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Space Shuttle/Payload Interface Analysis (Study 2.4) Final Report

Volume I
Executive Summary

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ADVANCED VEHICLE SYSTEMS DIRECTORATE
Systems Planning Division

31 August 1973

Prepared for OFFICE OF MANNED SPACE FLIGHT
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C.

Contract No. NASW-2472

Systems Engineering Operations
THE AEROSPACE CORPORATION

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SPACE SHUTTLE/PAYLOAD INTERFACE ANALYSIS (Study 2.4)

FINAL REPORT

Volume I: Executive Summary

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FOREWORD

The Space Shuttle/Payload Interface Analysis (Study 2.4) Final Report is comprised of five volumes, which are titled as follows.

Volume I	-	Executive Summary
Volume II	-	Space Shuttle Traffic Analysis
Volume III	-	New Expendable Vehicle with Reusable Solid Rocket Motors
Volume IV	-	Business Risk and Value of Operations in Space (BRAVO)
		Part 1 - Summary
		Part 2 - User's Manual
		Part 3 - Workbook
		Part 4 - Computer Programs and Data Look-Up
Volume V	-	Payload Community Analysis

The study effort was directed by Mr. William F. Moore, NASA Headquarters, OMSF Missions and Payloads Office.

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1. INTRODUCTION

The FY 73 Space Shuttle/Payload Interface Analysis (Study 2.4) consisted of three principal tasks:

1. Payload Capture and Cost Analysis
2. Business Risk and Value of Operations in Space (BRAVO) Analysis
3. Payload Community Analysis.

The Space Shuttle/payload capture and cost analysis techniques developed by The Aerospace Corporation have proved to be a valuable capability for NASA. In June of 1972 NASA decided to transfer the capability from The Aerospace Corporation to NASA's George C. Marshall Space Flight Center (MSFC), at the same time retaining the traceability of the analysis back to similar analyses accomplished by Aerospace over the previous two years under NASA sponsorship.

NASA continues to be interested in the development and assessment of new space systems in the 1980s and 1990s. A new approach to the analysis of space systems was developed and tested in the 1972 BRAVO study. This study showed that Shuttle-supported satellite systems can offer extremely low risk at low cost. The low risk is particularly attractive to potential commercial ventures in space; however, to demonstrate the benefits of space to potential users NASA needs a tool for rapid analyses defining space systems and assessing their value for such future potential users. The 1973 BRAVO study developed the low risk systems methodology into such a tool. The tool is documented in the four parts of Volume IV of this report: (1) a summary of the methodology developed and applicability, (2) a User's Manual, (3) a Workbook with forms for use in the analysis, and (4) the computer programs and tabulated data required to carry out BRAVO analyses. Technical backup for BRAVO methodology is on file at Aerospace Corporation.

The results of each BRAVO analysis include the definition, cost estimates, and a cost effectiveness assessment for each potential space system. For example, an earth observation satellite product (space images and signatures of earth's features) would be compared with ground-based systems (aerial photo and personal observation) for obtaining the same information. Thus the BRAVO study is a key element in attacking the problem of locating and working with future space, and therefore Shuttle, users.

Another element of the Space Shuttle user analysis is the payload community analysis, which assesses various charge policies for NASA STS users. The Space Shuttle differs from expendable launch vehicles in many respects. It returns payloads or payload elements to earth; has the capacity to operate flights shared by more than one payload; and has the capability for loitering in space and performing such payload services as on-orbit checkout, remove and replace maintenance, and replenishment of expendables. These new capabilities raise new issues with respect to the Shuttle user interface. For example, how should the Shuttle operator charge users of these new capabilities? Analysis of this problem was initiated in the third quarter of Study 2.4 to assist NASA in addressing these issues.

2. STUDY OBJECTIVES

The Study 2.4 objectives in FY 73 were:

1. To assist the NASA OMSF Missions and Payloads Office in relating the Space Shuttle system in the 1980s and 1990s to potential users of space in the payload community.
2. To assist NASA in establishing a launch vehicle/payload traffic analysis capability at MSFC.

The task of carrying out these objectives was accomplished by breaking down the study into three activities. The BRAVO and payload community analysis studies are Space Shuttle user studies. The traffic analysis study transferred the capability for this activity to MSFC so that this work could be accomplished using methodology consistent with previous traffic analyses, thus providing traceability.

3. RELATIONSHIPS TO OTHER NASA EFFORTS

The traffic analysis study makes extensive use of the payload effects study accomplished under NASA sponsorship by the Lockheed Missiles and Space Company (LMSC) in 1971 and 1972. LMSC furnished new low-cost payload data for this analysis through the MSFC Study Director, Mr. Milton Page.

The NASA MSFC contact for transfer of the traffic analysis capability was Mr. William A. Huff. Extensive liaison was carried on with Mr. Huff and members of the MSFC staff. The capture analyses carried out as a part of the traffic analysis effort made use of the DORCA-II payload capture computer program developed by Aerospace in FY 72 under NASA Headquarters sponsorship and carried on in Study 2.5 this year.

4. TRAFFIC ANALYSIS

A. METHOD OF APPROACH AND PRINCIPAL ASSUMPTIONS

The primary objective of this study was to furnish tools and guidance to NASA MSFC so that capture/cost analyses on the mission model can be performed in a manner which provides traceability to the analyses performed by Aerospace for NASA in 1971 and 1972. A second objective was to provide a parallel cost/capture analysis with NASA MSFC on the example mission model.

The approach to the transfer of hard elements of the analytical capability (e.g., computer programs and the data needed for the analyses) was to follow up the transfer of the hard copy with liaison between individuals responsible for working each area. The computer program listings were furnished on tape compatible with the MSFC codes and on cards. In addition an example run on each computer program was furnished complete with inputs and outputs. Transfer of soft elements (e.g., organization and flow of the analyses; sequencing information; operating instructions; engineering and analytical judgments used; and limitations, findings, and recommendations) was accomplished through briefings and working sessions by members of the Aerospace staff responsible for each area. After the transfer of the hard elements of the capability was complete, a typical mission model analysis was accomplished in parallel by MSFC and Aerospace.

The approach to the traffic analysis itself is depicted in Figure 4-1. Coordinating and preparing the study inputs and data for the analysis, the first steps in the data flow, took approximately the first month and a half of the contract period. The largest effort was expended in generating the payload data for the four types of payloads (e.g., current and low-cost expendable, and current and low-cost reusable) to be considered in the analysis for each mission. With these data as inputs the capture analysis for alternative payload programs is accomplished by matching expendable launch vehicles to expendable payloads, and all four types of payloads to the Shuttle and upper stages. Costs were next estimated for each payload type and the total payload program cost. Then, the best (lowest cost) payload for each mission was selected using the lowest payload program costs for the 1979-1990 period as the criterion. This best mix of payloads was dominated by low-cost payloads based on the LMSC studies.

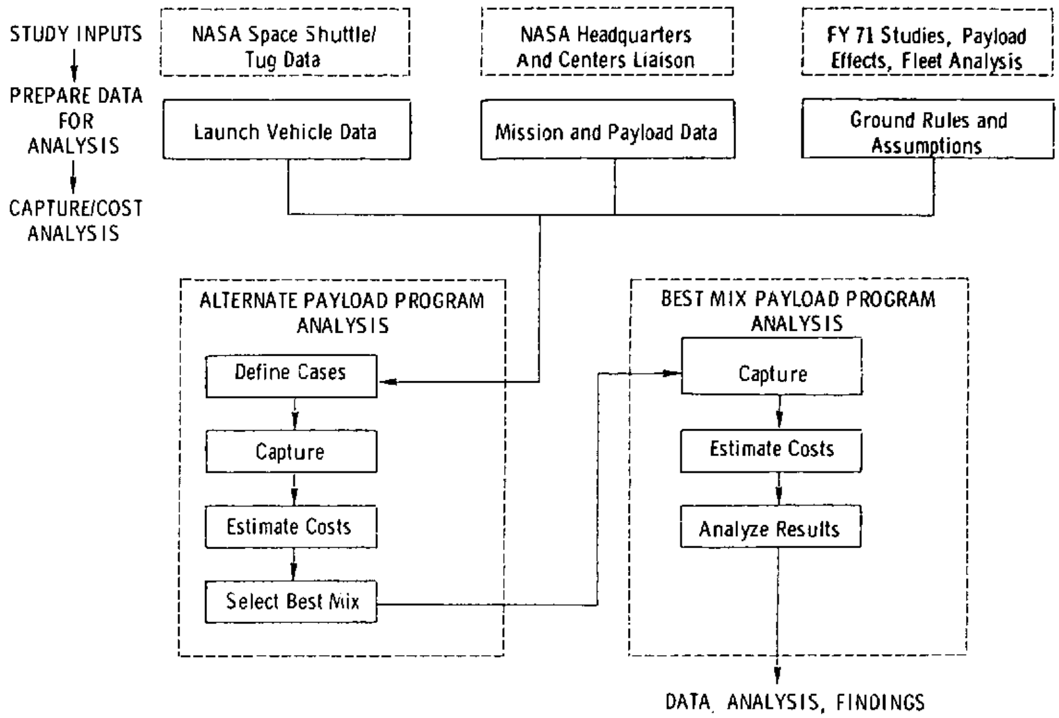

Figure 4-1. Data Flow

The best mix of payloads across the mission model was then recaptured on the STS and cost estimates made on the entire mission model. The principal assumptions made in the analysis were:

Payloads

1. Payload effects are Lockheed, TRW, and others.

2. Payload effects will be applied to each payload as appropriate from a cost effective viewpoint down to the subsystem level.

   a. Apply, where appropriate, to the entire mission model including NASA, non-NASA, and DoD.

3. Redesign for Shuttle utilization will neither degrade nor upgrade mission objectives.

4. Data source for costing payloads is the Aerospace payload cost model.

Shuttle

1. Governing data sources are the RFP, Level 1 Requirements, and JSC (formerly MSC) Payload Accommodation Document.

2. Shuttle availability and buildup rate are as specified in RFP for 1979 through 1983. For 1984 and on, assume Shuttle available as needed at both launch sites.

    a. Launch rate buildup at WTR similar to ETR.

3. Operations cost is $10.5 million per flight.

Launch Sites

1. KSC available for entire time period, as needed.

2. WTR available in 1981 and on, as needed.

3. Assume launch azimuth capability as currently practiced at KSC and WTR.

    a. No change from current practice on doglegs.

Capture Constraints

1. Time span is 1979-1990, inclusive.

    a. Extend to 1997 for cost only (does not identify meaningful missions).

2. On-orbit docking of Tug and payload may be used only when physically necessary to accommodate a spacecraft.

3. No expendable upper stages will be used in lieu of the Tug after Tug IOC.

4. For space station missions use Titan III M, Big Gemini.

5. Average number of payloads simultaneously carried by expendable vehicles will not exceed historical average.

6. DoD payloads will not be carried with those of other users.

Costing Constraints

1. Costs will reflect reliability effects of vehicles/carriers and payloads.

2. Only direct costs are included.

Tug

1. Tug IOC is 1983; Tug is available to meet requirements from then on.

2. Tug unit costs (but not RDT&E) will be amortized.

B. BASIC DATA GENERATED AND SIGNIFICANT RESULTS

The capture analysis resulted in voluminous data describing each payload, destination, and traffic. Tabulations of launch vehicle traffic and flight manifests (an example page from a flight manifest is shown in Table 4-1) for all 98 payload programs in the mission model were furnished to MSFC. Annual Shuttle traffic is described in Figure 4-2. The NASA Shuttle use rate (OA + OSS + OAST + OMSF) is about equal to the DoD Shuttle use rate. The use rate for the non-NASA commercial users is relatively low. Three or four flights per year are needed to refly missions aborted by either the launch vehicle or the payload. Thirty-five percent of the Shuttle flights in the Shuttle era are from WTR.

Annual Space Tug traffic is shown graphically in Figure 4-3. DoD is the biggest user of the Space Tug, followed by NASA and non-NASA. Approximately 39 percent of the Tug flights are from WTR.

Annual payload program costs were estimated for RDT&E, investment, and operations for each of the 98 payload programs. Copies of the tabulations of these cost streams, along with summary-type breakdowns, were furnished to MSFC. Shown in Figure 4-4 is the comparison of the direct cost estimate for the expendable launch vehicle-supported mission model and the Shuttle mission model. Direct costs include payload

Table 4-1. Typical Manifest, Payload Combinations and Flights - 1990 Best Mix of Payloads on STS

Shuttle Flight No.	Payload		Earth to Orbit Trip Payload + Stage		
	Earth to Orbit	Return	Length		Load Factors[1]
			m	ft	
1	Radio Astronomy Obs., Tug	Tug	17.9	58.7	0.81
2	Sync. Earth Obs., Small ATS Sync., Tug	Tug	17.3	56.6	0.92
3	Sync. Earth Obs. Tug	Sync. Meteorology Tug	14.1	46.3	0.98
4	Tug	U. S. Domestic Comm. Tug	10.7	35.0	0.91
5	Tug	U. S. Domestic Comm. Tug	10.7	35.0	0.91
6	U. S. Domestic Comm. Tug	Small ATS Sync. Tug	18.3	60.0	1.00
7	U. S. Domestic Comm. Tug	Foreign Domestic Comm. Tug	18.3	60.0	0.95

(1) Load Factor = $\frac{\text{Weight of Payload + Stage}}{\text{Orbiter Capability to Orbiter Destination}}$

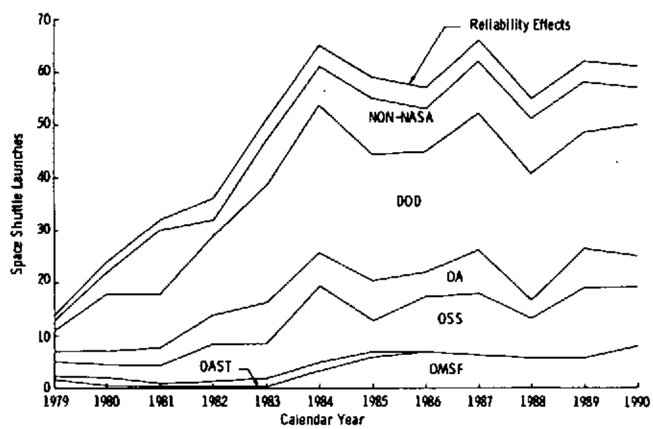

Figure 4-2. Space Shuttle Traffic, Study 2.4

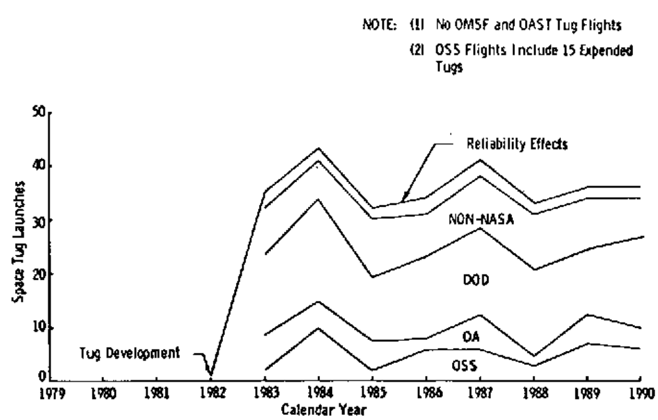

Figure 4-3. Space Tug Launches, Study 2.4

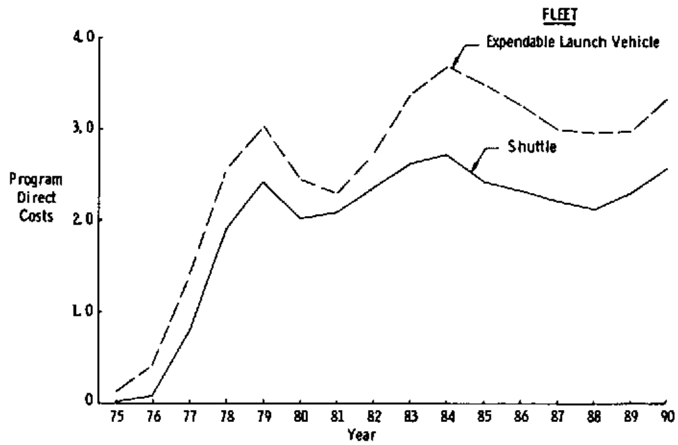

Figure 4-4. Total Direct Cost Estimate Comparison - Study 2.4, Sortie Science Included

program life-cycle costs plus the direct launch vehicle charges. Sortie science was included in the analysis by operating the Shuttle with sortie modules for the Shuttle-supported case. For the expendable launch vehicle the equivalent sortie science was carried out on a small modular space station visited from time to time by using the Big Gemini reentry vehicle for carrying the astronauts, a cargo trailer for carrying the experiment and supplies, and a Titan III launch vehicle as a booster. This was the first time that sortie science had been included in a comparative analysis between Shuttle and expendable launch vehicle-supported space activities across an entire mission model. It was recommended to NASA that the space laboratory or sortie science be included in future mission model analyses since it is now integrated with the automated space station programs in the NASA planning.

Additional observations that were made from the traffic analysis data include the following.

When expendable upper stages are flown on the Shuttle, capturing the payloads with the largest upper stage option will decrease launch costs by increasing multiple payloads, thus saving transportation costs. The largest upper stage included in this analysis was the 3.3-meter (10-foot) diameter Centaur.

It is also recommended to NASA that consideration of standardized spacecraft hardware be factored into these cost analyses. Standardized spacecraft hardware in the form of standardized module spacecraft or standardized component spacecraft shows considerable promise for lowering costs of payload programs in the Shuttle era through decreased RDT&E costs and increased residual value for retrieved spacecraft.

5. BUSINESS RISK AND VALUE OF OPERATIONS IN SPACE (BRAVO)

A. METHOD OF APPROACH AND PRINCIPAL ASSUMPTIONS

The objective of the BRAVO effort is to develop and document a tool for analysis of potential space users' problems. NASA needs this tool for rapidly analyzing a potential user's problem, such as the generation of power from solar cells in space, to assess its cost effectiveness potential.

The work accomplished in this study built on the previous risk analysis effort reported last year. The technical accomplishments in Study 2.4 include:

1. Expanding the risk analysis to include the ability to define the space system itself prior to estimating the costs, optimizing the system to risk, and assessing the cost effectiveness.

2. Generalizing the methodology to include such types of space systems as navigation, earth observations, and power generation in addition to the telecommunications area.

3. Organizing the BRAVO process in an orderly procedure.

4. Initiating analyses on potential user problems.

Specific technical additions to the capability include a satellite synthesis capability; a generalized economic mission equipment definition capability; reorganization of the risk analysis from a concept development tool to a more routine analytical tool; reprogramming the payload program cost estimating computer program so that it is suitable for analysis of individual payload programs, and so that mission equipment costs can be separated from spacecraft costs; and expanding the cost effectiveness analytical tool into an orderly procedure to calculate revenue required and perform cash flow analysis.

The flow diagram for the BRAVO analysis is shown in Figure 5-1. The complete analysis can be made with a minimum of descriptive information of the problem. Information is needed on the objective of the space system in terms of its purpose, function, service performed, or product.

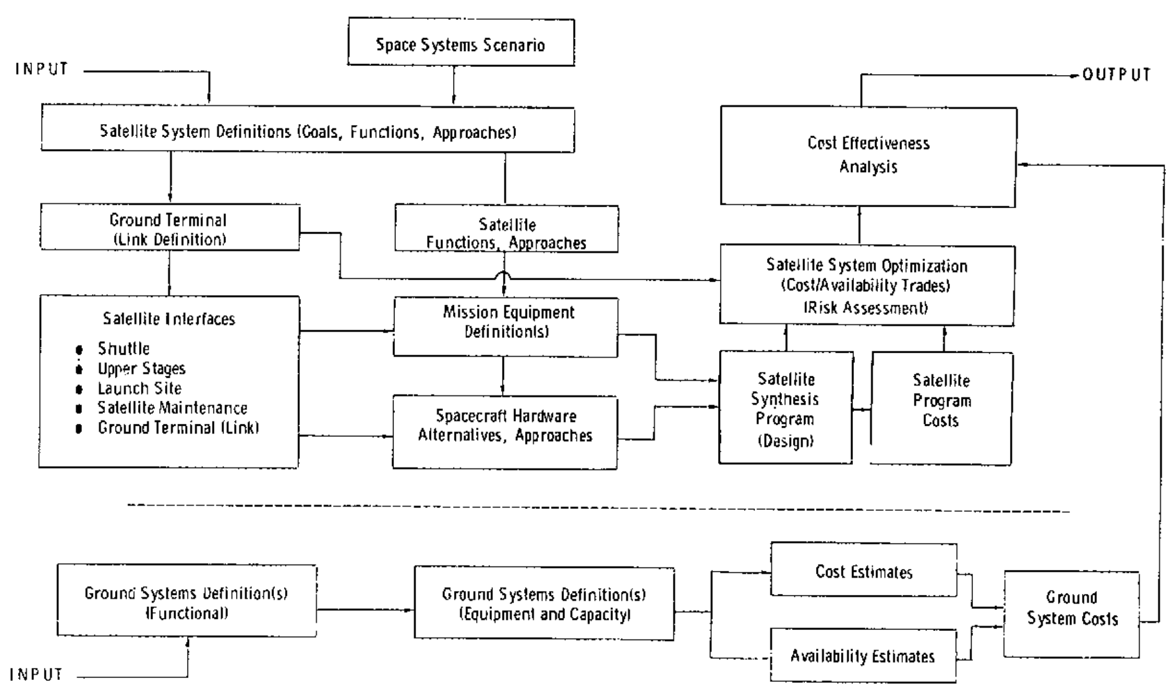

Figure 5-1. BRAVO Information Flow

The peak rates of information to be sensed or transmitted, and its form whether visual, digital, infrared, voice, or other type of transmission, must be designated. The geographic locations to be served by the space system and types of competitive terrestrial systems must be known. These sets of information are the basic inputs to the BRAVO analysis. The analysis itself consists of a series of steps, each step being a subset of the overall BRAVO analysis. The steps are:

- Step 1 - Definition of the Problem (BRAVO Input)
- Step 2 - Space System Analysis
  - a. - Select System Approach(es) and Goals
  - b. - Satellite Mission Equipment Selection
  - c. - Select Specific Satellite Interface Concepts
  - d. - Spacecraft Synthesis
  - e. - Space System Cost Estimating
  - f. - Satellite System Optimization Analysis
- Step 3 - Terrestrial System Analysis
- Step 4 - Cost Effectiveness Analysis.

B. BASIC DATA GENERATED AND SIGNIFICANT RESULTS

Each of the BRAVO analysis steps is documented in the BRAVO User's Manual (Volume IV, Part 2 of this report). Part 3 contains the work sheets required to analyze a potential space user's problem. Part 4 contains the computer program listings and reference data required for these analyses.

The Postal Service was visited for the purpose of discussing potential uses of space for mail. There is considerable potential there, and the Postal Service is working on it with the Office of Applications.

The Federal Power Commission (FPC) was visited for the purpose of discussing its future problems and the potential for application of space systems. The FPC showed interest in the possibility of power generation using solar cells or other sources of energy in space. An analysis has been initiated on the definition and cost effectiveness of solar cell power generation satellites making use of the A. D. Little, Inc./ Raytheon/Spectro Lab solar power satellite approach.

6. PAYLOAD COMMUNITY ANALYSIS

A. METHOD OF APPROACH AND PRINCIPAL ASSUMPTIONS

The objective of the Payload Community Analysis is to assist NASA in developing an approach to handling STS user charges by determining alternative STS charge policies and analyzing the resulting charge estimates against the criteria and issues involved.

This rate effort was started during FY 73. Approximately six man-months were spent on payload community analysis. This level of effort was sufficient to define the shared-flight charge problem, devise methods for analysis, and make an initial analysis.

There are many important policy issues that should be addressed in the selection of STS user charge policy. Some of these issues are related to management policy decisions that can be tested directly as a priori ground rules, by analysis of their effects on the user costs; other issues require further insight into the effect of alternative charge policies on individual payload programs before they can be adequately understood and resolved. The intent of the payload community analysis study is to gain this required insight by investigating the impact of alternative charge policies on numerous payload programs.

B. BASIC DATA GENERATED AND SIGNIFICANT RESULTS

The preliminary payload community analysis studies conducted under Aerospace Study 2.4 addressed the following two tasks:

1. Develop a methodology for analyzing the cost impact on the payload user community of alternative STS charge policies.

2. Use the methodology to evaluate several potential STS charge policies.

The alternative charge policies investigated were chosen to provide insight into the major policy issues. General findings relative to the issues were:

A. STS costs (direct operating, or other costs) can be recovered on either a flight- or cargo-charge basis, presuming the costs are known or can be reasonably estimated.

B. Several approaches have been developed which achieve minimum down leg flight charges for payloads.

C. The STS performance-oriented payload charge splits tend to favor the lighter and smaller payload packages. The trip charge and other arbitrary charge splits, considering payload units rather than weights, tend to favor the large, low-cost payloads with lower transportation charges.

D. Comparing STS transportation costs with expendable launch vehicle costs presents a disadvantage to the STS due to the greater number of flights resulting from payload retrieval. A fair comparison involves both payload and transportation costs.

E. The cargo-charge approaches, using a constant dollar per pound charge factor, resulted in some payloads being charged in excess of the cost per launch for the STS. A more complex cargo charge approach limits the maximum transportation costs for one payload flight to the STS launch costs and compensates by charging smaller payloads at a higher dollar per pound rate, thus avoiding the potential overcharge complaint.

7. SPECIAL STUDIES

In addition to briefing the GAO in answer to its list of 20 questions relating to Space Shuttle program justification, NASA requested several special studies of Aerospace in the January-April 1973 time period. Assistance was given to NASA in preparing responses to the GAO adjustments proposed in their review of the 1972 NASA Space Shuttle Fact Sheet. The adjustments dealt with directly by Aerospace were in the reliability area. These adjustments disappeared from the final GAO report issued in June 1973.

NASA also requested a study of the influence of the reuse of the Titan III Solid Rocket Motor (SRM) on the cost of operating the mission model with a new expendable launch vehicle. The results of this study are reported in Volume III of this report.

The purpose of the reusable SRM study was to estimate the cost savings which would be achieved by utilizing a recoverable, reusable SRM with a new expendable booster from the Titan III family used in the Integrated Operations/Payloads/Fleet Analysis (Study A) of 1971. Two approaches to a recoverable SRM were analyzed. The first was a scaled-down Space Shuttle SRM developed with the objective of minimizing refurbishment costs. The second approach used the existing Titan III SRM modified for recovery and reuse. The refurbishment costs for the latter were higher than for the first approach but not enough to make up for the development costs of the new motor. The modified Titan III SRM was selected as the baseline for the study. The reusable SRM saves $324 million over the 12-year mission model analyzed. This savings represents 4.4 percent of the launch vehicle costs and 1 percent of the total program costs over the 12-year period.

8. STUDY LIMITATIONS

The scope of the traffic analysis was limited by the funds available. Special studies replaced the development of analytical methods for handling the costing and revisit capture analysis for standardized subsystem spacecraft.

9. IMPLICATIONS FOR RESEARCH

The traffic analysis indicates the desirability of demonstrating certain modes of operation such as payload retrieval, maintenance, repair, revisit, and refurbishment. The analysis also indicates the desirability of STS payload hardware standardization. Additional study will be required to define the implications for research, if any.

10. SUGGESTED ADDITIONAL EFFORT

The results of the traffic analysis indicate that with the Space Shuttle cost per launch of approximately $10 million, the attractiveness of the Shuttle for automated payloads has been significantly reduced relative to the fully reusable system; however, the analysis does not include the effects of payload hardware standardization, a concept which is very attractive with the STS system for several reasons.

1. Once it is qualified for launch on the Space Shuttle, the standard equipment should not need to be requalified for launch by other payload programs.

2. Standardization has been shown to save development costs by eliminating the redevelopment of the same or similar hardware.

3. The residual value of on-orbit spacecraft which have experienced hardware failures is considerably enhanced for reuse with standardized hardware which can be refurbished for reflight on the same payload program or other payload programs making use of that hardware.

It is recommended that NASA further study hardware standardization and analyze its effect on NASA and other payload programs.

The BRAVO effort has developed a tool for defining and assessing space systems applied to new problems. It is recommended that this tool be put into full operation, leading off with a series of discussions with responsible industrial and service organizations (U. S. and foreign) which may have long-range problems on which space applications could be competitive.

The payload community analysis study has uncovered a series of issues relative to STS user charges. Many options have been identified as potential policies for STS use charging. It is recommended that this effort be followed up with further studies of these options against criteria acceptable to NASA, with the objective of eliminating the less desirable options.