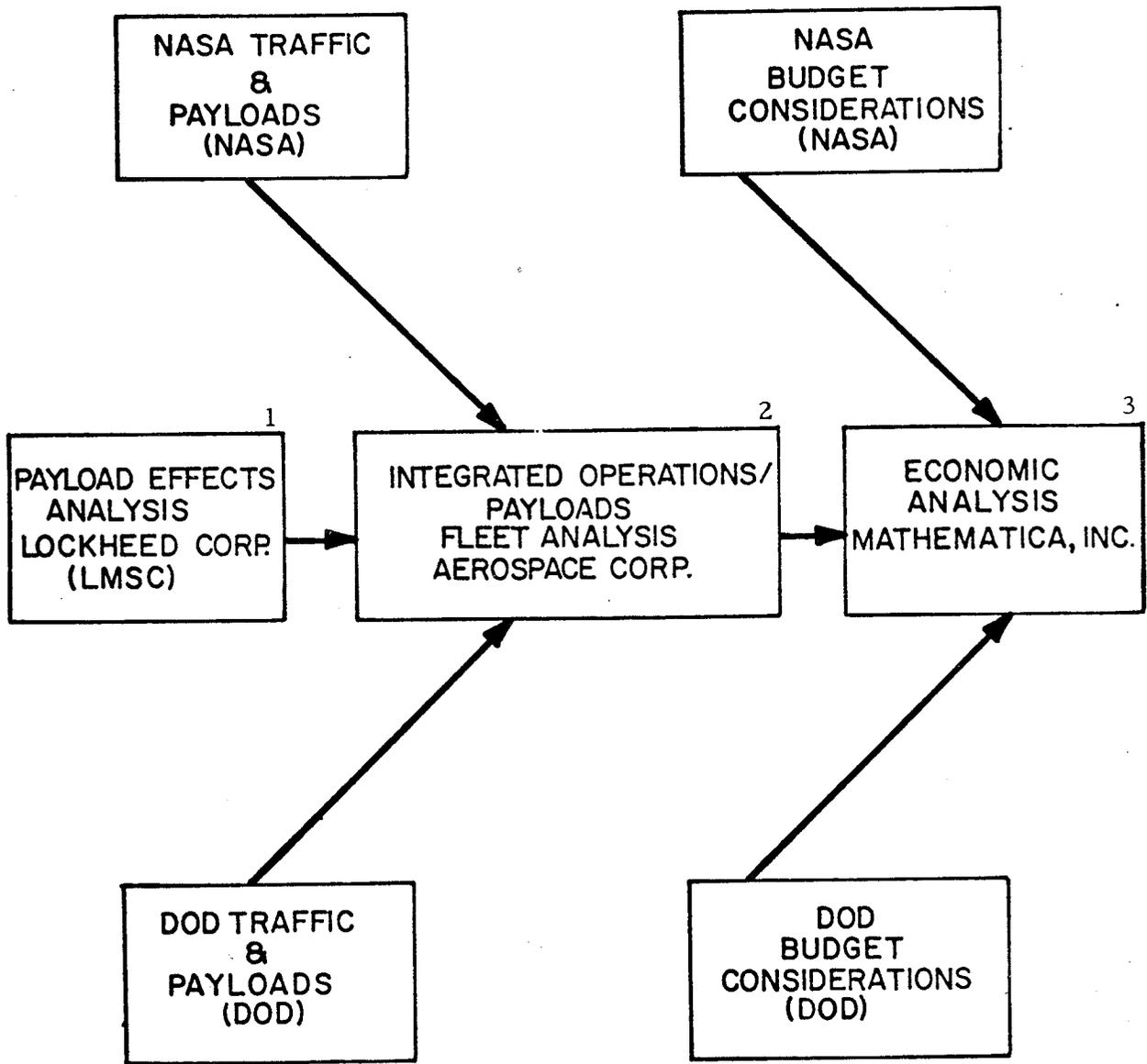


Figure 0.2 Flow of Inputs to Economic Analysis

-
- ¹ Contract NASW-2156, approximately 12 man-years of effort
 - ² Contract NASW-2129, approximately 25 man-years of effort
 - ³ Contract NASW-2081, approximately 8 man-years of effort

resulted in analysis of twenty-six scenarios that bracket the most likely possibilities for the 1978 - 1990 period. All of the aforesaid considerations formed the basis on which MATHEMATICA performed the economic analysis of the new, fully reusable Space Shuttle Transportation System.

It should be emphasized that the systems data used in the analysis were generated for this study principally by NASA, by the Department of Defense, by Aerospace Corporation, by LMSC and to some extent by other contractors. They were not generated by MATHEMATICA. MATHEMATICA reviewed the data generated including the Cost Estimating Relationships (CERs) used by the Aerospace Corporation and is satisfied that they reflect current standards for such efforts and represent the best procedures available at this time.

Aerospace Corporation stated that it tested its cost estimating relationships by estimating costs of well known aerospace systems with good approximation of actual costs. On the other hand, it must be recognized that the fully reusable Space Shuttle Transportation System advances major new areas of technology, and therefore involves cost uncertainties not easily related to present aircraft or spacecraft costs.

The analysis is based on data published by Aerospace Corporation in Integrated Operations/Payloads/Fleet Analysis, Mid-Term Report, (6 Volumes), dated 31 March 1971. Aerospace Corporation plans to publish an update of these data in June 1970. MATHEMATICA will undertake a study to assess the impact of the updated data on the findings of this report.

MATHEMATICA is continuing its validation of the cost data and the details of their aggregation from individual components to larger units.

MATHEMATICA has designed the model for the benefit-cost analysis into which the data provided for MATHEMATICA have been inserted. This model is comprehensive and takes into account the relevant concepts provided by advanced, modern economic analysis. The present model has been modified and expanded for general use in cost effectiveness analyses of new Space Transportation Systems (STS).

In the Report only expendable launch vehicle systems and the fully reusable, two-stage Space Shuttle and Tug System are considered. An economic evaluation of other viable alternative concepts has as yet not been made by MATHEMATICA. Assessment of the cost effectiveness of other Space Shuttle configurations to determine the most economic choice can be performed in accordance with the methodology of this analysis, once technical validation is accomplished and comparable technical performance and cost data are available.

0.2 STATEMENT OF THE ECONOMIC PROBLEM

NASA is studying the development of a new, fully reusable Space Shuttle Transportation System for the 1980's to replace its Current Expendable Space Transportation System. Table 0.1 gives the complete life cycle cost summary of launch vehicle systems and payloads for the alternative Space Transportation Systems considered in this study. The two-stage, fully reusable Space Shuttle System as estimated by Aerospace Corporation on March 31st, 1971 is expected to have non-recurring launch vehicle costs of approximately \$12.8 billion (RDT&E and initial fleet investment costs) in constant 1970 dollars. (Section 0.3.7. See also p. 0-31.). In terms of past historical experience in either NASA or the Department of Defense, this is a major research and development project--about half of the cost of the Apollo program of the 1960's--and, therefore, deserves very careful examination and scrutiny.

Any investment in large scale RDT&E projects has either or both of two major economic objectives:

- (a) to develop a new good or service,
- (b) to reduce (future) production and operating costs.

An example for (a) is the development of space transportation capability in the United States during the 1950's and the 1960's. Today the United States has an Earth orbital space transportation capability and the aim of future RDT&E outlays is mainly (b), that is, the expected reduction of space activity costs; however, added capabilities are also anticipated from such a program.

Table 0.1

SPACE TRANSPORTATION SYSTEMS

LIFE CYCLE COST SUMMARY

(Scenario 1)

(in Millions of Undiscounted 1970 Dollars)

	Current Expendable	New Expendable	Space ¹ Shuttle & Tug
<u>Expected Launch Vehicle Costs</u>			
RDT&E (FY 1971-1980)	\$ 960	\$ 1,185	\$ 9,920
Investment (FY 1973-1990)	<u>584</u>	<u>727</u>	<u>2,884</u>
TOTAL NON-RECURRING	1,544	1,912	12,804
Recurring Costs (FY 1978-1990)	13,115	12,981	5,510
TOTAL LAUNCH COSTS ²	\$15,000	\$15,000	\$18,000
<u>Expected Payload Costs (Satellites)</u>			
RDT&E (FY 1974-1990)	12,382	11,179	10,070
Recurring Costs (FY 1976-1990)	31,254	28,896	15,786
TOTAL PAYLOAD COSTS ²	\$44,000	\$40,000	\$26,000
EXPECTED TOTAL SPACE PROGRAM COSTS ²	\$58,000	\$55,000	\$44,000

¹ Table 2 gives a breakdown of these costs over time.

² Small zeroes indicate rounding to nearest billion.

In the case of the Space Shuttle and Tug System, the expected cost reductions in the 1980's will occur in two major areas: first, the launch system recurring costs will be reduced from \$13 billion total to \$5.5 billion due to the repeated use of the launch system. Second, the cost of payloads--the major portion of space program costs--will be reduced from about \$40 billion to \$26 billion due to the reuse, refurbishment and updating of payloads. Once the Space Shuttle System is in operation the total direct costs of the national space program will consist of the recurring launch costs and the total (i. e., non-recurring plus recurring) costs of the payloads to be carried. Table 0.1 illustrates that recurring launch costs make up about 20 percent or less of space program costs (1978-1990), while 80 percent or more are due to the total cost of payloads. Therefore, an economic analysis of the New Space Transportation System has to look at payload costs as the major part of total space program costs, and not only at launch costs.

In economic terms the problem can be stated as follows: What must the future savings in space program costs (launch--as well as payloads) be to justify an RDT&E and Initial Investment outlay on the Space Shuttle of, say, \$13 billion? Or, as illustrated in Figure 0.3, one can ask the reverse question: considering the expected cost of the national space program using an Expendable Space Transportation System in the 1978 - 1990 period and given the expected savings in the operating phase of space programs with the Space Shuttle System, both launch costs and payload costs considered, what are the justifiable non-recurring costs of New Space Transportation System concepts? A convenient way to illustrate all the possible economic configurations of recurring versus non-recurring costs of different technologies is shown by the trade-off line in Figure 0.3. Estimates and configurations below the trade-off line are, in economic terms, better than the Current Expendable System, while configurations of non-recurring costs and recurring cost estimates above the trade-off line are worse than the expected Expendable System costs.

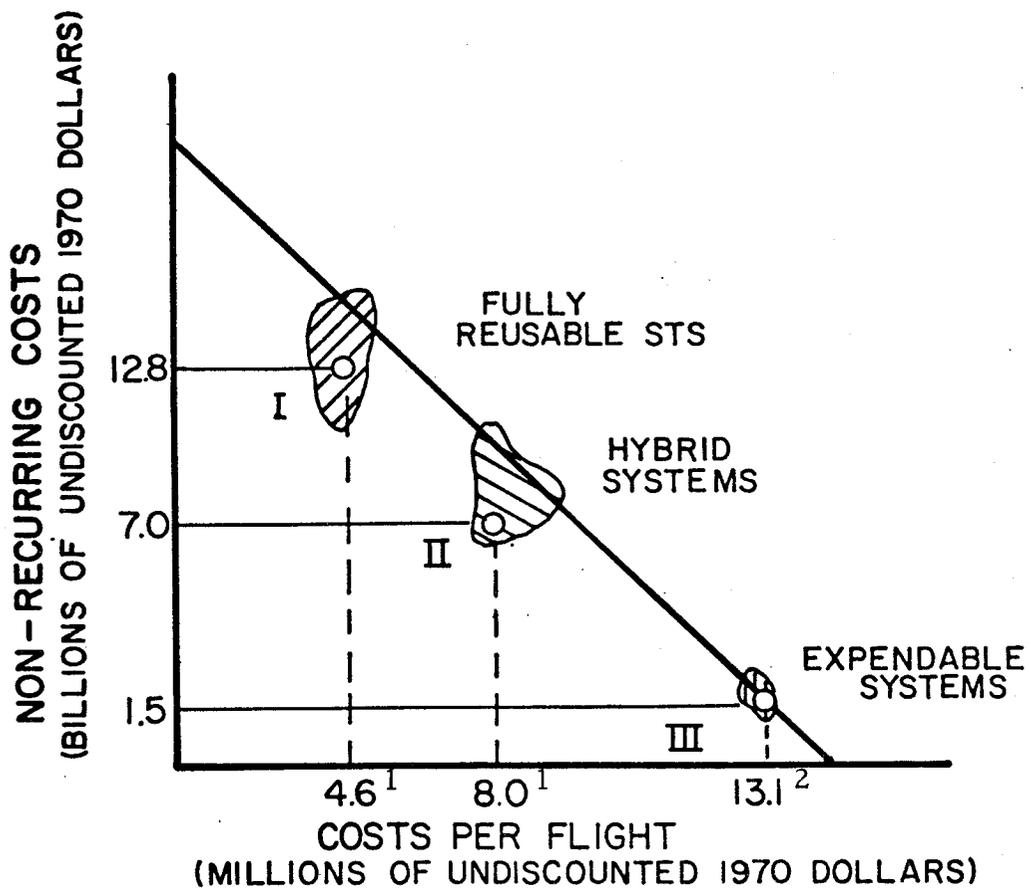


Figure 0.3 STS Recurring vs. Non-Recurring Launch Cost Trade-Offs at Given Discount Rate e.g., 10 percent, Payload Effects and Space Transportation Activity.

¹ For Space flights that require the Space Tug, \$0.46 million have to be added.

² In the expendable case the Upper Stage Costs have to be included, where required. They vary from \$2.5 million to \$5.0 million.

Figure 0.3 shows the trade-off line between the launch costs for one additional flight and the expected non-recurring costs of different systems. Underlying each of these regions of economic choice shown in Figure 0.3 is a very complicated and extensive set of cost estimates, demand estimates, and estimates of other economic variables influencing system choice which will be listed subsequently and which are analyzed in detail in the main Report, Chapters 2.0 and 6.0.

The costs may be subdivided into two major broad categories:

(a) The non-recurring costs associated with the RDT&E and investment phase, including both launch vehicle and payload costs.

(b) The recurring costs per mission or per year for both the expendable and the fully reusable system after the Initial Operating Capability (IOC) date, again including both launch vehicle and payload costs.

Figure 0.3 does allow for the correct adjustment of the trade-off line for payload effects (see 2.4 and 2.6)¹. The fully reusable Space Shuttle and Tug Transportation System is shown with an estimated non-recurring cost of \$12.8 billion and an estimated cost per launch (based on incremental costs) of \$4.6 million. Alternate (Hybrid) systems that consist of both expendable and reusable elements may have a wide range in expected non-recurring and recurring costs: the one shown has \$7 billion in non-recurring costs and a recurring cost per launch of \$8 million, again on an incremental cost basis. The Expendable systems would also have an associated non-recurring cost, to meet mission requirements of the 1980's, of about \$1.5 billion, but an expected cost per launch of \$13.1 million--averaged over a large family of expendable rockets (from \$3.2 million to \$27.0 million, see

¹ These numbers, as well as similar subsequent numbers, refer to sections in the Main Report.

Chapter 6.0, Table 6.3). An analysis comparing the cost of Expendable systems to expected costs of the Space Shuttle and Tug was made on a mission-by-mission and payload-by-payload basis. The figures shown in the summary graph are aggregate, averaged figures. The regions around the point estimates indicate the uncertainty in non-recurring and recurring cost estimates of the various systems.

The particular trade-off line in Figure 0.3 was drawn based on a 10 percent social rate of discount.¹ There are a set of other economic factors that influence the location, the shape, and the slope of the trade-off line in Figure 0.3; among these are the level of demand for space transportation and the magnitude of payload effects for different systems.

Figure 0.4 illustrates the space program cost streams (annual cost vs. time) associated with the Space Shuttle System and with the Current Expendable System. It reflects the space program activities of the mission model established by NASA and by the Department of Defense for this study. Figure 0.4 summarizes the total life cycle costs for RDT&E, investment and operations phases of both launch vehicles and payloads.

MATHEMATICA introduced considerable variations to these activities, called Scenarios, to cover a broad range of space transportation demand in the 1980's. In Table 0.2 the Scenario 1 (NASA and DoD Baseline model) life cycle cost summary data are presented for the Space Shuttle System. The cost data are given by year from 1971 to 1990 for launch vehicle RDT&E, initial fleet and operation costs as well as for payload RDT&E and operation costs. Total costs are also shown for each year and for each category, all in undiscounted 1970 dollars.

¹ The social rate of discount is discussed in Section 0.3.3.

SPACE PROGRAM COSTS (1978-1990 OPERATIONS) SCENARIO 1 (NASA and DoD BASELINE MODEL)

CURRENT EXPENDABLE SYSTEM vs SPACE SHUTTLE AND TUG SYSTEM

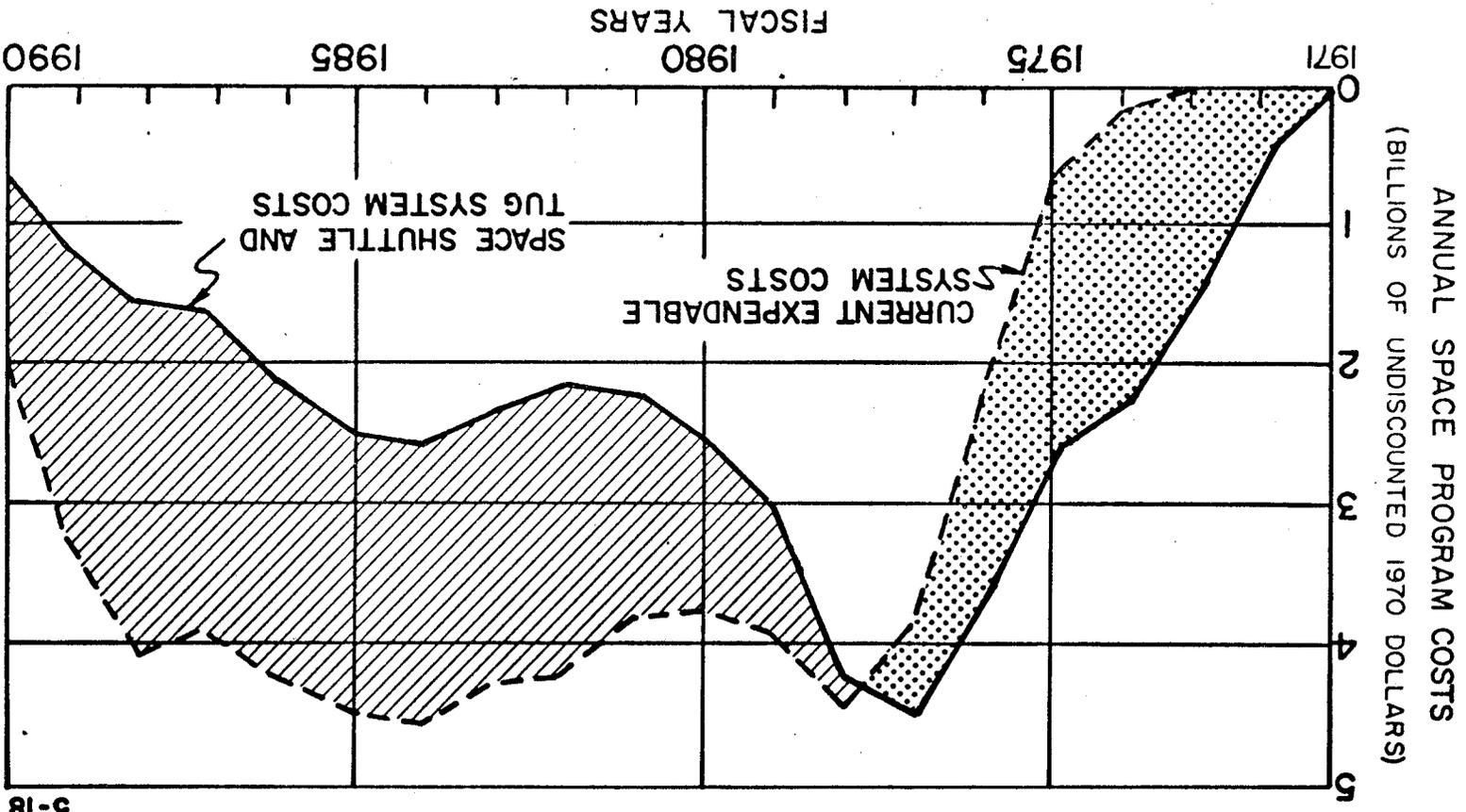


Figure 0.4

5-18

Table 0.2

LIFE CYCLE COST SUMMARY DATA
 SCENARIO 1 - NASA + DOD BASELINE MODEL
 SPACE SHUTTLE SYSTEM
 (MILLIONS OF UNDISCOUNTED 1970 DOLLARS)

FISCAL YEAR	NON-RECURRING COSTS			RECURRING COSTS		TOTAL
	LAUNCH RDT&E	VEHICLE INVEST.	PAYLOAD RDT&E	LAUNCH	PAYLOAD	
1971	18	0	0	0	0	18
1972	492	0	0	0	0	492
1973	1528	0	0	0	0	1528
1974	2289	0	33	0	0	2322
1975	2344	32	262	0	0	2638
1976	1914	85	1198	0	465	3662
1977	970	314	1814	0	1526	4624
1978	365	533	1101	678	1690	4367
1979	0	800	650	365	1205	3020
1980	0	613	551	415	970	2549
1981	0	310	617	364	906	2197
1982	0	74	796	409	891	2170
1983	0	49	883	364	1059	2355
1984	0	49	894	381	1272	2596
1985	0	25	591	420	1480	2516
1986	0	0	242	479	1364	2085
1987	0	0	113	386	1143	1642
1988	0	0	149	437	930	1516
1989	0	0	137	366	686	1189
1990	0	0	39	446	199	684
TOTAL	9920	2884	10070	5510	15786	44170

0.3 ECONOMIC PRINCIPLES APPLIED IN THE ANALYSIS

Given the expected reductions in space transportation system costs in the 1980's, MATHEMATICA analyzed the circumstances and consequences of an investment in a New Space Transportation System made in the 1970's. For this, total life cycle costs of the investment were used. MATHEMATICA gave additional attention to the costs per flight for the different Space Transportation Systems and their effect upon the demand for space transportation in the 1980's. For the purpose of considering efficient use of alternative transportation systems the incremental costs of space flights are relevant. The actual pricing policy of flight operations is subject to institutional constraints and one has a variety of choices, ranging from total cost recovery down to recovery of incremental cost per flight only; it could also be based on demand elasticities of users. However, the two problems of cost effectiveness and demand analysis (for pricing strategy) should not be confused with each other.

The principal economic considerations are the following:

0.3.1 Cost Effectiveness Analyses.

Under cost effectiveness analyses, in a strict sense, MATHEMATICA includes only those economic analyses that use a definition of economic benefits which are either directly or indirectly derived from expected cost savings between alternative systems. Within cost effectiveness analyses MATHEMATICA chose two alternative and equally valid approaches that lead to different economic results:

- a. Equal Capability Effectiveness. These cost effectiveness analyses assume that the same demand (capability) has to be met. Estimates of the net cost savings are made

that can be achieved when introducing new technology. These cost savings are then compared to the expected outlay of RDT&E and hardware costs of the new system. In Figure 0.5a the approach is illustrated (see Chapter 2.0).

- b. Equal Budget Effectiveness. These analyses assess whether the direct cost savings implied by (a) above and increases in the demand for space transportation induced by the new system up to the same annual budget level justify the expected RDT&E and initial fleet investment over the complete uselife of the new system. The new system is operated with the same budget level that the existing technology requires to meet the space transportation capabilities within each scenario. This approach is indicated in Figure 0.5b (see Chapter 2.0).

Figures 0.5a and 0.5b illustrate these two types of cost effectiveness analyses. Neither approach considers potential additional benefits and options that a fully reusable Space Transportation System can offer the Nation, i. e., capabilities that with the Expendable rocket technology simply are not achievable for technical reasons. In making cost effectiveness analyses in this strict sense, one need only make the assumptions that prior to the development of the New Space Transportation System society is willing to spend, say, \$3 billion to place 46 payloads into orbit, per year, (this was the average over the years from 1963 to 1970 for the unmanned programs, excluding the manned space program completely) and that the projected space budget for NASA and the Department of Defense jointly is being spent in an efficient way.

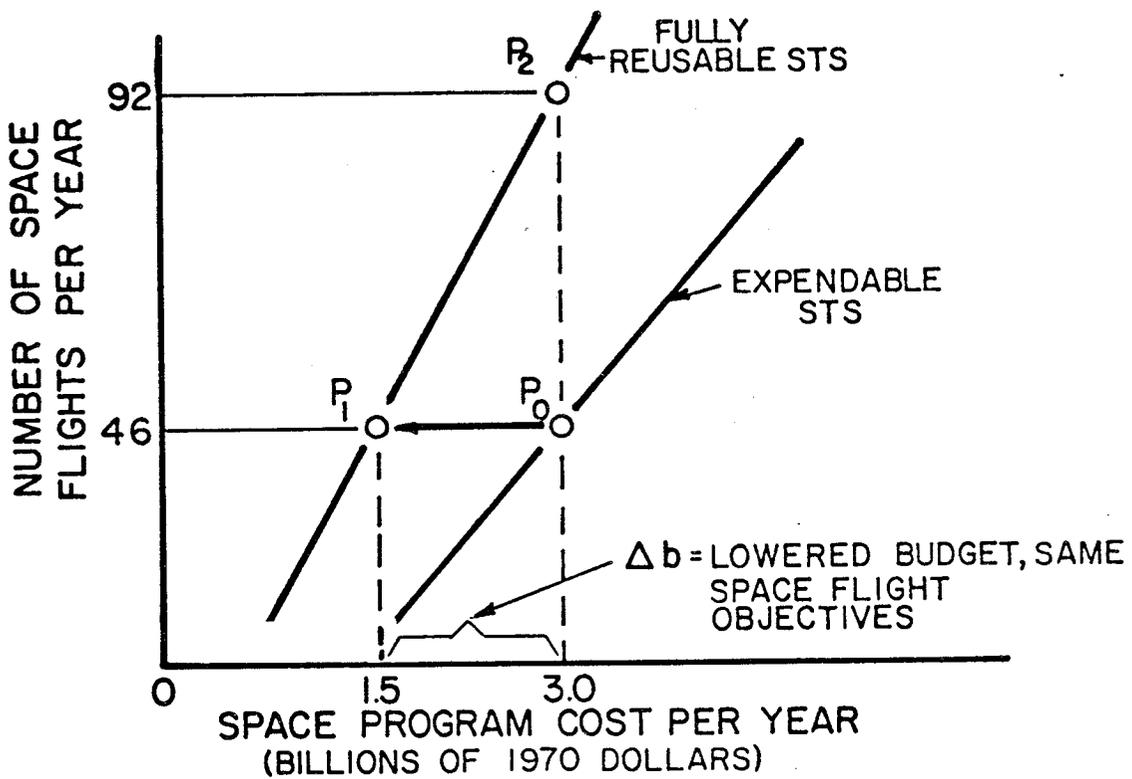


Figure 0.5a

Equal Capability Analysis, NASA, DoD and Other Users

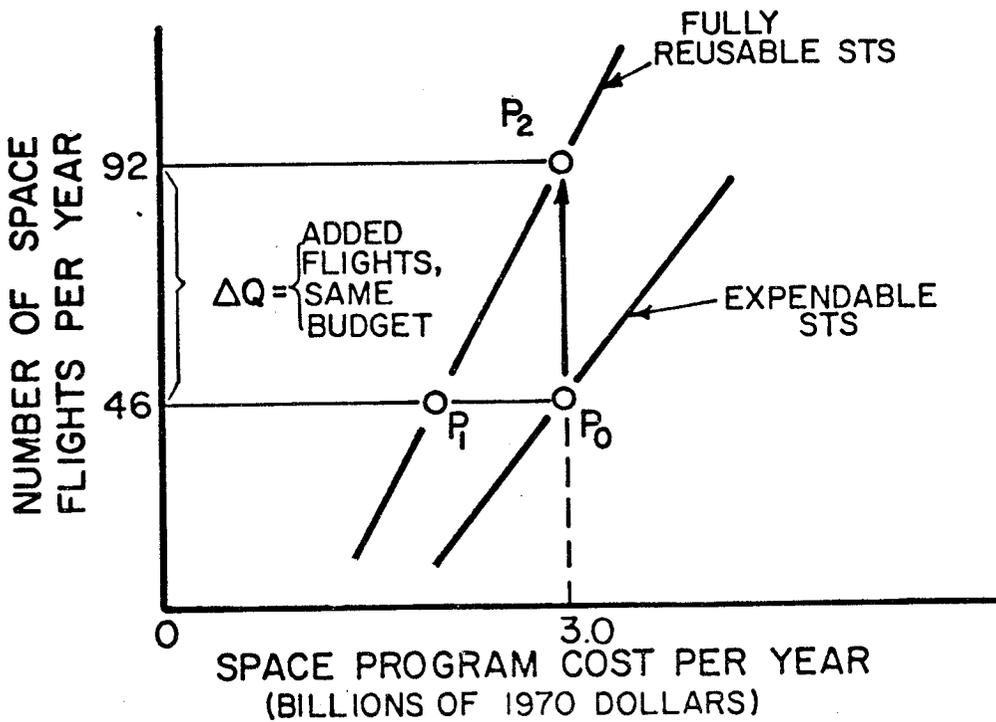


Figure 0.5b

Equal Budget Analysis, NASA, DoD and Other Users

This means that with the existing technology, sizeable cost savings cannot be achieved for the same program capabilities either in the Department of Defense or in the science and applications programs of NASA.

Equal capability analyses and equal budget analyses were performed for a whole range of expected space programs, from 450 to 900 flights, over a 13-year (1978-1990) period for expendable and fully reusable systems. The range of space programs (scenarios) considered is described further in the quantitative summary, Section 0.4.

0.3.2 The Measurement of Induced Benefits from Incremental Space Activities.

When performing "Equal Budget" analyses one has to allow for one basic axiom of economic theory: the decreasing marginal value of goods and services. In keeping with this fundamental principle, as additional missions are added to the existing space program, they increase the total value received by society, by the agency, or by the scientific community; however, the increment in utility received by society or the consumer will be decreasing as the number of missions increases. This holds for NASA, for the Department of Defense, and for other government agencies. The assumptions made for the "Equal Budget" analyses in measuring the benefits of additional space flights beyond those undertaken with the Expendable Space Transportation System in the 1980's are illustrated in Figure 0.6. The horizontal axis shows the number of space flights demanded per year, and the vertical axis shows the price or cost per space flight, including payload costs. (Ignoring, correctly, fixed costs and considering incremental costs; see 0.3.6.). The

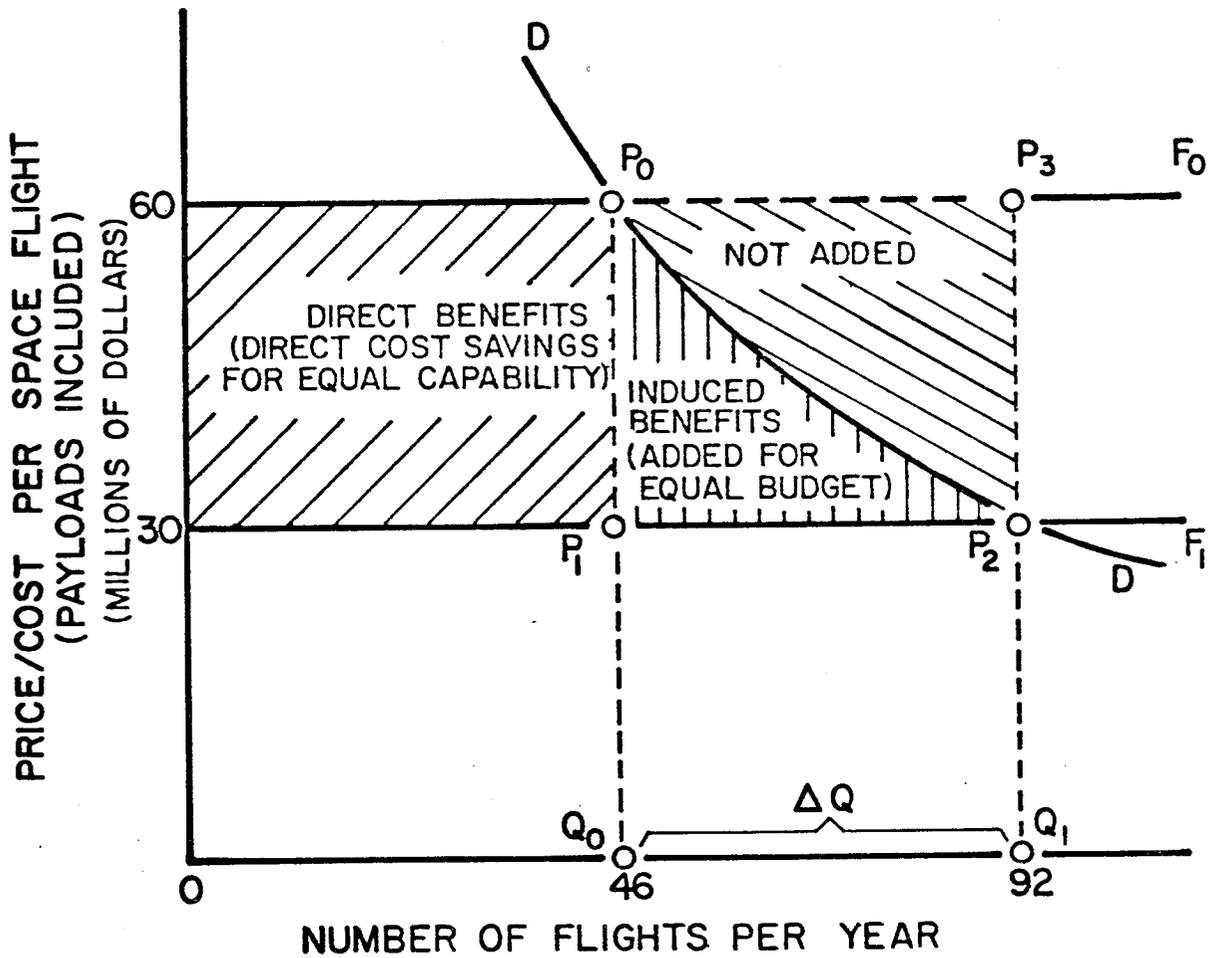


Figure 0.6
 The Measurement of Induced Benefits
 from Incremental Space Activities

direct benefits are the cost savings if the Space Shuttle would undertake the same missions (equal capability) as those done under the Expendable Space Transportation System. The demand curve which goes through P_0 was constructed under the assumption of a constant budget for NASA and the Department of Defense space activities, launching all the space flights possible within the limits of a given budget. The downward sloping demand curve, therefore, shows a constant U.S. space expenditure; it reflects how changes in the cost per space flight (launch costs and payload costs considered in combination) influence the number of flights demanded with such an assumption. If the nominal cost savings of the Space Shuttle System compared to current technology had been included in the equal budget analyses as a benefit, then a considerable overestimate of the "benefits" of the New Space Transportation System would result.

In general, the "Equal Capability" analyses are the most conservative way of looking at the economic efficiency of New Space Transportation Systems. The "Equal Budget" analyses do allow, in part, for the increased activity to be expected by lower cost systems. The lower and upper limits of space activities for the economic analyses were determined within the context of the history of space flights in the 1960's for the United States and for the Soviet Union, as illustrated in the summary charts in Section 0.4 of this Executive Summary.

MATHEMATICA tested the constant budget hypothesis on the example of Department of Defense payloads in the 1960's and found an elasticity of demand exceeding that implied by the constant budget hypothesis. This would indicate that demand for space transportation in the 1980's with the Space Shuttle System may well be larger than that indicated by the Equal Budget demand curve. To the extent possible

the precise shape and location of the demand curve should be established but its determination is a major task.

0.3.3. The Social Rate of Discount.

No proper investment analysis is possible, whether private or public investment is considered, without using a discount or interest rate. For private investment the interest rates in the capital market provide the critical information. For public investment the correct rate is more difficult to determine because the allocation of resources both to and within the government is directed only in part by the forces of the market.

For the government sector the social rate of discount fulfills the function of the interest rate in the private capital market. It reflects the sacrifice that is borne by the economy when resources are withdrawn from other production or consumption in the economy and are instead transferred to a public investment project. MATHEMATICA analyzed the investment alternatives of the Space Transportation Systems for discount rates ranging from 1 percent to 20 percent. The discount rates included in this Summary concentrate mainly around the 10 percent rate of discount. For purposes of comparison, results are also given for 5 percent and 15 percent rates of discount. The 10 percent social rate of discount used for the summary of MATHEMATICA's results is among the highest discount rates used in the federal government for the evaluation of an investment project of this type. The use of the 10 percent rate, therefore, is a very conservative way to evaluate the economics of the Space Shuttle System.

A survey of the major government agencies for Fiscal Year 1969 indicates a wide variation in the use or non-use of social rates of discount for the evaluation of public research and development projects. The rates used by government agencies varied between 0 percent, i. e., the use of no discount rate to a concentration among major agencies around 4 percent to 5 percent. For some projects, mainly of the Department of Defense, the rates used were 10 percent or more. One of the major advances, yet to be achieved, is the use of a single discount rate to evaluate public investment projects across government agencies. In the light of the present usage, the 10 percent rate used by MATHEMATICA is among the highest applied. A survey of the recommended social rates of discount by economists again leads to the conclusion that a 10 percent rate ranks among the highest rates suggested by different economists. A survey, extending from 1958 to the present, of the rates suggested by economists indicates a range from 4 percent to 13.5 percent. Only two economists out of fifteen suggested in the published literature rates in excess of 10 percent.

One must emphasize that the 10 percent social discount rate was applied to constant 1970 dollars and not to an inflated benefit stream in current dollars over the 1970's and 1980's. This fact adds further conservatism to the economic analysis performed for the New Space Transportation System.

The higher the social rate of discount applied to a project, whether private or public, the less likely is the economic acceptance of such a project. Figure 0.7 shows the net present value of an investment project such as the Space Shuttle as a function of the discount rate applied to the benefit and cost stream over the expected lifetime of the project.

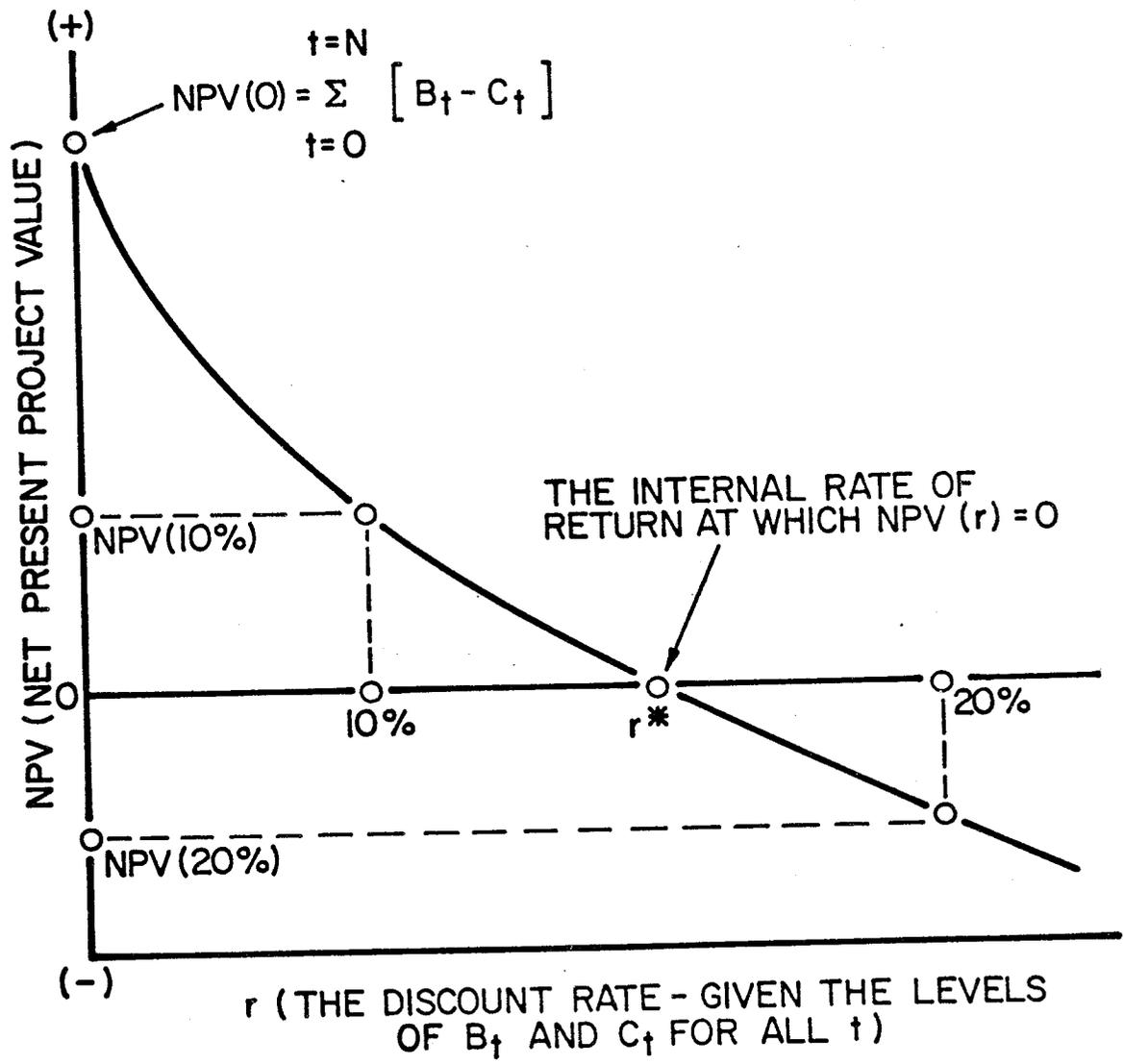


Figure 0.7 Sensitivity of Net Present Project Value (NPV) to the Discount Rate (r), given the levels of Benefits (B_t) and Costs (C_t) over time (t).

The problems of estimating the discount rate from empirical data, the problem of ranking alternative projects, and the uses and misuses of the internal rate of return have been discussed in considerable detail in this Report and in an earlier paper.¹ The matter is somewhat intricate and for the purposes of a summary we shall not repeat the discussion here. The correct intuitive interpretation of the social discount rate can, however, be explained as follows: When the government undertakes a public investment project, the resources absorbed by the project must necessarily be withdrawn from the pool of investment and consumption resources in the economy. The government can justify the transfer of the resources to a particular project only if it can put these resources to a more productive use than the private sector could have achieved with them. In the case of the Space Shuttle System, this applies to the \$12.8 billion for RDT&E and Initial Fleet costs. The opportunity costs of using the resources for the public sector are the foregone benefits that would have been produced with these resources by the private sector. The social rate of discount reflects the magnitude of these opportunity costs for government investment projects.

Though MATHEMATICA also shows in the summaries the results for the 5 percent and 15 percent discount rates applied to the Space Shuttle investment decision, we, nevertheless, recommend 10 percent and draw our conclusion based on the 10 percent social discount rate applied to the different space programs.

¹ Heiss, K. P., Reinhardt, U., "On the Principles of Public Project Evaluation," Volume 1, Cost Benefit Analysis of New Launch Systems, MATHEMATICA, prepared for the National Aeronautics and Space Administration, Princeton, N.J., July 17, 1970.

0.3.4. The Uselife of RDT&E Investments in the Space Transportation System.

The economic uselife of an investment project is normally something short of infinity. This is so because the typical investment project ceases to have economic value when the physical uselife of the project ends. The technology created with the development of the Space Shuttle, however, does not vanish. MATHEMATICA submits that, after careful consideration of all the issues involved in choosing between a finite or an infinite uselife for RDT&E investments, the selection of an infinite uselife for such projects is the correct procedure.

To limit the uselife of these expenditures to, say, the year 1990 assumes that all scientific and technical knowledge used as part of the Space Shuttle development will be lost by 1990, and that the development of whatever new system might be built in 1990 will not have to draw on such knowledge and not have to prove cost effectiveness compared to the 1978 Space Shuttle, but rather the Expendable systems of the 1960's and 1970's. Such an assumption is obviously not realistic and would lead to a serious understatement of the true economic value of RDT&E investment activities.

0.3.5. Other Economic Parameters: Program Start, Gestation Period and the Initial Operational Capability Date.

In most cost effectiveness analyses the program start and gestation period, as well as the initial operational capability of the system to be developed, are very important variables affecting the cost effectiveness of alternative systems. MATHEMATICA has allowed in the analysis for a considerable variation in the gestation period of the

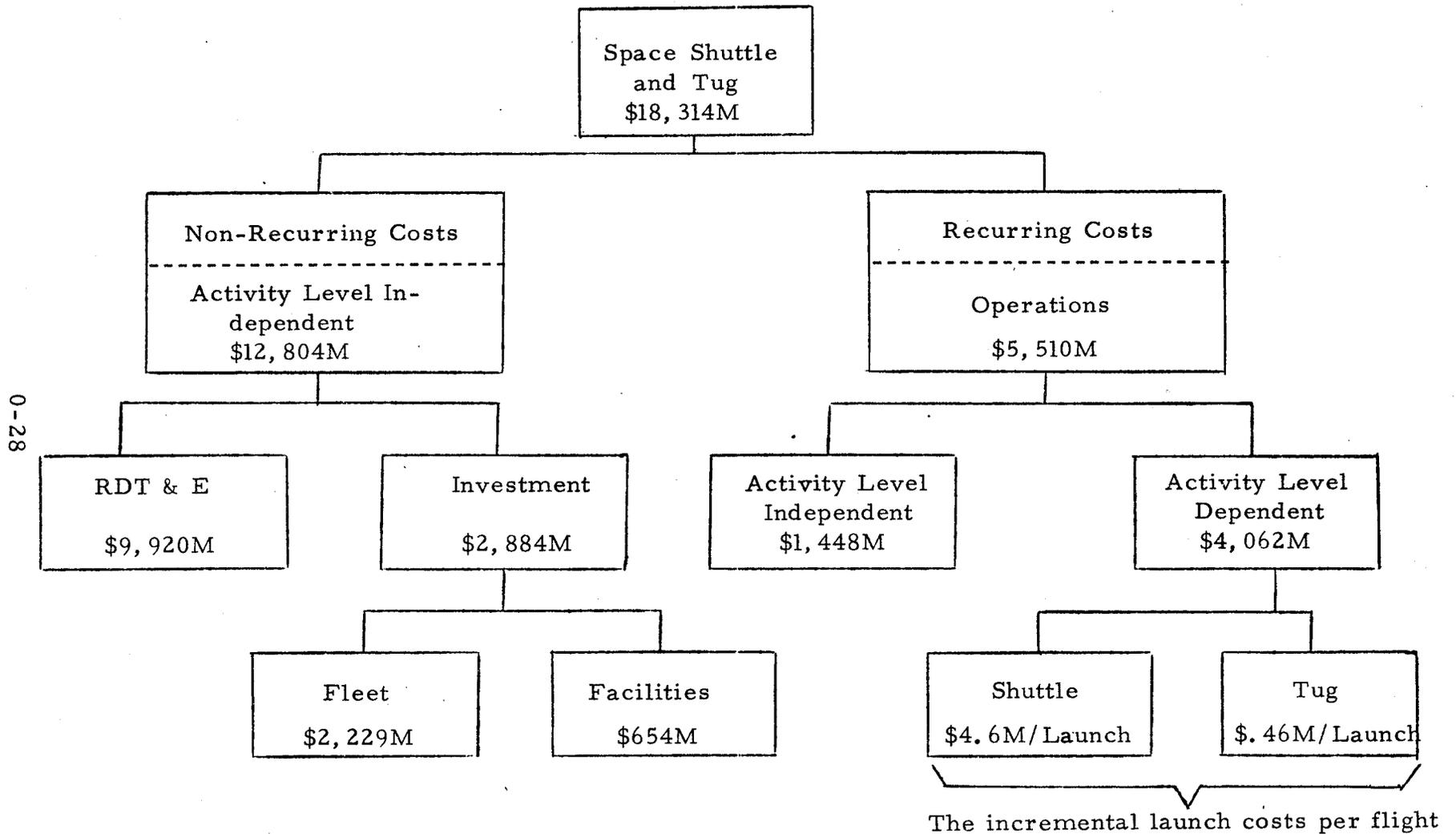
RDT&E program, the Initial Operational Capability (IOC) date, and the program start of the Space Shuttle. The gestation period of the Space Shuttle program was extended by up to 50 percent of the time estimate of the present development schedule. With regard to the IOC date and the slippage of the development program, delays in the IOC date of one and two years have been considered by MATHEMATICA. Although delays in each of these variables (the program start, the lengths of the gestation period, and the IOC date) do influence negatively the net present value of the Space Shuttle investment project, none of them has sufficiently significant effects, within the limits analyzed by MATHEMATICA, to change the decision to accept or reject the Space Shuttle investment. However, the conclusion has to be based on a careful understanding of the complete methodology of the economic analysis. Data points for the evaluation of such space programs are included in the summary charts and the results are reflected in the general economic findings.

0.3.6. The Incremental Costs of Space Flights in the 1980's of Different Space Transportation Systems.

Table 0.3 presents an economic breakdown of the launch vehicle life cycle costs of the Space Shuttle and Tug. The total costs are classified into non-recurring and recurring costs. While the non-recurring costs are independent of activity level, the recurring costs may be further classified into activity-level dependent (incremental) and activity-level independent costs.

For the fully reusable Space Transportation System, the incremental or marginal cost is estimated to be \$4.6 million per launch for the Space Shuttle and \$0.46 million for the Space Tug. Costs

Table 0.3
 Launch Vehicle Cost Classification for Economic Analysis¹
 (Millions of Undiscounted 1970 Dollars)



¹ Shown are Space Shuttle and Tug Transportation Costs, for NASA-Department of Defense Baseline Mission Model

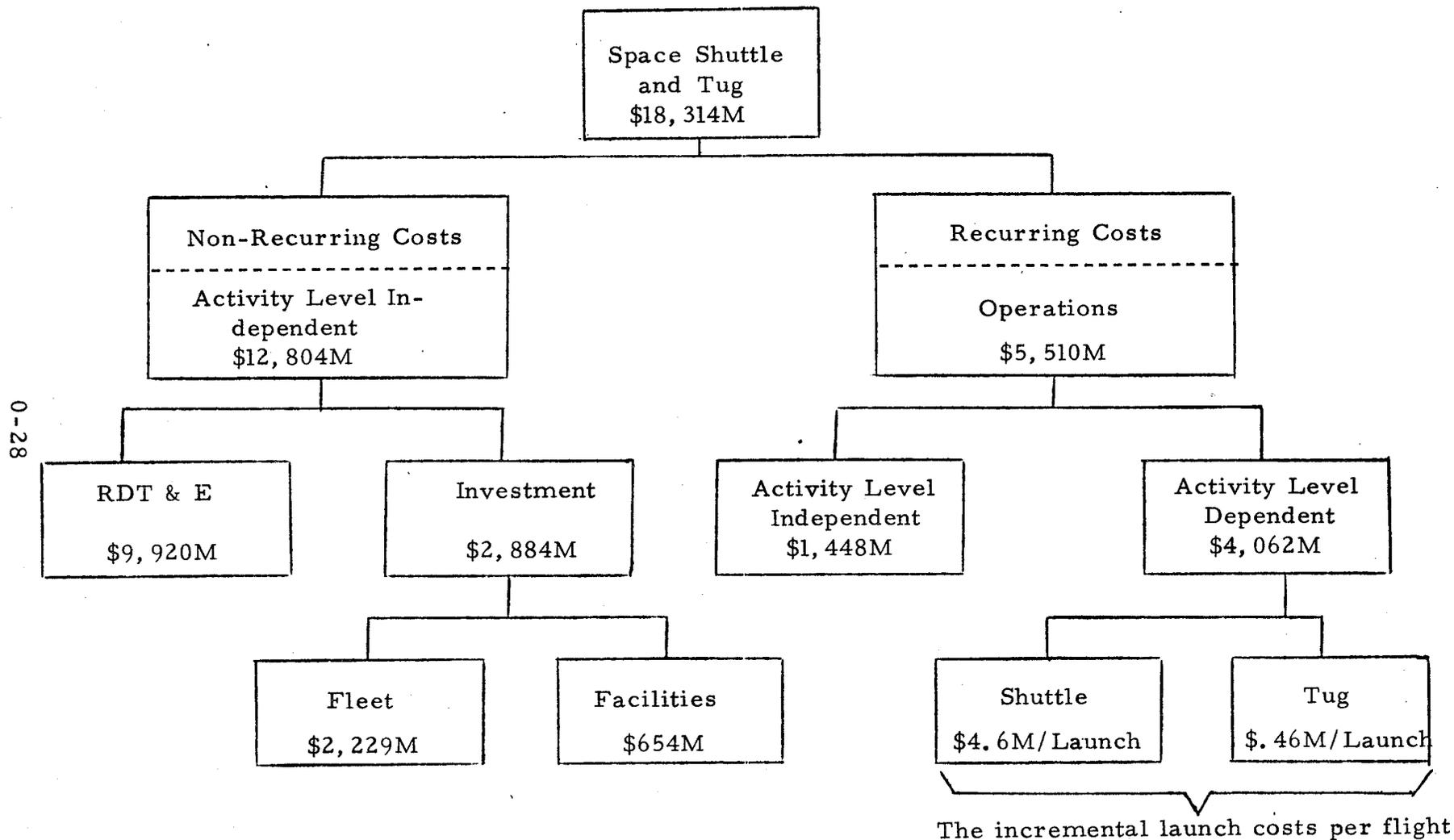
RDT&E program, the Initial Operational Capability (IOC) date, and the program start of the Space Shuttle. The gestation period of the Space Shuttle program was extended by up to 50 percent of the time estimate of the present development schedule. With regard to the IOC date and the slippage of the development program, delays in the IOC date of one and two years have been considered by MATHEMATICA. Although delays in each of these variables (the program start, the lengths of the gestation period, and the IOC date) do influence negatively the net present value of the Space Shuttle investment project, none of them has sufficiently significant effects, within the limits analyzed by MATHEMATICA, to change the decision to accept or reject the Space Shuttle investment. However, the conclusion has to be based on a careful understanding of the complete methodology of the economic analysis. Data points for the evaluation of such space programs are included in the summary charts and the results are reflected in the general economic findings.

0.3.6. The Incremental Costs of Space Flights in the 1980's of Different Space Transportation Systems.

Table 0.3 presents an economic breakdown of the launch vehicle life cycle costs of the Space Shuttle and Tug. The total costs are classified into non-recurring and recurring costs. While the non-recurring costs are independent of activity level, the recurring costs may be further classified into activity-level dependent (incremental) and activity-level independent costs.

For the fully reusable Space Transportation System, the incremental or marginal cost is estimated to be \$4.6 million per launch for the Space Shuttle and \$0.46 million for the Space Tug. Costs

Table 0.3
 Launch Vehicle Cost Classification for Economic Analysis¹
 (Millions of Undiscounted 1970 Dollars)



¹ Shown are Space Shuttle and Tug Transportation Costs, for NASA-Department of Defense Baseline Mission Model

independent of activity level are not relevant when measuring the incremental costs. One could calculate average costs of space flights by considering the flights of an arbitrary 10 to 13 year space program and allocating to them the total RDT&E costs as well as the initial fleet and operating costs, which would then lead to figures ranging from \$25 million to \$30 million per launch. The use of this average as a price would prevent the Nation from using the Space Shuttle optimally. The examination of this assertion is presented in Appendix A to Chapter 1.0.

Figure 0.8 illustrates the difference between (a) total average cost, (b) the average operating cost, and (c) the incremental cost for Space Shuttle flights. On the horizontal axis we show again the number of Space Shuttle flights, and on the vertical axis the cost per launch of those flights. While total average costs range from \$24 million to \$18 million as a function of expected Space Shuttle flights, and average operating costs range from \$7.1 million to \$6.0 million, several alternative calculations of the incremental costs of additional Space Shuttle flights ranging over many different flight levels, indicate that the incremental cost of Space Shuttle flights is \$4.6 million (see 2.5.4.). This is the cost incurred when launching an additional flight, e. g., when increasing the flights from 56 to 57 per year. The incremental costs of Space Shuttle flights prove to be very close to this figure when different approaches are taken to determine incremental costs. Also, the incremental costs are found to be constant over a large range of flight levels.

For Expendable launch vehicles the incremental costs per flight are much higher, and close to their average total operating cost. The main reason for this is that with each expendable launch all the flight

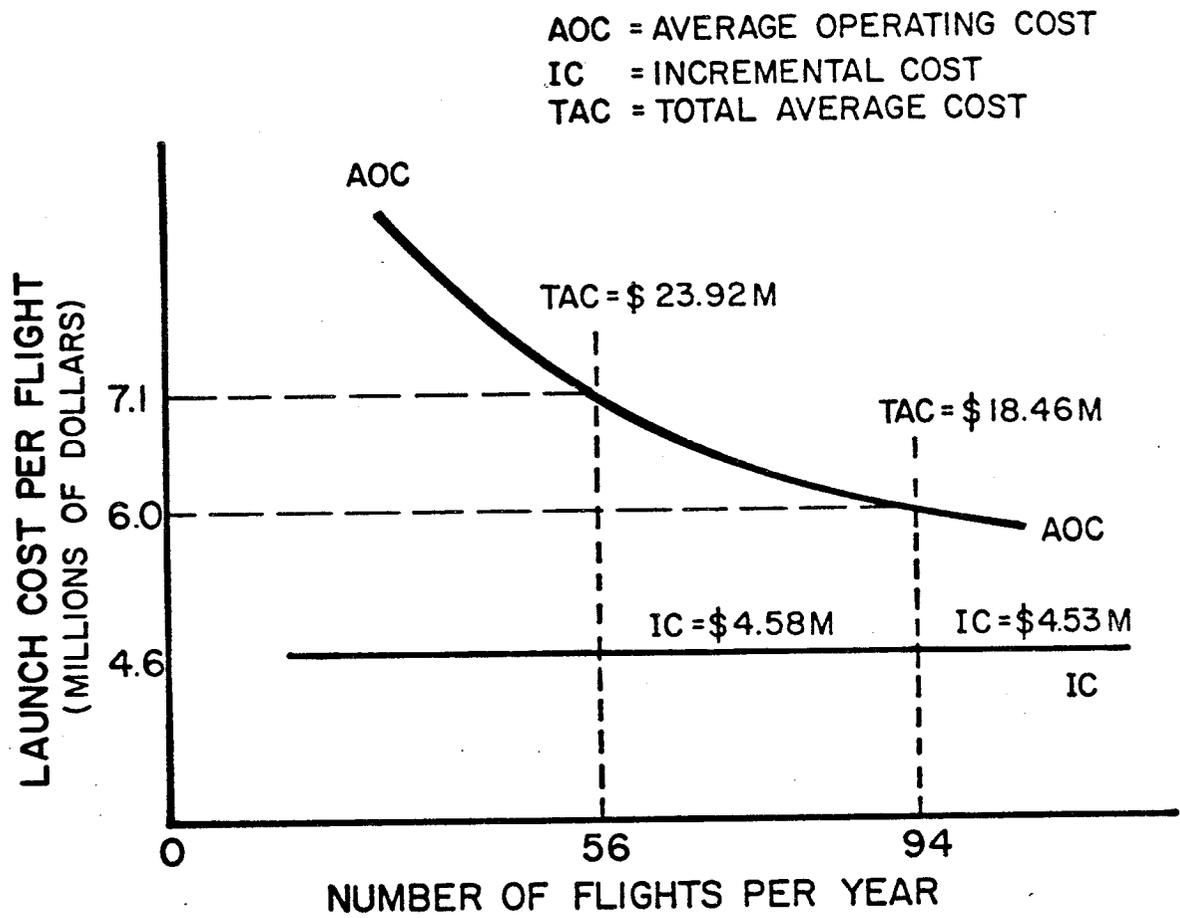


Figure 0.8 Average and Incremental Launch Costs of the Space Shuttle as a Function of Flights per Year.

hardware (and associated testing) is "thrown away." Chapter 6.0 and Table 6.3 of the Report detail the cost range of the Expendable launch vehicles. These costs range from \$3.2 million (Scout) to \$27.0 million (Titan III L2/Centaur).

When selecting the vehicle assignments (between Expendables and Space Shuttles), one has to include the different mission costs due to payload effects in addition to the incremental launch costs of the Expendable and the fully reusable Space Shuttle and Tug Systems. The process by which vehicle assignments are made on the basis of incremental costs is called "capture analysis." A complete set of these, i. e., choice of Space Shuttle or Expendable modes, has been performed on the Space Shuttle and Tug Transportation System. Analyses of the sensitivity of system selection to changes in incremental costs of the Space Shuttle and Tug System have also been performed in the context of mission capture analyses and are further described in Chapters 2.0 and 6.0 of the Report.

0.3.7. Risk and Uncertainty.

First and foremost, in terms of the acceptability of the Space Shuttle investment, must loom the estimate and the accuracy of the non-recurring costs in the 1970's to develop a fully reusable New Space Transportation System. Different system configurations which would provide a reusable capability are associated with different levels of research and development efforts as well as initial fleet requirements. With regard to the selection of the best system, the effects of these differences have yet to be fully evaluated. Nevertheless, MATHEMATICA believes that the present estimate for the non-recurring costs of the Space Shuttle and Tug System, as used in the Report, should not be equated with either a "political" price to get the Space Shuttle accepted

or with very early estimates of non-recurring costs of research and development investments.

The estimates of the non-recurring costs of the Space Shuttle and Tug System have changed significantly over the past two years. RDT&E costs of the Space Shuttle and Tug System have shifted from the early estimates of \$5.2 billion (Space Task Group Report, September 1969) to \$9.3 billion (Aerospace Corporation, March 31, 1971).¹ Although further changes in the estimated RDT&E, and the Initial Fleet costs of the Space Shuttle and Tug System will occur, MATHEMATICA feels that with an efficiently managed development program of the Space Shuttle and Tug System, the cost escalation experience of the early and middle 1960's should not apply to the present non-recurring cost estimates of the Space Shuttle System. This holds in particular if the non-recurring cost estimates are all made in constant 1970 dollars and, therefore, eliminate the artificial effects of inflationary cost escalation that will continue to occur in the 1970's.

MATHEMATICA has also performed a cost uncertainty analysis of the Space Shuttle cost savings to be expected in the 1980's. It should be recalled that the major advantage of the New Space Transportation System, when compared to the Expendable mode, lies in the following areas:

- (a) The reduction in: First, payload RDT&E costs; second, payload first unit costs; third, the costs of space programs after 1978 upon inclusion of reuse, refurbishment and update of payloads, made possible by the Space Shuttle System.
- (b) In comparison with the Expendable Space Transportation System, the Space Shuttle and Tug System has lower launch costs.

¹ Both estimates expressed in 1970 dollars.

However, these expected cost savings are in the future and by their very nature relatively uncertain as to their particular level as well as to the time by which they can be realized. MATHEMATICA has applied risk analysis methods to the payload and Space Shuttle launch cost streams classified as "activity level dependent" costs. Although the estimation of cost uncertainties will, admittedly, always remain an area of major concern, by applying techniques of risk analysis to the recurring cost streams of the Space Shuttle, MATHEMATICA found the Space Shuttle investment unquestionably superior to the New Expendable System at a 5 percent social discount rate and calculated an 0.86 probability that the Space Shuttle investment will have a rate of return of at least 10 percent.¹ Although by the very nature of large scale RDT&E projects as exemplified by the Space Shuttle investment, an element of uncertainty will persist, the analytic tools available show that the Space Shuttle investment is confirmed to be economically acceptable.

On the other side, there is an additional consideration which favors a Space Shuttle System: the mission reliability as measured by the initial assured functioning of the payload in orbit is significantly higher than that of expendable systems. Empirical evidence shows that the majority of failures of payloads occur very early, within the first several days from launch; these failures can--for all practical purposes--be eliminated by the Space Shuttle System through in-orbit checkout before payload release. This benefit has not been allowed for in this study. It may have a major effect on the commercial and national security demand for space activities in the 1980's, favoring the Space Shuttle System.

¹ In other words, the analysis will show a breakeven on present value at a social discount rate of at least 10 percent.

0.4 SUMMARY OF THE QUANTITATIVE RESULTS OF THE ECONOMIC ANALYSES

MATHEMATICA evaluated a range of space programs covering the expected range of space activities in the 1980's, on the basis of conservative projections of the history of United States space flights in the 1960's.

In this Report the term "space program" is defined as a particular combination of NASA, Department of Defense, and commercial space applications. The term "space program" is used interchangeably with the term "scenario." "Space program costs" (the costs of a scenario) as used in this Report include the cost of development, construction, launch and operation, and payloads. These costs also allow for the associated support costs such as the cost of launch sites. Excluded are general administrative costs.

The space programs analyzed by MATHEMATICA cover widely different mixes of scientific, defense, and commercial applications of space. About thirty different space programs for the 1980's were analyzed with regard to their economic effects on the choice between Current Expendable technology and a fully reusable Space Transportation System. The payloads and traffic of the Baseline Mission Model (with wide variations provided by the scenarios) and the various Space Transportation System concepts are described in detail in Chapters 2.0, 4.0 and 5.0.

The space program identified as Scenario 1 (736 missions over 13 years, with an average of 56 missions per year, see also Figure 0.4) describes the program requirements established for this study by NASA and the Department of Defense for the 1980's. This program includes a substantial Office of Space Science and Applications (OSSA) budget, a

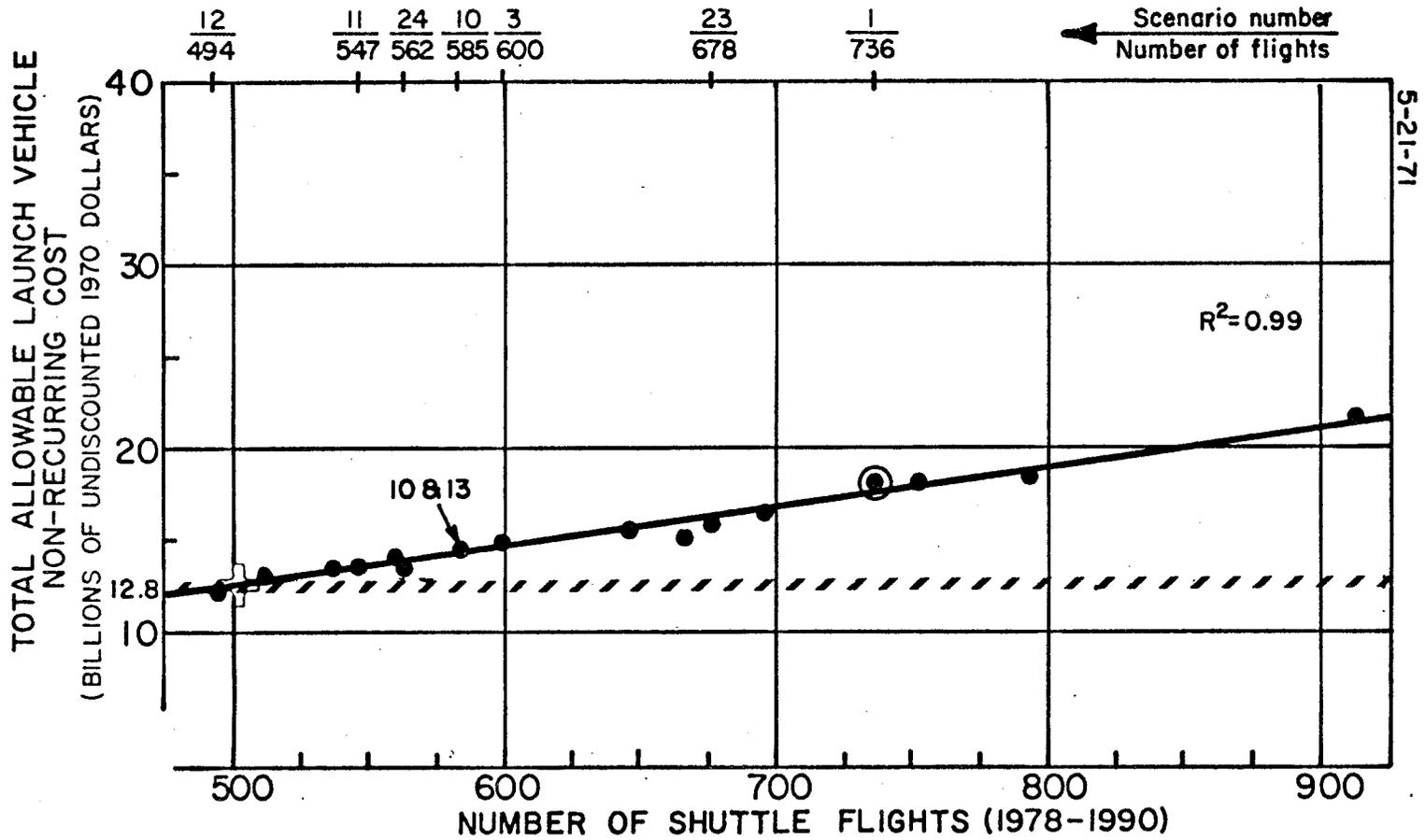
Department of Defense budget in line with current projections of the Department of Defense, commercial space applications of about \$300 million a year, and manned space flight activities of only \$200 million per year on the average (that is, only Space Station support missions of four to five flights per year were included). Cost streams were estimated for Current Expendable and fully reusable Space Transportation Systems. These cost streams include both launch vehicle and payload costs (RDT&E, investment and operating costs). (See Figures 0.4, 0.17, 0.18, 0.19 and Tables 0.2 and 0.3.) The cost streams were then used as a basis for the different cost effectiveness analyses.

Figure 0.9 summarizes results of "Equal Capability" cost analyses of the fully reusable Space Shuttle. On the horizontal axis a great variety of alternative, postulated space programs are ranked in ascending order based on the average number of flights they imply. The vertical axis shows the economically justifiable¹ (or allowable) reusable launch vehicle RDT&E and Investment costs (in undiscounted 1970 dollars) associated with these alternative space programs. By economically "justifiable" cost in this context is meant the maximum RDT&E and Investment outlays which could be incurred without depressing the net present value of the reusable Space Transportation System, (i.e., the present value of all future benefits minus the present value of all costs associated with the reusable Space Transportation System) to a level below zero, at a 10 percent discount rate. All the benefits attributable to this investment--i.e., cost savings in the recurring launch costs and all of the expected payload cost savings (RDT&E included)--are reflected in the

¹ The upward-sloping line in Figure 0.9 is a least-squares fit to a number of points closely scattered along this line with an R^2 of better than 0.99.

"EQUAL CAPABILITY" COST ANALYSES (10% DISCOUNT RATE)

- DATA POINTS FOR VARIOUS SCENARIOS
- ⊙ DATA POINT FOR SCENARIO I (NASA & DoD Baseline: 736 flts, 57 flts/yr)
- ⊕ BREAK EVEN POINT (506 flts, ~ 39 flts/yr, 1978-1990)
- ▨ ESTIMATED NON-RECURRING SPACE SHUTTLE+TUG COSTS (3/31/71)



0-36

Figure 0.9

evaluation of these allowable non-recurring launch vehicle costs, as a function of either the flight level or the annual space budget levels. The \$12.8 billion lines reflect the 31 March 1971 estimate of these non-recurring costs. Therefore, any particular point on the upward sloping line indicates, on the vertical axis, quite closely, the maximum allowable RDT&E and Investment costs for transportation vehicles associated with the corresponding average annual traffic flow on the horizontal axis. As an example, the 1964 - 1969 U. S. traffic equivalent is represented by an annual traffic of 51 Space Shuttle flights. This is equal to 663 flights over the 1978 to 1990 period. The allowable RDT&E and Investment costs for this traffic rate are \$15.8 billion.¹ (See Figures 0.14 and 0.16). The 1965 - 1970 equivalent traffic of the USSR was 65 flights per year. This amounts to 845 flights over the 1978 - 1990 period. If this rate were projected for the United States a total of \$20 billion in RDT&E and Investment costs could be incurred for the Space Shuttle System without reducing the net present value of the Space Shuttle System to a level below zero, i. e., without rendering the Space Shuttle System economically unjustifiable. Any other point on the upward-sloping line is to be interpreted analogously. Thus, as long as the allowable non-recurring Space Shuttle System costs exceed the actual, estimated non-recurring costs (\$12.8 billion), the Space Shuttle System is economically better than the Expendable System. The level of space activity (over 13 years) where allowable and actual costs are equal is identified as "break-even point."

MATHEMATICA's Baseline space program for the 1980's, identified in Figure 0.9 as Scenario 3, contains an OSSA budget using the Expendable System of about \$900 million for 20 flights per year. This is one-half of the budget and traffic for OSSA projected by Scenario 1, the NASA-DoD Baseline model.

¹ Total absolute funding level over about ten years.

The Department of Defense budget of about \$1.2 billion and 28 flights per year on the average, as well as the commercial applications and manned space flight programs, are the same as those of Scenario 1. The other scenarios are variations around the MATHEMATICA Baseline space program for the 1980's. Of particular interest are Scenarios 23 and 24 which reflect historical levels of space funding for OSSA and the Department of Defense, with commercial and other civil applications and manned space flight activities at the level of MATHEMATICA's Baseline space program only. Scenario 23 is based on the 1963 to 1971 average funding level for the different agencies, while Scenario 24 projects for the 1980's a space program based on the funding levels of Fiscal Years 1970 and 1971--historical low points for recent United States space activities.

Even though the different space programs include (1) a drastic variation in the mix of activities between OSSA, the Department of Defense, and commercial applications; (2) a variation in the phase-in of the Space Shuttle--the period between 1978 and 1984 was considered; and (3) different build-up rates, we find an extremely good fit of the different economic results to the line shown in Figure 0.9. One would have expected a wider scatter of the economic answers from benefit-cost analyses of these different programs. If this had been the case, the defined measure of capability by which the space programs were ranked--i. e., the number of space flights--would not have been sufficient to adequately describe and measure the costs of space activities. In that case one would have to estimate not only the overall level of space transportation activities for the 1980's relatively accurately, but also the actual composition of the 1980's space flight programs as they divide up into defense, science and commercial and other civil applications.

In constructing the scenarios the same relative cost distribution of payloads was maintained within each agency. As the different space programs also covered options including and excluding manned space flights the results are divorced from the issue of manned-versus unmanned space exploration although all systems considered maintained a manned space flight capability. The results of the economic analyses indicate that a decision on a future manned program is not required to justify or reject the fully reusable Space Transportation System for the 1980's.

What this implies is that the complete set of economic analyses (methodologies and results), presented in Chapters 2.0 and 7.0 of the Report, lend themselves to reliable conclusions with regard to the economic desirability of Space Transportation Systems, once the overall demand for space transportation in the 1980's can be established.

Furthermore, given the detailed descriptions of the space programs (scenarios), the space history of the United States, and projections of space activities over the 1970's and 1980's in NASA and the Department of Defense--with a potential underestimate of commercial applications--one can draw reasonably accurate conclusions of whether or not a New Transportation System with reuse and refurbishment capability of payloads is desirable, taking into account the expected budgetary environment for space applications in the 1970's and 1980's. MATHEMATICA took the United States space flight activity from 1964 to 1969, and made for the 1980's a similar 13-year average projection of space flight activity--not in budgetary terms, but in numbers of flights only. We see that this leads to an "Equal Capability" scenario of 663 flights, roughly in the neighborhood of space programs of Scenarios 2, 7 and 8. MATHEMATICA then took the historic funding level of United States space flight activity by agency--excluding the manned space flight

program--between 1963 and 1971 as the basis for a budget constrained analysis for the 1980's and again arrived at a flight level corresponding exactly to the number of flights between 1964 and 1969. In the "budget constrained" case the number of possible flights, given the cost estimates for Current Expendable technology was found to be a 13-year total of 663 flights, or the exact 1964-1969 average of 51 United States flights per year. Thus the agreement of these two analyses tends to support the consistency of the economic analysis.

The results of the economic analysis are summarized in Figures 0.9 to 0.16.

Figure 0.9 shows the allowable non-recurring costs for developing, testing and producing the fleet of necessary, fully reusable vehicles as a function of the numbers of flights from 1978 on, with the total flights shown over a 13-year horizon, and using a discount rate of 10 percent. The space flight level varies between 450 flights and 900 flights, the range covered by our analyses. Figure 0.9 shows the allowable non-recurring costs in terms of the "Equal Capability" cost effectiveness analysis (see 0.3.1). This line shows the case where no allowance is made for increased space flight activities within each space program due to the greater incentive of using a lower cost Space Transportation System. It assumes that the space activities of NASA, the Department of Defense, and commercial applications will not increase at all when the costs of space missions are reduced by nearly one-half! This is a very conservative way of evaluating any economic investment. Figure 0.9 relates the cost savings of a fully reusable Space Transportation System in the operating phase of the program to the allowable non-recurring costs of developing such a system.

With the "Equal Capability" analysis, a non-recurring cost for the new, fully reusable Space Transportation System of \$12.8 billion (undiscounted 1970 dollars) would be justified, at 10 percent, with a space flight program from 1978 to 1990 of 506 flights, or 39 flights per year. We find that the range of allowable non-recurring costs goes from \$12.1 billion in the case of Space Program 12 up to \$21.4 billion in the case of Space Program 5, the two extremes analyzed by MATHEMATICA (38 flights per year up to 70 flights per year). Space Program 3 --the program used by MATHEMATICA as its projection for the 1980's--gives an allowable non-recurring cost of \$14.5 billion (undiscounted 1970 dollars in all cases).

Two major points should be added here:

1. If a substantial manned space flight program were added, the economic advantage of the Shuttle would improve.
2. If a substantial lunar exploration program were to be added to the options used in our analyses, significant reductions in lunar space transportation costs could be expected from the Space Shuttle.¹ Scenarios 25 and 26 analyze the effects of such an option on the economics of Scenarios 1 and 3. Figure 0.15 shows the effects of such an option on the economic results of our analysis. Scenario 25 included the NASA-DoD Baseline (Scenario 1) and Lunar Option 1; and Scenario 26 includes the MATHEMATICA Baseline (Scenario 3) and Lunar Option 1. For both of these scenarios the launch costs of the

¹ This reduction is due to both the increased advantage of the Shuttle in expanded space programs, and the ability to use a 100 percent load factor in flying hydrogen as a Space Shuttle payload.

Space Shuttle are but one-third of the Current Expendable and New Expendable cases. The Lunar option makes use of the Nuclear Shuttle for Earth orbit to Lunar orbit flights.

Figure 0.10 shows the allowable non-recurring costs for the fully reusable Space Transportation System as a function of the annual space program budget in terms of the "Equal Budget" cost effectiveness analyses performed at a 10 percent rate of discount. The allowable non-recurring costs for developing a fully reusable Space Transportation System are increased by about 25 percent when compared to the "Equal Capability" analyses of the same scenarios. The "Equal Budget" line shows, for each scenario, what the economic return is, if each space program had allowed for the same funding level as that required by Current Expendable technology. Again, the economic analyses give results that fit very closely the "Equal Budget" line shown in Figure 0.10 and lend themselves to similar conclusions as gained from the results presented in Figure 0.9, both at discount rates--in real terms-- of 10 percent. With the "Equal Budget" analyses, a non-recurring cost of the new, fully reusable Space Transportation System of \$12.8 billion (undiscounted 1970 dollars) would be justified, at 10 percent, by a space flight program requiring an annual funding of \$2.0 billion for NASA and the Department of Defense (launch costs and payload costs). The MATHEMATICA Baseline space program (Scenario 3) for the 1980's now yields allowable non-recurring costs for a New Space Transportation System of about \$19.5 billion (undiscounted 1970 dollars). The NASA and Department of Defense requirements of Scenario 1 yield a comparable, allowable non-recurring cost of about \$23.7 billion. The historic expenditure level of the United States unmanned space program

"EQUAL BUDGET" COST ANALYSES (10% DISCOUNT RATE)

● DATA POINTS FOR VARIOUS SCENARIOS
 ◎ DATA POINT FOR SCENARIO I (NASA & DOD Baseline: 736 flts, 57 flts/yr)

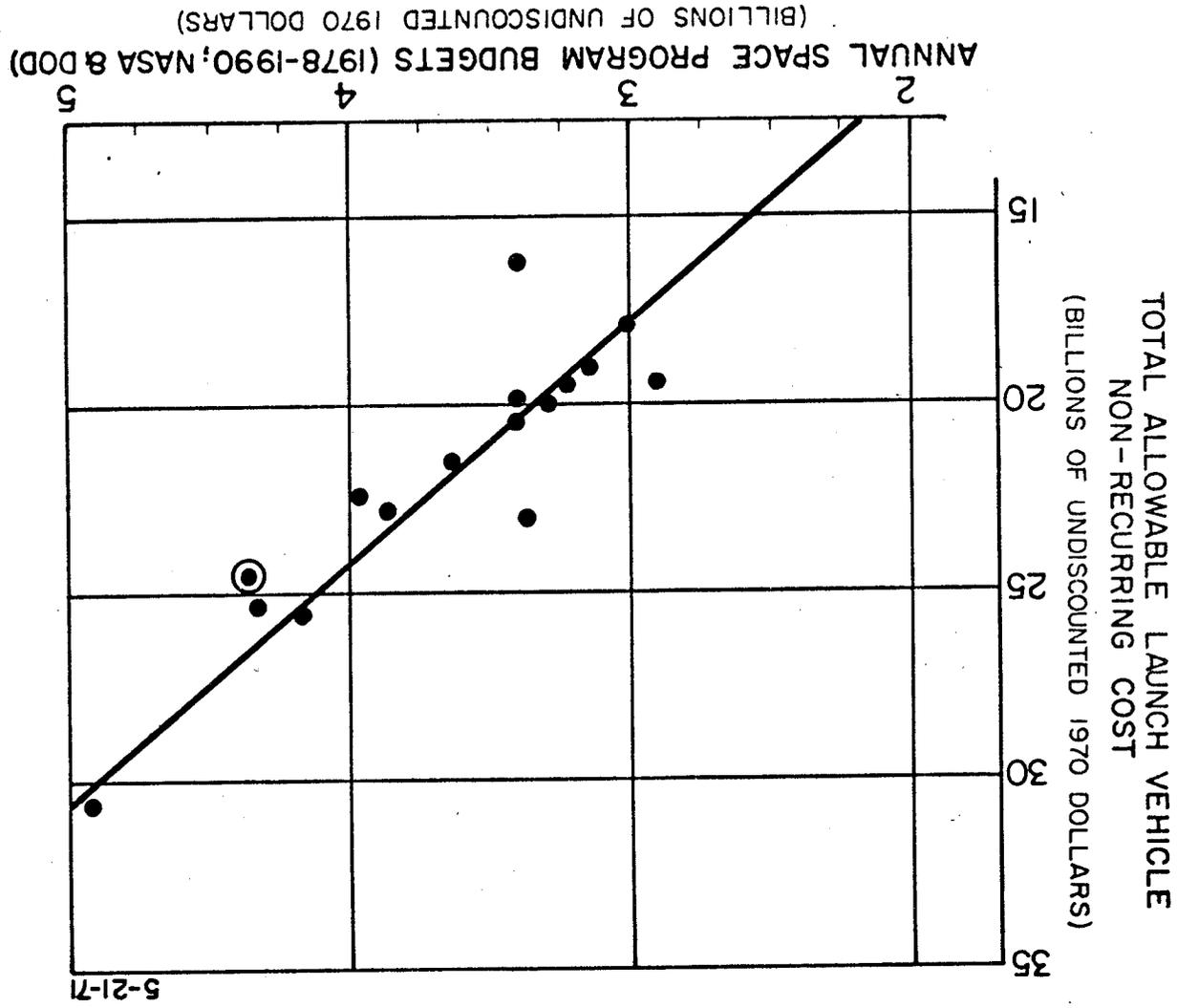


Figure 0.10

gives an "Equal Budget" figure close to \$22.1 billion. That is, if the United States were to continue to spend for scientific, defense and commercial space applications (the unmanned U. S. space program) similar funds as in the 1960's, the economic analysis shows that the New Space Transportation System would still be an economic investment with a 10 percent rate of return if it cost \$22.1 billion in non-recurring outlays (RDT&E and Fleet Investment). In this example, as in all others, we assume that the non-recurring launch vehicle costs are distributed proportionately over time in the same way as shown in Table 0.1.

The strongest, most conservative results of the economic analysis are shown, however, in Figure 0.11. In the analyses summarized in this figure, MATHEMATICA proceeded on an "Equal Capability" cost effectiveness basis for all space programs listed. In addition to this, MATHEMATICA excluded in these calculations--at 10 percent--volume and mass (weight) related payload effects that may also be realized with expendable systems. MATHEMATICA included reduced space program payload costs due to the reuse and refurbishment capability of satellites made possible by a fully reusable Space Transportation System. With this analysis the new, fully reusable Space Transportation System breaks even at a space program of 566 flights (1978-1990), or about 44 flights a year (cf. Figure 0.11). The economic analyses, at 10 percent, still indicate allowable non-recurring costs for "buying" a fully reusable Space Transportation System of:

- a. \$12.9 billion for the projected space program in Scenario 3;
- b. \$15.4 billion for the projected space program in Scenario 1; and

"EQUAL CAPABILITY" COST ANALYSES

(NET MASS EFFECTS, 10% DISCOUNT RATE)

- DATA POINTS FOR VARIOUS SCENARIOS
- ⊙ DATA POINT FOR SCENARIO I (NASA & DoD Baseline: 736 flts, 57 flts/yr)
- ⊕ BREAK EVEN POINT (566 flts, ~44 flts/yr, 1978-1990)
- ▨ ESTIMATED NON-RECURRING SPACE SHUTTLE+TUG COSTS (3/31/71)

$\frac{12}{494}$	$\frac{11}{547}$	$\frac{24}{562}$	$\frac{10}{585}$	$\frac{3}{600}$	$\frac{23}{678}$	$\frac{1}{736}$	← Scenario number
							Number of flights

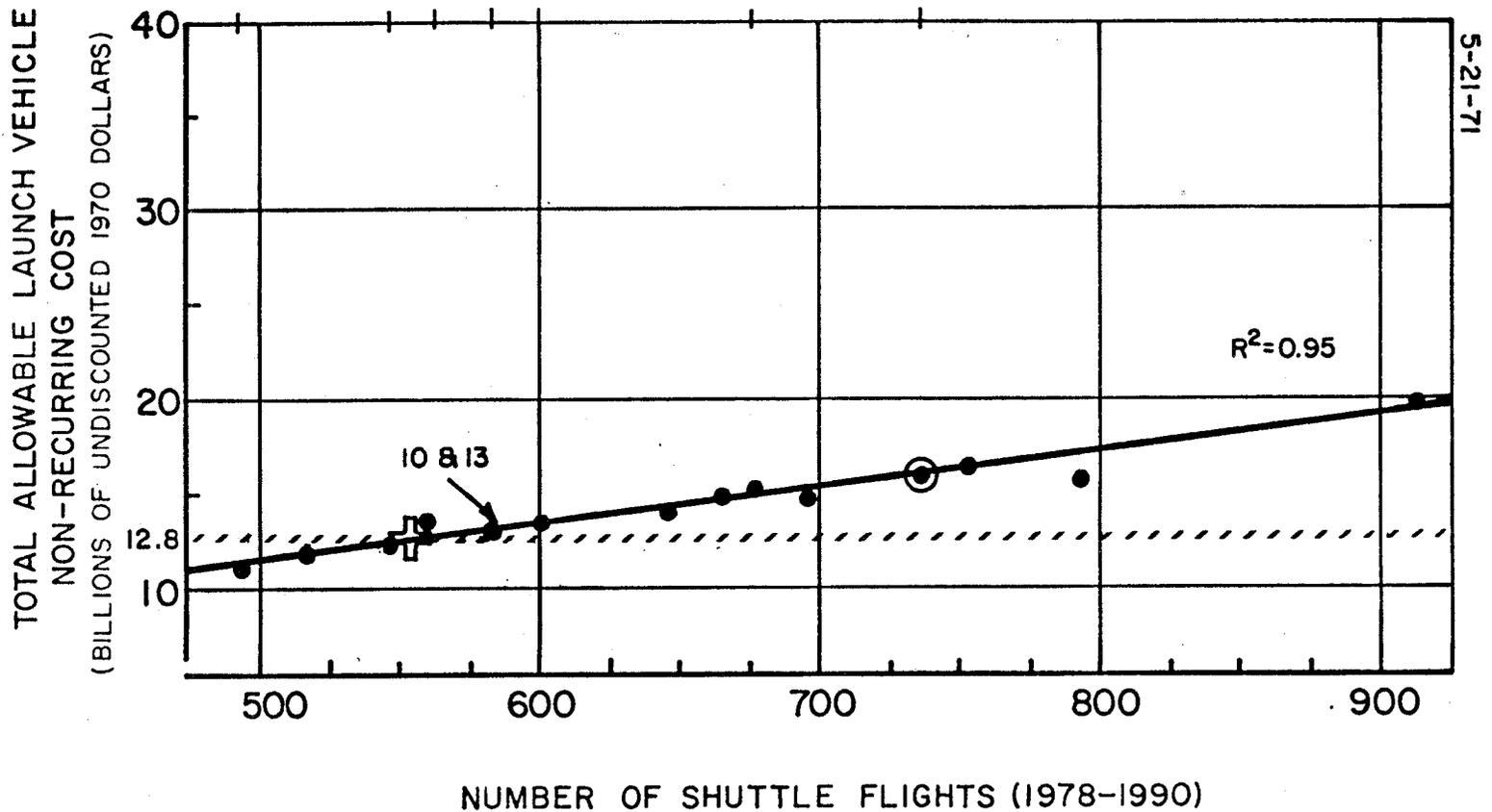


Figure 0.11

- c. \$14.6 billion for the historic flight and funding level of the unmanned United States space program of the 1960's.

All of these allowable funds are expressed in undiscounted 1970 dollars.

If the development of the two-stage, fully reusable Space Shuttle now being considered by NASA were delayed by one year--with a corresponding shift of the Initial Operating Capability date--the results from our economic analysis do change, but not significantly. This conclusion is, of course, predicated on the assumption that engineering research and advanced development in the critical areas of the Space Shuttle technology are continued. Similar economic results also hold for a reduction in the rate of the phase-in of the Space Shuttle after its introduction into operation. The scenarios identified as 10, 11 and 12 in Figures 0.9, 0.10 and 0.11, show the economic effects of phasing-in the Space Shuttle over successively longer periods holding the Initial Operating Capability date constant at 1978, while the space program objectives of Scenario 3 are maintained. Scenario 10 phases the Space Shuttle in over a two-year period (1980). For that scenario (538 flights), this delay in the full operation date from 1978 to 1980 reduces the economically justifiable non-recurring program costs from a range of \$14.5 billion to \$19.5 billion to a range of \$14.2 billion to \$18.9 billion. The likely economic gains from slippage or stretch-out--with continued or increased funding of research and advanced technology--are greater cost certainty and potential RDT&E cost reductions due to the possibilities of more certain, flexible development scheduling. The economic costs of slippage or stretch-out are the foregone reductions in the expected recurring costs of the space program for the year(s) 1978,... in which the Space Shuttle and Tug System is not available--including increased payload costs.

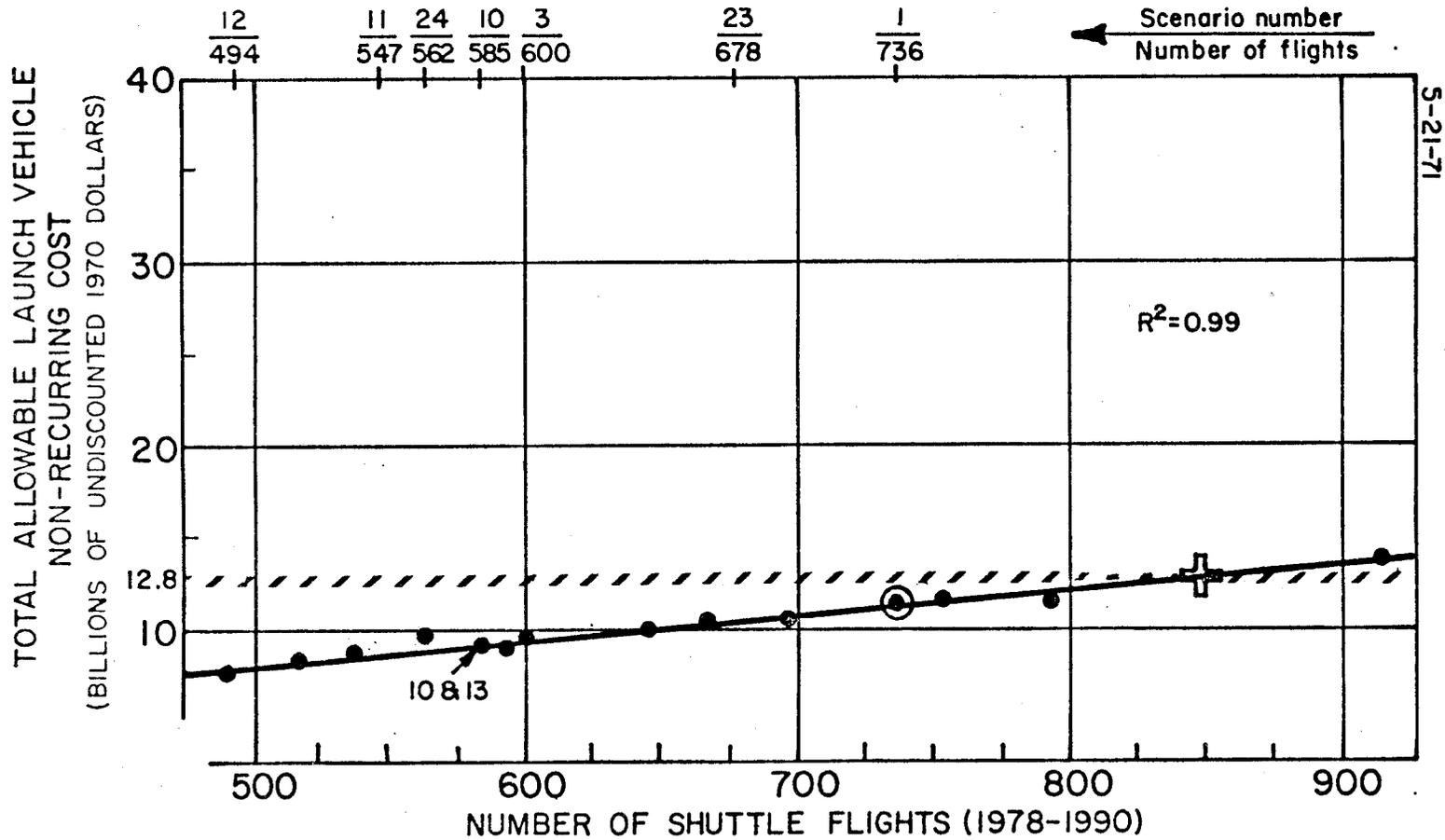
Figure 0.12 and Figure 0.13 show the influence of the different rates of discount used on the results of the economic analyses. MATHEMATICA recommends a 10 percent discount rate as a basis for evaluating the New Space Transportation Systems funding. Nevertheless, Figure 0.12 shows the summary of economic analyses when the evaluation is made at 15 percent on an "Equal Capability" basis. At this high a discount rate the relative advantage of the Space Shuttle naturally decreases. Yet, even with a 15 percent rate of discount and the conservative "Equal Capability" analyses, the fully reusable Space Transportation System does break even at a space program of 845 flights (1978-1990 total) or 65 flights a year. The summary of results indicates that up to \$11.4 billion could be spent on a new, fully reusable STS program, if the NASA-Department of Defense model for the 1980's were taken as baseline. At MATHEMATICA's projection of unmanned space activities for the 1980's, the Space Transportation System investment would have an allowable, non-recurring cost of \$9.4 billion (at 15 percent), a figure too low to cover the expected non-recurring costs of the new, fully reusable Space Transportation System as estimated by Aerospace Corporation, the Phase B contractors and various centers of NASA.

Figure 0.13 shows the summary of economic analyses performed at a 5 percent discount rate, which gives much higher allowable non-recurring costs since the opportunity cost of time is valued here relatively low, at 5 percent. For Scenario 3, the allowable non-recurring costs increase to nearly \$30.0 billion.

Figure 0.14 is a summary of all economic calculations that were performed at 10 percent, i. e., for "Equal Budget" cost effectiveness, for "Equal Capability" cost effectiveness, and for "Reuse-Refurbishment-Update Payload Effects" only. It also shows MATHEMATICA's estimate of the historic flight and funding levels of the United States and of the USSR,

"EQUAL CAPABILITY" COST ANALYSES (15% DISCOUNT RATE)

- DATA POINTS FOR VARIOUS SCENARIOS
- ⊙ DATA POINT FOR SCENARIO I (NASA & DoD Baseline: 736 flts, 57 flts/yr)
- ⊕ BREAK EVEN POINT (845 flts, ~ 65 flts/yr, 1978-1990)
- ESTIMATED NON-RECURRING SPACE SHUTTLE + TUG COSTS (3/31/71)



0-48

Figure 0.12

"EQUAL CAPABILITY" COST ANALYSES (5% DISCOUNT RATE)

- DATA POINTS FOR VARIOUS SCENARIOS
- ⊙ DATA POINT FOR SCENARIO 1 (NASA & DOD Baseline: 736 flts, 57 flts/yr)
- + BREAK EVEN POINT (206 flts, ~16 flts/yr, 1978-1990) OFF GRAPH
- ESTIMATED NON-RECURRING SPACE SHUTTLE+TUG COSTS (3/31/71)

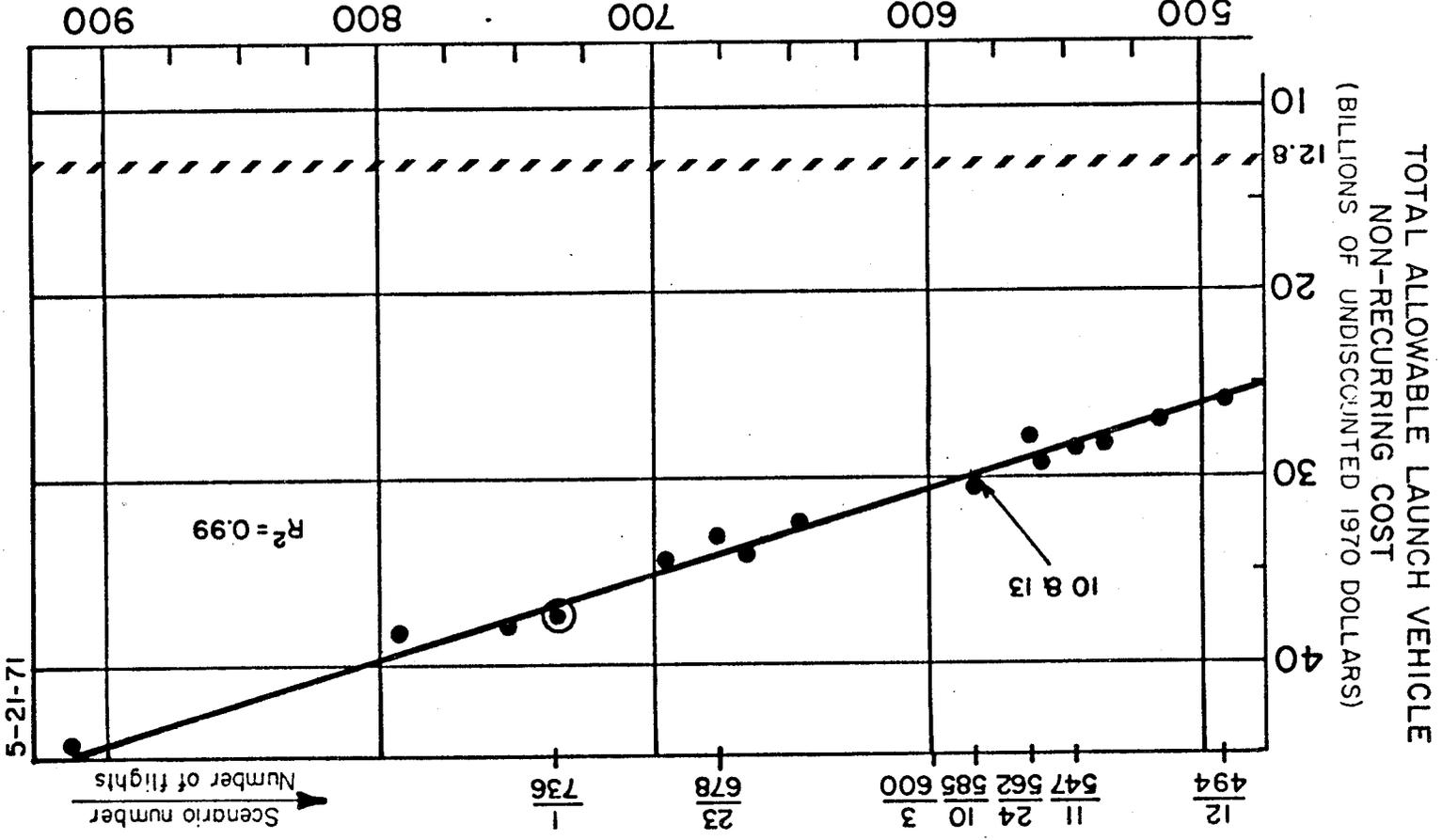


Figure 0.13

SUMMARY OF DIFFERENT COST EFFECT ANALYSES (10% DISCOUNT RATE)

(1) EQUAL BUDGET, (2) EQUAL CAPABILITY, (3) NET MASS EFFECTS

--- ESTIMATED NON-RECURRING SPACE SHUTTLE+TUG COSTS (3/31/71)

/// U.S. FLIGHT AVERAGE, 1964-1969 (51 fits/yr). FUNDING AVERAGE, 1963-1971

||||| USSR FLIGHT AVERAGE, 1965-1970 (65 fits/yr)

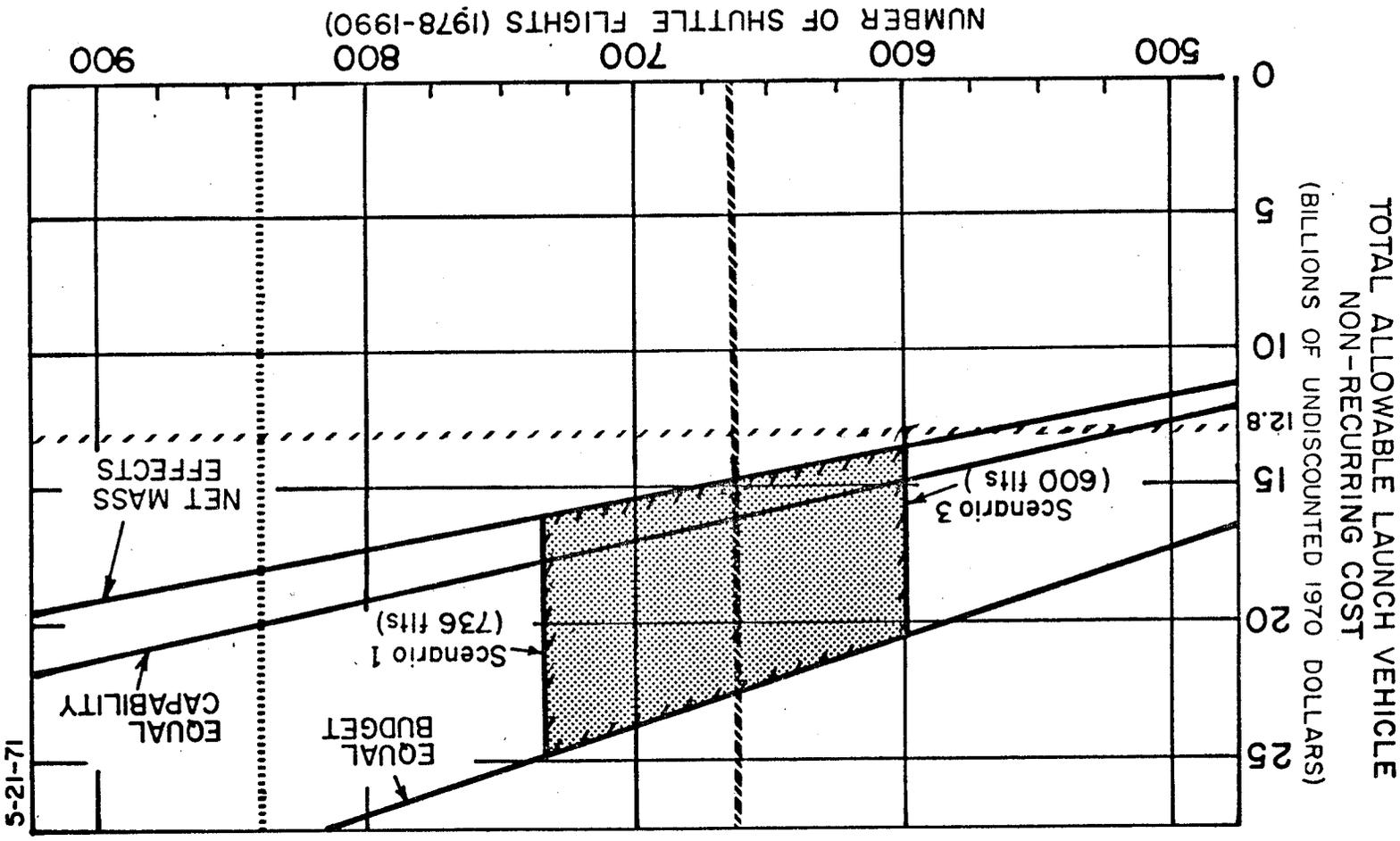


Figure 0.14

in terms of equivalent Space Shuttle flights (the vertical lines).

Figure 0.15 shows the impact on the economic evaluation of the Space Shuttle System of the addition of the NASA Lunar Option 1. The net increase in economic benefits is due to launch cost savings only since lunar payloads have not been included in the analysis. (The exclusion of Lunar Option payloads, however, cannot adversely affect the economic analysis since some of the payloads may well exhibit favorable cost effects when the Space Shuttle System is used.) The incremental cost savings have been converted into allowable non-recurring costs, and for all scenarios considered, as shown in Figure 0.15, this amounts to an additional \$3.0 billion. The allowable non-recurring cost for the Space Shuttle System evaluated for Equal Capability under Scenario 3 and a 10 percent discount rate is \$17.5 billion with Lunar Option 1 and, excluding Lunar Option 1, it is \$14.5 billion. The important conclusion to be drawn from this result is that when some large lunar or planetary (or defense) space flight option is considered for the 1980's the Space Shuttle System offers economic advantages also in terms of transportation costs only. These have not been included in any of the other MATHEMATICA scenarios.

Figure 0.16, finally, summarizes the economic calculations done at different discount rates (5 percent, 10 percent, and 15 percent) for the "Equal Capability" cost effectiveness analyses.

The complete set of economic analyses performed by MATHEMATICA on which these results are based, at discount rates from one to 20 percent, and the statistical backup to judge the quality of these results--as conditioned by the validity of the input cost data--are given in Chapter 7.0 of the Report.

"EQUAL CAPABILITY" COST ANALYSES WITH LUNAR OPTION I ADDED (USING NUCLEAR SHUTTLE WITH SPACE SHUTTLE SYSTEM) (10% DISCOUNT RATE)

- DATA POINTS FOR VARIOUS SCENARIOS
- ⊙ DATA POINT FOR SCENARIO I (NASA & DoD Baseline: 736 flts, 57 flts/yr)
- + BREAK EVEN POINT (506 flts, ~ 39 flts/yr, 1978-1990)
- ESTIMATED NON-RECURRING SPACE SHUTTLE+TUG COSTS (3/31/71)

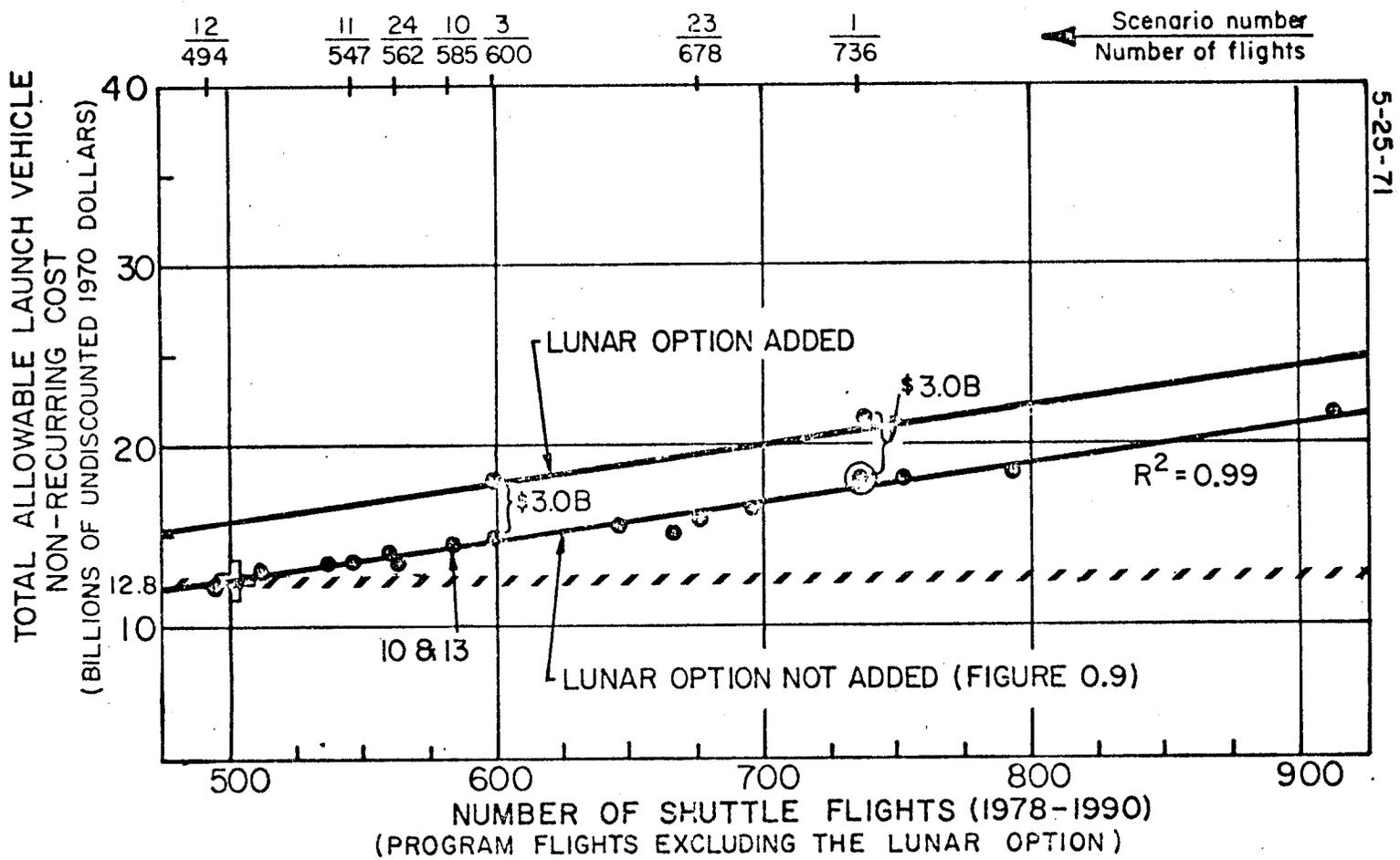
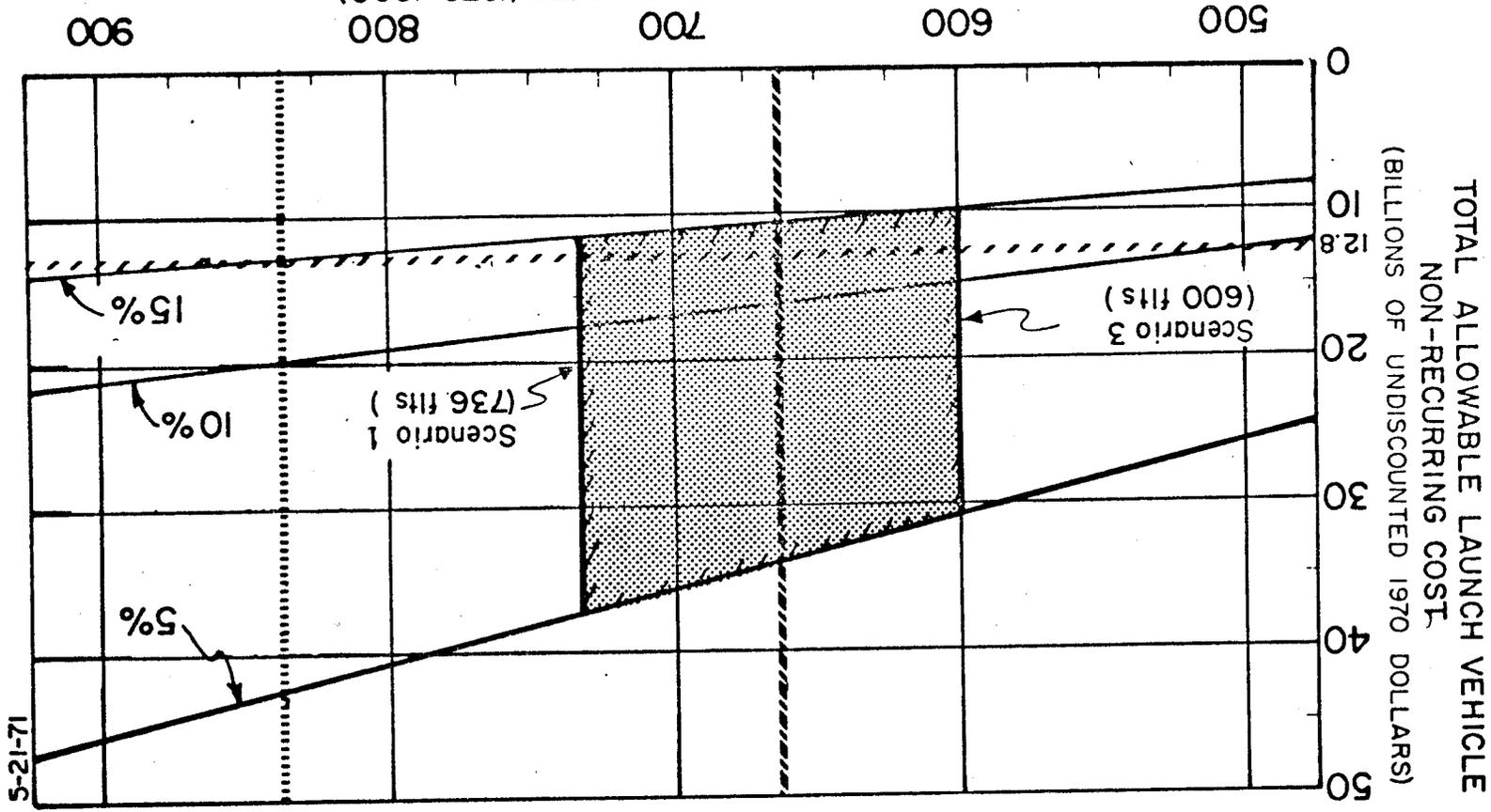


Figure 0.15

0-52

SUMMARY OF "EQUAL CAPABILITY" COST ANALYSES
 DIFFERENT DISCOUNT RATES: 5%, 10%, 15%

--- ESTIMATED NON-RECURRING SPACE SHUTTLE+TUG COSTS (3/31/71)
 - - - U.S. FLIGHT AVERAGE, 1964-1969 (51 fits/yr). FUNDING AVERAGE, 1963-1971
 USSR FLIGHT AVERAGE, 1965-1970 (65 fits/yr)



500
600
700
800
900
NUMBER OF SHUTTLE FLIGHTS (1978-1990)

TOTAL ALLOWABLE LAUNCH VEHICLE
 NON-RECURRING COST
 (BILLIONS OF UNDISCOUNTED 1970 DOLLARS)

Figure 0.16

Figures 0.17, 0.18 and 0.19 depict the budgetary implications of the following three space programs: Scenario 3, the MATHEMATICA Baseline projection; Scenario 23 which is based on the historic funding level of U.S. programs from Fiscal Years 1963 to 1971; and, Scenario 24, which is based on projections of FY 1970 and FY 1971 funding levels. The Current Expendable funding level in Scenario 23 is about \$3 billion (NASA and Department of Defense) and in Scenario 24 it is \$2.5 billion. The expected costs for new Space Transportation System operations at the same funding level ("Equal Capability") are also shown.

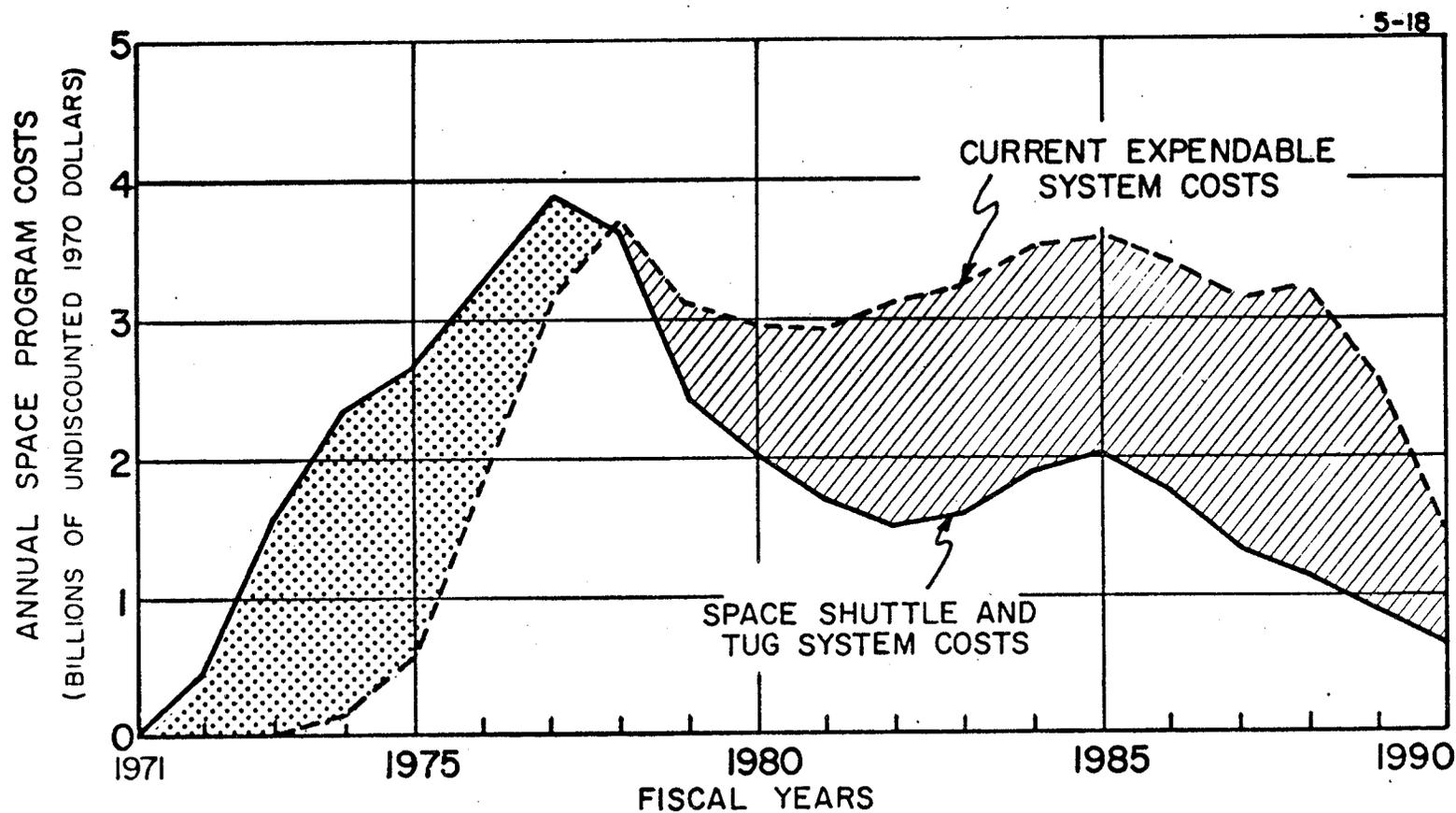
Figures 0.20 and 0.21 consider the addition of the NASA Lunar Option 1 transportation costs to the life cycle costs of Scenarios 1 and 3. This Lunar option assumes the existence of a Nuclear Space Shuttle for Earth orbit to Lunar orbit transportation. The Lunar payload costs have not been included, and potential Space Shuttle payload effects for this traffic has not been allowed for.

All the life cycle costs for transportation and payload costs are given in detail in Chapter 6.0.

SPACE PROGRAM COSTS (1978-1990 OPERATIONS)

SCENARIO 3 (Funding Basis Described in Text)

CURRENT EXPENDABLE SYSTEM vs SPACE SHUTTLE AND TUG SYSTEM



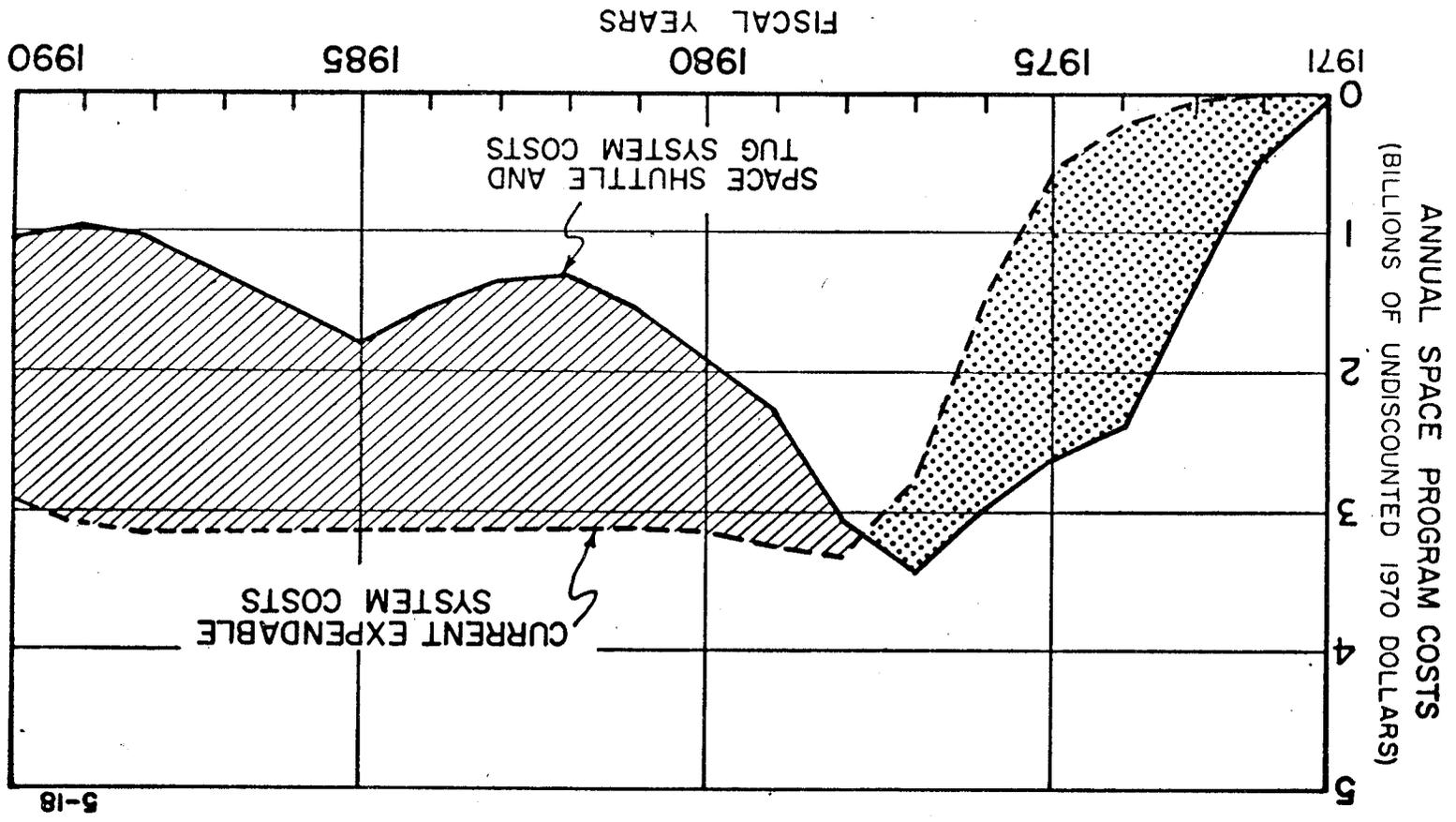
0-55

Figure 0.17

SPACE PROGRAM COSTS (1978-1990 OPERATIONS)

SCENARIO 23 (Based on U.S. Funding, 1963-1971)

CURRENT EXPENDABLE SYSTEM vs SPACE SHUTTLE AND TUG SYSTEM



5-18

SPACE PROGRAM COSTS (1978-1990 OPERATIONS)

SCENARIO 24 (Based on U.S. Funding, 1970-1971)

CURRENT EXPENDABLE SYSTEM vs SPACE SHUTTLE AND TUG SYSTEM

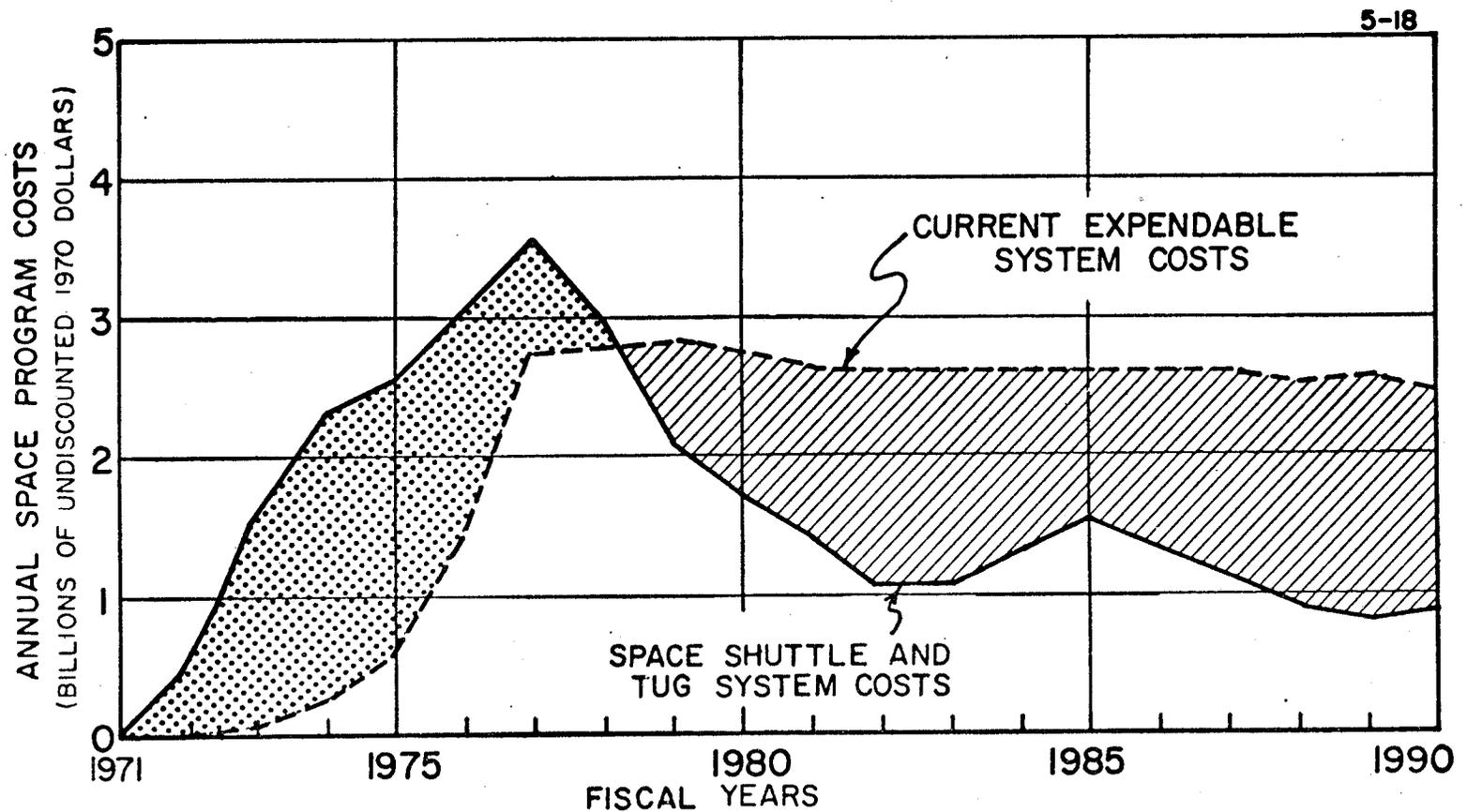


Figure 0.19

SPACE PROGRAM COSTS (1978-1990 OPERATIONS) SCENARIO 25 (NASA - DOD Baseline & Lunar Option I)

CURRENT EXPANDABLE SYSTEM vs SPACE SHUTTLE AND TUG SYSTEM

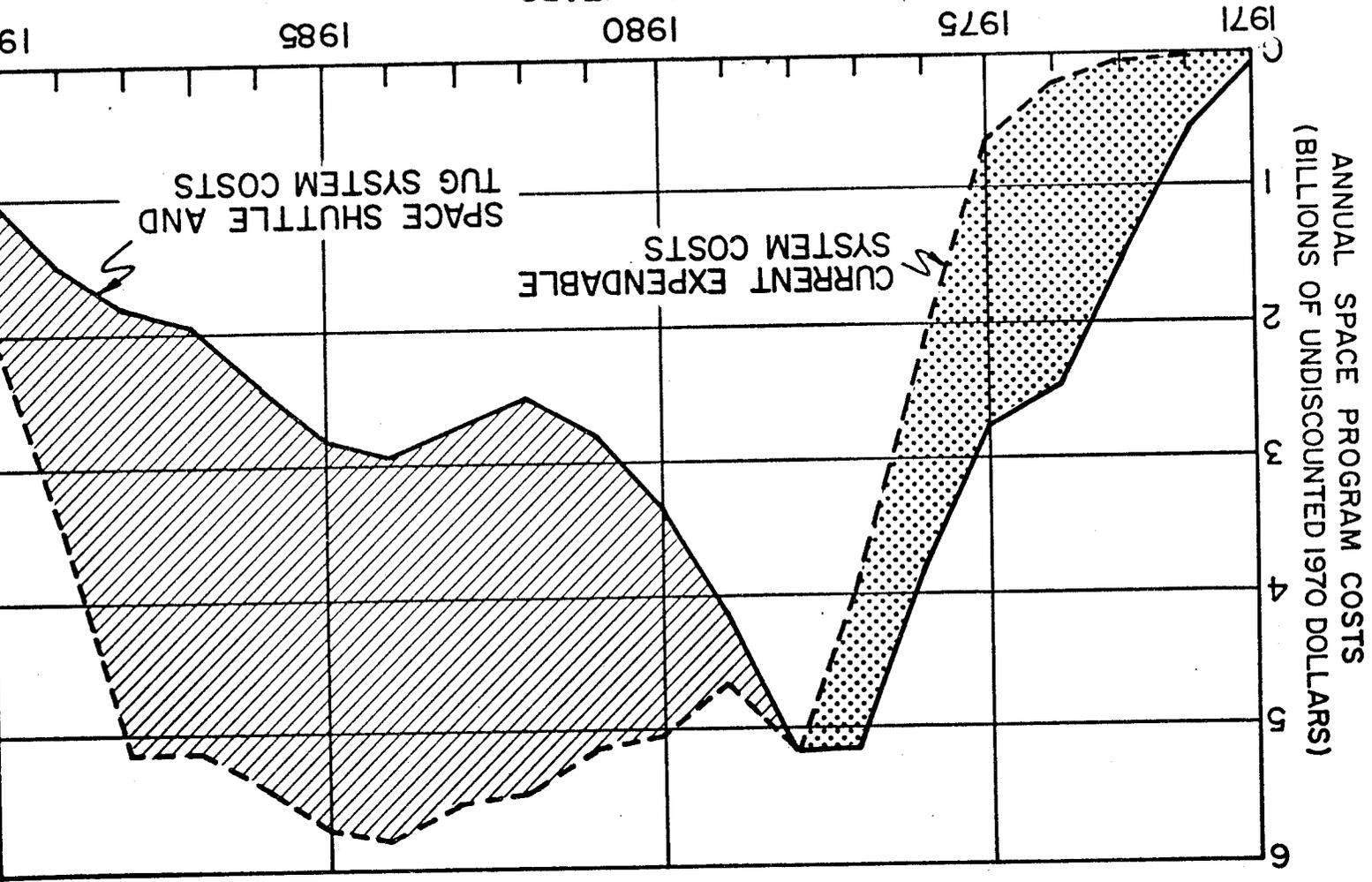


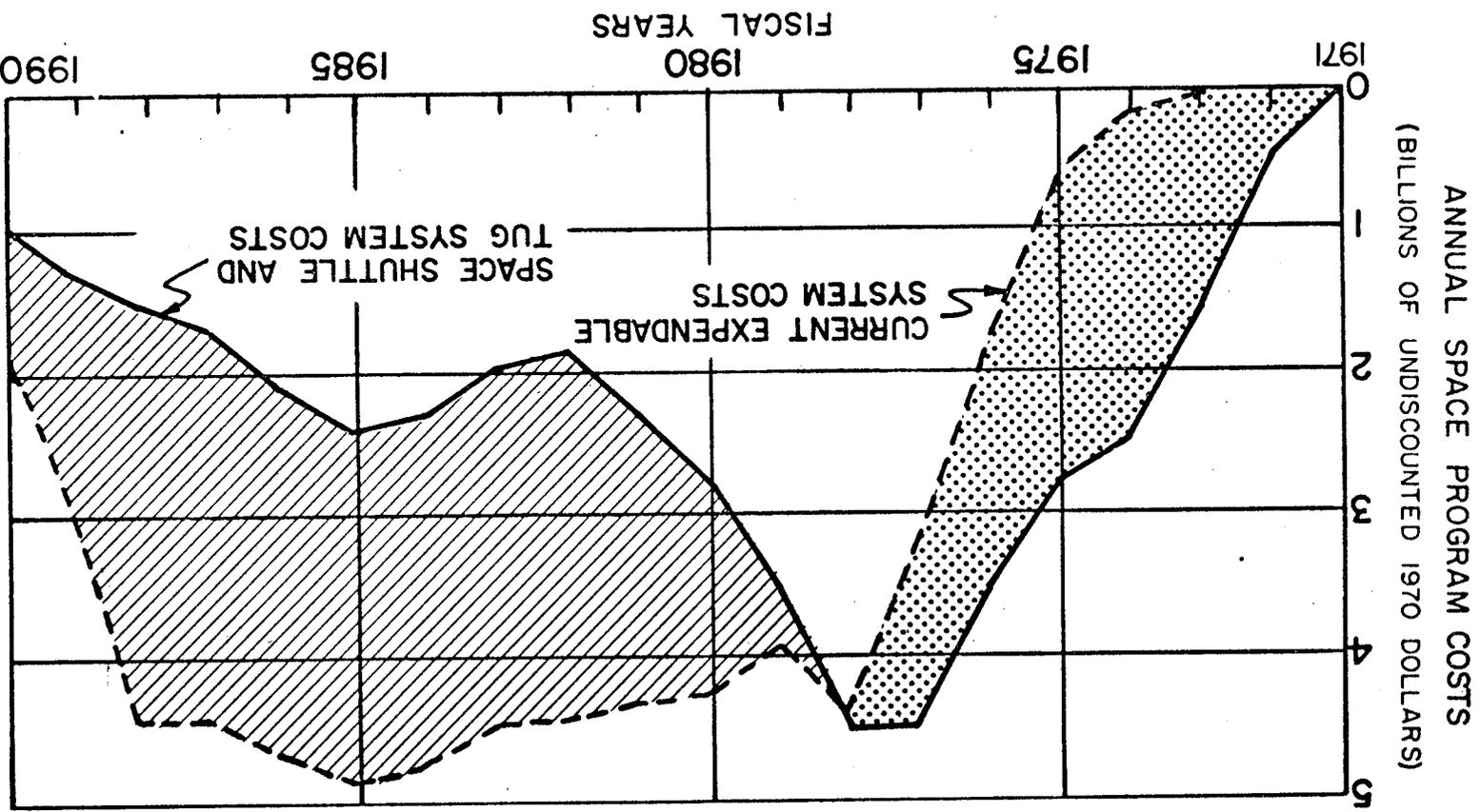
Figure 0.20

5-18

SPACE PROGRAM COSTS (1978-1990 OPERATIONS)

SCENARIO 26 (Scenario 3 & Lunar Option I)

CURRENT EXPENDABLE SYSTEM VS SPACE SHUTTLE AND TUG SYSTEM



5-18

Figure 0.21

0.5 CONCLUSIONS

1. The most conservative economic analyses show, at a 10 percent social discount rate, that the allowable non-recurring costs for "buying" a fully reusable Space Transportation System are:

- a. \$12.9 billion for an annual activity level of 46 Space Shuttle flights (Scenario 3).
- b. \$15.4 billion for an annual activity level of 56 Space Shuttle flights (Scenario 1).
- c. \$14.6 billion for the historic flight level of the unmanned United States space program of the 1960's, corresponding to 51 Space Shuttle flights (Scenario 23).

The present estimate of the actual non-recurring costs of the Space Shuttle and Tug System is \$12.8 billion. All of these estimates are made in constant (1970) dollars.

2. 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 Space Shuttle is a major system--but conceivably not the only system--identified to achieve this reuse, refurbishment, and updating of payloads. Other technically acceptable systems should be studied to determine the extent and the cost at which they can achieve reuse, refurbishment and updating of payloads. Any such studies must be performed in adequate depth to generate meaningful comparative data for an economic evaluation.

The cost reductions originate in three distinct areas: (a) the Research, Development, Test and Evaluation (RDT&E) phase of new payloads (satellites); (b) the unit cost and operating cost of payloads (satellites) for different space missions; (c) the cost of launching payloads into orbit.

Although it is, perhaps, natural to identify the economic effects of a reusable Space Transportation System primarily as reductions in launch costs, it is apparent that the major cost savings lie in the area of payload development, construction and operation. For example, with the Expendable System, launch costs constitute only 20 to 25 percent of the cost of a typical United States space program; 75 to 80 percent are payload related costs (see payload costs and recurring launch costs of Table 0.1).

3. The currently projected non-recurring costs associated with developing a Space Shuttle and Tug are shown by the economic analysis to be covered by the identified benefits, provided the United States intends to operate a space program with a 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 Space Transportation System.

These conclusions are based on what MATHEMATICA considers to be realistic and, indeed, conservative projections of space activities in the 1980's--with most of the projected unmanned space programs operating below the level maintained during the 1960's, and with the manned space flight program limited to about \$200 million a year.

The analysis of the lunar option has shown that the Space Shuttle System offers economic advantages also in terms of transportation costs only, when some large lunar or planetary (or defense) space flight options are considered for the 1980's. Due to the great uncertainty of these options being adopted by the United States, MATHEMATICA did not allow for these advantages in the basic conclusions.

4. 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.

5. The economic justification of a reusable Space Transportation System is independent of the question of manned versus unmanned space flight. The space programs used and analyzed by MATHEMATICA 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). This does not preclude the possibility that the future unmanned space program can be much larger than in the past.

6. This Report analyzes the economically allowable non-recurring costs of a reusable Space Transportation System. The task of identifying the best reusable Space Transportation System among all the viable alternatives requires equally detailed economic consideration.

7. Finally, we state with emphasis: any investment can only be justified by its goals. This applies to business as well as to government, hence also 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 military (to meet military space efforts of other countries or use the potential of space to meet needs of national security), scientific (e. g., astronomy, environment), commercial (e. g., earth resources applications, communications, weather forecasting) or political (rivalry with the space programs of other countries). 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.