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CR #171968

AN INVESTIGATION OF SELECTED ON-ORBIT SATELLITE SERVICING ISSUES

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For

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Houston, TX 77058

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FOREWORD

This study was conducted between August 1985 and October 1986 for the Engineering Directorate of NASA's Lyndon B. Johnson Space Center, Gordon Rysavy - Technical Monitor. The purpose of this study has been to investigate several issues identified during the previous phase of this contract, the development of a satellite services systems program plan. Specifically, this study examined cost criteria from the customer's perspective, satellite servicing by the Space Shuttle during the Space Station era, and methods for on-orbit exchange of large modules. This information will be used by NASA planners to assist in the development of a NASA program plan in this area.

Stephen J. Hoffman served as Principal Investigator for this effort with significant contributions provided by Deanna Limperes, James McAdams, Terri Ramlose, and John Soldner.

ACRONYMS AND ABBREVIATIONS

EURECA	EUROPEAN RETRIEVABLE CARRIER
EVA	EXTRAVEHICULAR ACTIVITY
FSC	FAIRCHILD SPACE COMPANY
FSS	FLIGHT SUPPORT SYSTEM
GEO	GEOSYNCHRONOUS ORBIT
HPA	HANDLING AND POSITIONING AID
ICD	INTERFACE CONTROL DOCUMENT
IOC	INITIAL OPERATIONAL CAPABILITY INITIAL ORBITAL CAPABILITY (WITH SPACE STATION)
IVA	INTRAVEHICULAR ACTIVITY
LEO	LOW-EARTH ORBIT
MPS	MATERIALS PROCESSING IN SPACE
MSFC	MARSHALL SPACE FLIGHT CENTER
OMS	ORBITAL MANEUVERING SYSTEM
OMV	ORBITAL MANEUVERING VEHICLE
ORU	ORBITAL REPLACEMENT UNIT
OTV	ORBITAL TRANSFER VEHICLE
OUPM	OUTSIDE USER'S PAYLOAD MODEL
PBS	PAYLOAD BERTHING SYSTEM
PIP	PAYLOAD INTEGRATION PLAN
RCA	RCA ASTROELECTRONICS DIVISION
RCS	REACTION CONTROL SYSTEM
RMS	REMOTE MANIPULATOR SYSTEM
RSSS	RECONFIGURABLE SATELLITE SERVICING SYSTEM
SII	SPACE INDUSTRIES, INC.
SS	SPACE STATION
STS	SPACE TRANSPORTATION SYSTEM

REPORT OVERVIEW

This report documents the results of three separate investigations performed by Science Applications International Corporation (SAIC) between August 1985 and October 1986 as the second phase of the two-phase Satellite Services System Program Plan contract for the Engineering Directorate of the Lyndon B. Johnson Space Center. Issues addressed by these studies resulted from questions and concerns identified during the first phase of this contract, conducted between September 1984 and July 1985.

The objectives of the first phase of this contract (reported in SAIC-85/1762) were to determine the potential for servicing a diverse range of spacecraft from the Space Shuttle Orbiter and to assess NASA's role as the catalyst in enabling routine on-orbit servicing. Specifically, the study sought to determine the requirements, in terms of both funds and time, to make the Shuttle Orbiter not only a transporter of spacecraft but a servicing vehicle for those spacecraft as well.

The scope of this effort was the near-term (1986-1993) development of a generic servicing capability. To make this capability truly generic and attractive required that the customer's point of view be taken and transformed into a widely usable set of hardware. To enable a near-term realization of this capability, minimal reliance was placed on advanced technology.

Given this background and scope, the phase one study proceeded through three steps to arrive at the desired program costs and schedule. The first step used a survey to determine user community servicing requirements. Information gathered provided the basis for the second step, which was to develop hardware concepts to meet these needs. Finally, costs were estimated for each of the new hardware concepts, and phased hardware development plans based on inputs obtained from the user community were established for the acquisition of these items.

Three areas of potential further investigation resulted in the definition and performance of the study efforts conducted under phase two of this contract. The first was the result of interest shown in the cost criteria issue discussed briefly in the user community survey conducted in the first phase of this contract. To gain further insight into this issue, a more detailed survey was prepared and distributed. Responses were obtained from 25 cognizant individuals from both civilian and military user groups. Several areas of strong agreement across both communities were identified; this should provide NASA with a useful starting point in user requirements cost criteria responses.

The second area of investigation was prompted by the need to understand satellite servicing requirements in the far term (1995-2010) and how results from the first phase of this contract could support these requirements. The mission model developed during the first phase was extended using new data and information from studies which address the later time period. Two new assumptions were introduced -- the inclusion of the Orbital Maneuvering Vehicle (OMV) to expand the accessibility range of the Space Shuttle, and the operation of the Space Station, which will have its own servicing capability. Results indicate that all hardware for near- term usage will still be applicable but several new servicing modes which will require development of additional hardware were identified. The main recommendation from this study is for the early agreement on standard interfaces which can then be used by those agencies starting to design vehicles for use in the far term.

The third area of investigation looked at a new servicing mode which had not been studied previously. This mode involves the on-orbit exchange of very large modules with masses greater than approximately 9,000 kilograms and/or lengths greater than approximately nine meters. Materials processing spacecraft designers have found that modules containing raw material or finished products must be at least this size, for economic reasons. Discussions with two firms (Fairchild Space Company and RCA AstroElectronics) with experience in this area were held to identify major requirements for this type of operation and the hardware combination(s) which would be of greatest use. These discussions were consolidated to provide an indication of the generic hardware which could serve a variety of concepts.

The following sections of this document contain the viewgraphs used for the final briefing for each of the three investigations, as presented to NASA. A more detailed discussion of each of the viewgraphs has been provided on the facing page. As mentioned earlier, each investigation was conducted independently, and as such the presentation material has been organized into three stand-alone sections.

TASK 1

SATELLITE SERVICING COST CRITERIA

INTRODUCTION

This study was part of a follow-on effort to work completed by SAIC in July of 1985. At that time, a satellite services system program plan was developed, using inputs obtained from the user community, to identify required hardware types and availability dates. During the data gathering phase, SAIC also queried the user community about some of the higher level issues associated with the cost of conducting servicing operations. The results were of sufficient interest that a larger-scale data collection and evaluation were undertaken in this follow-on effort. Specifically, the objective of this task was to obtain and evaluate preliminary cost criteria for on-orbit servicing from the potential customer's perspective. This information will then be available to NASA for its consideration when a pricing policy in this area is formulated.

INTRODUCTION

- STUDY OBJECTIVE

  - OBTAIN AND EVALUATE PRELIMINARY COST CRITERIA FOR ON-ORBIT SERVICING FROM THE CUSTOMER'S PERSPECTIVE

- RESULTING INFORMATION AVAILABLE TO NASA FOR USE IN FORMULATING PRICING POLICY

BACKGROUND AND ASSUMPTIONS

The approach taken for this task was to use a survey containing multiple choice answers for a variety of cost criteria questions. The possible choices for these answers were constructed to cover a wide range of responses to help avoid forcing the participants into a prejudged reply. With this type of format, a direct comparison of all responses was possible.

The subject material used for the questions was developed through previous discussions with both the user community and NASA personnel. Few assumptions had to be made to convert these issues into the multiple choice question format. However, due to the current uncertainty in the schedule and level of activity for the STS program, the following working assumptions were made in the process of developing these survey questions. Unless otherwise specified, the survey questions were to be answered as though these conditions did in fact exist:

- On-orbit satellite servicing is an activity which can only be accomplished by the Space Shuttle and/or unmanned servicer vehicles; therefore, it is exempt from any restrictions which would limit or preclude the launch of commercial missions on the Space Shuttle.
- Sufficient Space Shuttle capacity exists to allow flexibility in the choice of launch dates (i.e., no backlog of government flights exists; launch window chosen to suit user requirements).
- Multiple servicing sorties are possible on a single Shuttle flight.
- All cost rates (i.e., $/workhour, $/activity, etc.) have been defined by NASA and are known by the user.

BACKGROUND AND ASSUMPTIONS

- APPROACH FOR DATA COLLECTION
  - MULTIPLE CHOICE SURVEY
  - ALLOWS FOR DIRECT COMPARISON OF RESPONSES
- ASSUMPTIONS (UNLESS OTHERWISE SPECIFIED)
  - ON-ORBIT SERVICING NOT AFFECTED BY RESTRICTIONS ON COMMERCIAL LAUNCHES BY STS
  - LAUNCH DATE FLEXIBILITY
  - MULTIPLE SERVICING SORTIES POSSIBLE ON EACH SHUTTLE FLIGHT
  - ALL COST RATES ARE KNOWN BY THE USER

PARTICIPATING ORGANIZATIONS

The approach taken for this analysis was to target specific individuals within the user community to fill out the survey. This allowed for the selection of those people who have a working knowledge of the subject matter and provided for a high rate of return. Individuals from a wide range of aerospace organizations were surveyed to ensure that a sampling of a diverse set of opinions would be obtained from those who are reasonably close to the issues involved. These individuals were asked to provide their personal opinion to the questions asked in order to avoid possible delays or restrictions associated with an official response representing their organization or company. The facing page indicates the number of responses returned and the organization with which each participant was associated. The organizations have been identified here to indicate the breadth of the survey and maintain individual anonymity, not to imply any official response from these organizations.

PARTICIPATING ORGANIZATIONS

BALL AEROSPACE - 1

BOEING - 1

CENTER FOR SPACE POLICY - 1

FAIRCHILD SPACE COMPANY - 2

GRUMMAN - 1

LOCKHEED - 1

MARTIN MARIETTA - 1

ROCKWELL - 1

SPAR - 1

TRW - 2

USAF/SPACE COMMAND - 4

USAF/SPACE DIVISION - 9

NUMERICAL VALUES INDICATE NUMBER OF RESPONSES RECEIVED

SURVEY SECTION 1: GENERAL ISSUES*

The first section of the survey contained nine questions addressing a variety of issues. These included the relative importance of pricing policy, familiarity with and opinion of current policies affecting on-orbit servicing, and overall trends in this area.

One of the first questions asked in the survey addressed the importance attached to a pricing policy; whether knowing pricing details is more important, equally important, or less important than simply knowing a servicing option is available and what its associated capabilities are. The survey results indicate that overall knowledge of the pricing policy is more important. Those from commercial organizations expressed this opinion two out of three times. Those from military organizations leaned toward equal importance with just over half expressing this opinion.

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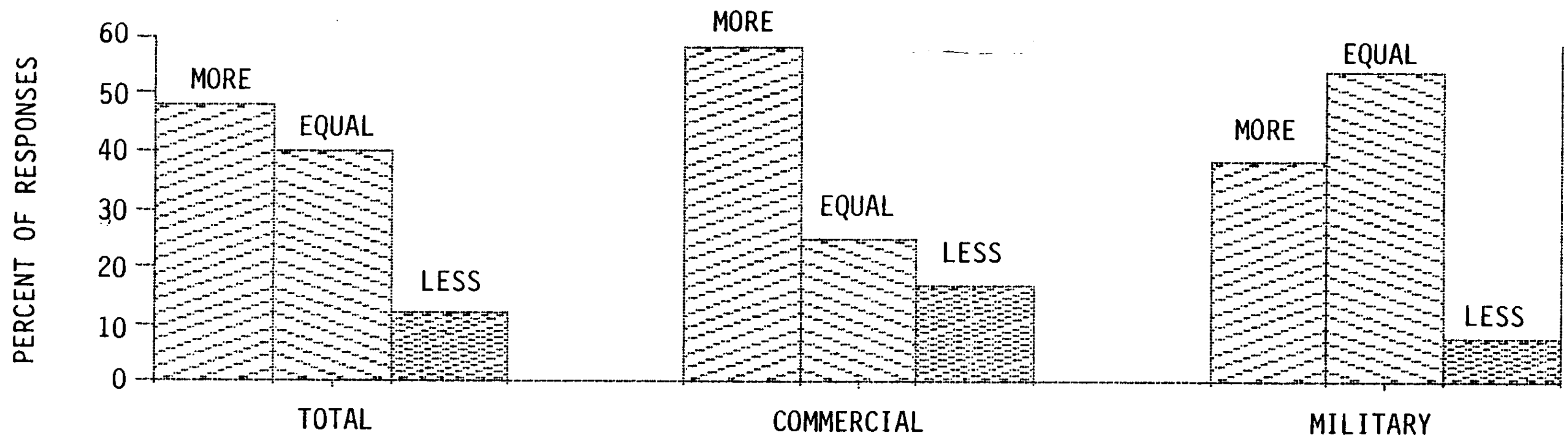
* The appendix contains a copy of all questions and possible answers along with a summary of the responses for each individual question.

- GENERAL QUESTIONS REGARDING:
  - THE RELATIVE IMPORTANCE OF A PRICING POLICY
  - FAMILIARITY WITH AND OPINION OF CURRENT POLICIES
  - TRENDS IN THE SATELLITE SERVICING AREA

- IMPORTANCE OF A KNOWLEDGE OF PRICING POLICY VERSUS A KNOWLEDGE OF SERVICING CAPABILITY



COST GUIDELINE FORMAT

Question 1.4 from the survey asked the participants to indicate the desirable format for any cost guidelines published by NASA. Two options were offered:

(1) A single fixed price based on the type of servicing activity

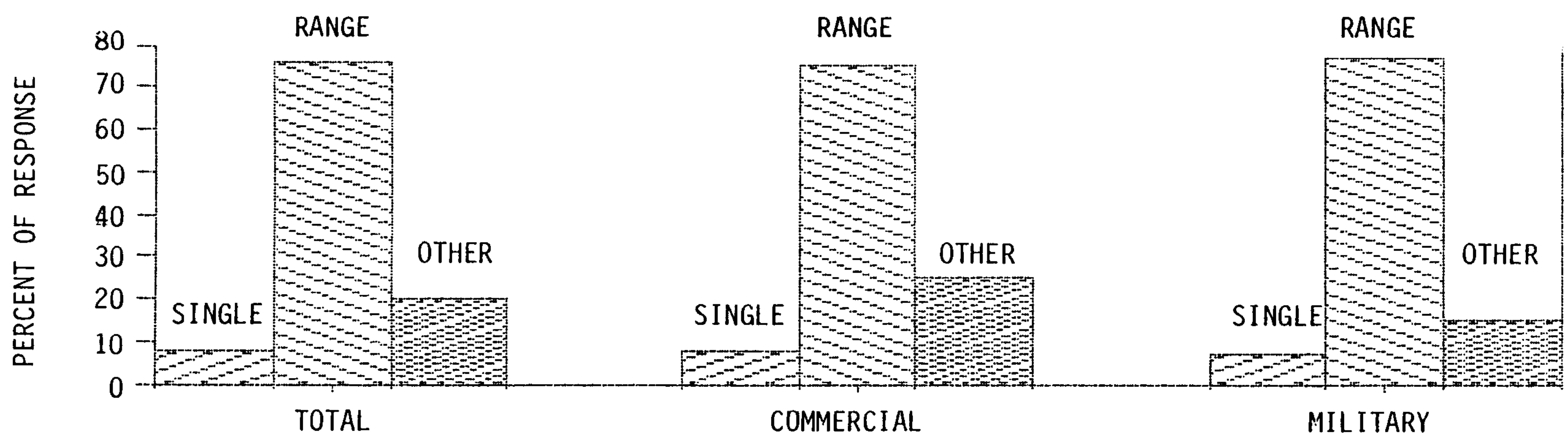
(2) Fixed price ranges with the final price negotiated on a case-by-case basis.

Space was also available to write in another alternative had either of these options been unacceptable.

As can be seen on the facing page, the price range option was selected by over 70 percent of the participants in both groups. Several individuals chose one of the two available options and then offered suggested modifications in the "other" section. The remainder of the "other" comments did not follow any particular trend.

COST GUIDELINE FORMAT

- IF SATELLITE SERVICING PRICE GUIDELINES EXIST, HOW SHOULD NASA PUBLISH THE CHARGES FOR SERVICES IT RENDERS?



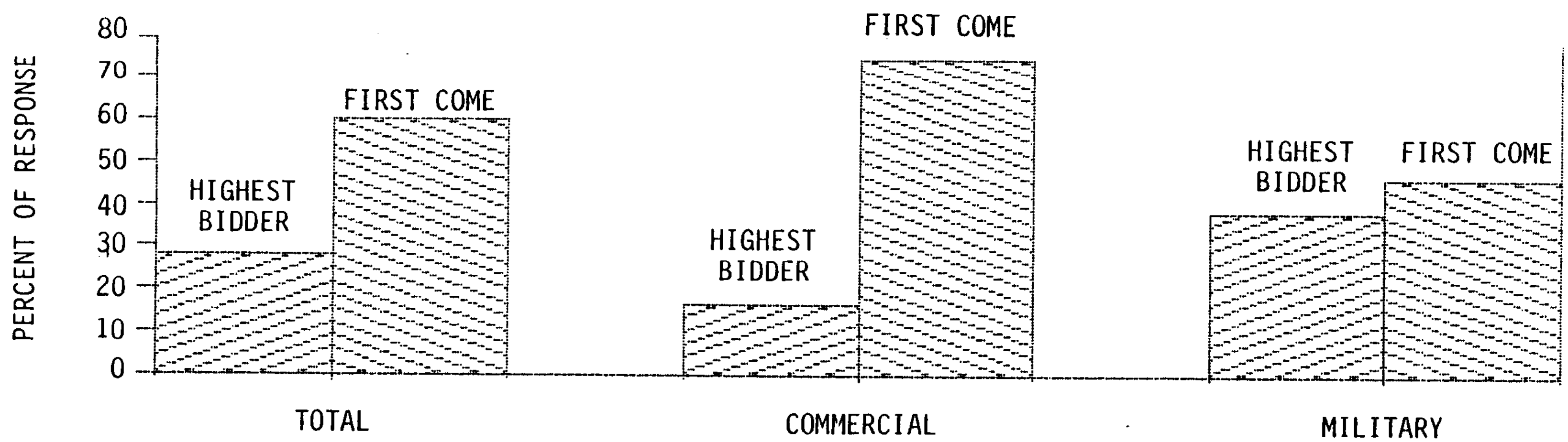
LAUNCH SLOT RESERVATIONS

Question 1.5 from the survey asked whether launch slots/payload reservations for satellite servicing should be awarded to the highest bidder or assigned on a first come-first served basis. Those from the commercial group strongly preferred the latter option while the military group was only slightly in favor of the first come-first served option.

As part of this question, a proposal was made to assign top priority to a servicing mission if the target spacecraft were in danger of being lost if servicing were delayed. This proposal was endorsed by over 80 percent of the individuals in both groups.

LAUNCH SLOT RESERVATIONS

- SHOULD STS LAUNCH SLOTS/PAYLOAD RESERVATIONS FOR SATELLITE SERVICING MISSIONS BE AWARDED TO THE HIGHEST BIDDER OR ASSIGNED ON A FIRST COME - FIRST SERVED BASIS?



RELATIVE COSTS OF SERVICING MISSION PHASES

In Question 1.7 the participants were asked to rank the costs associated with various phases of a servicing mission based on their perception of the current magnitude of these costs. These costs were ranked for both the NASA portion and the customer portion of the mission. Averaged over both groups, the results from this question indicated that both the NASA and customer phases were ranked in the same order, namely:

Highest Cost - Launch (standard STS launch cost)

- Prelaunch (R&D, tool usage fees, training, insurance, etc.)
- On-orbit Operations (rendezvous, servicing, product retrieval, etc.)

Lowest Cost - Return (reentry preparation, post-flight ground operations, etc.)

These results indicate that design efforts should be focused on the launch and prelaunch phases to reduce overall mission costs.

RELATIVE COSTS OF SERVICING MISSION PHASES

- PARTICIPANTS ASKED TO RANK THE RELATIVE COSTS FOR BASIC SATELLITE SERVICING MISSION PHASES

- ON AVERAGE, THE COSTS INCURRED BY NASA AND BY THE CUSTOMER WERE BOTH RANKED IN THE SAME ORDER:

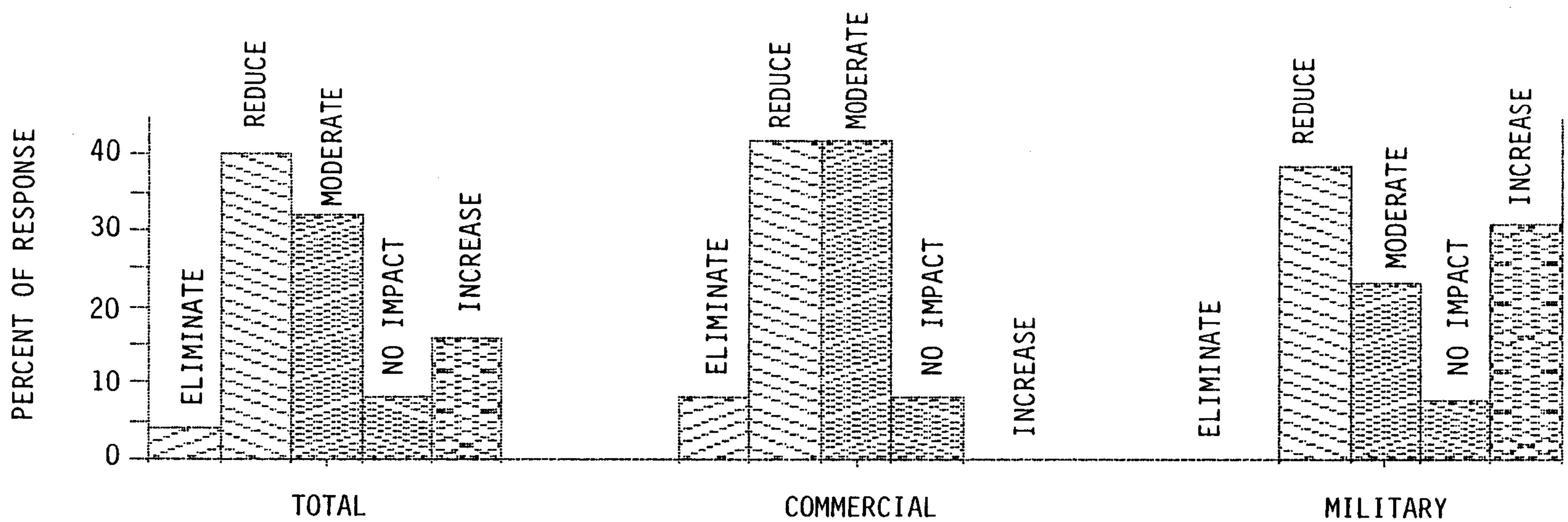
HIGHEST	-	LAUNCH (STANDARD STS LAUNCH COST)
	-	PRELAUNCH (R&D, TOOL USAGE FEES, TRAINING, INSURANCE, ETC.)
	-	ON-ORBIT (RENDEZVOUS, SERVICING, PRODUCT RETRIEVAL, ETC.)
LOWEST	-	RETURN (REENTRY PREPARATION, POST FLIGHT GROUND OPERATIONS, ETC.)

EFFECT OF THE CHALLENGER ACCIDENT ON SERVICING MISSION PLANNING

The purpose of this question was to determine the level of effort which would now be put into planning for on-orbit servicing in light of the changes being made after this accident. This could also be interpreted as the level of optimism or pessimism within the user community for this activity. The responses from the commercial group indicated that the accident will have a detrimental effect not only on planning but also on operations. This interpretation was based on the fact that several individuals felt that all planning would halt, thus precluding any actual missions, and that there would be no increase in planning to revise current plans in light of a new set of ground rules. Alternatively, the military seems to be split into two groups, those who are ready to push ahead with this activity, as indicated by the "increased planning" level, and those who foresee a reduced overall level, as exhibited by the number of individuals who indicated that planning would be reduced.

EFFECT OF CHALLENGER ACCIDENT ON SERVICING MISSION PLANNING

- WHAT EFFECT WILL THE SHUTTLE ACCIDENT, THE INDEFINITE POSTPONEMENT OF FUTURE SHUTTLE FLIGHTS, AND THE APPARENT REMOVAL OF COMMERCIAL PAYLOADS FROM NEAR-TERM FLIGHTS, HAVE ON PLANNING FOR SATELLITE SERVICING?



SURVEY SECTION 1: GENERAL ISSUES (concluded)

Important results from questions in this section can be summarized as follows:

- More exposure of current policies is needed to improve the user community's awareness of what is and what is not available and how much it will cost.
- At a minimum, the current policies should be updated and expanded to reflect the evolving operations in space.
- A strong desire exists for establishing satellite servicing costs as a minimum/maximum range for each service or activity offered and negotiating the final cost (within that range) on a case-by-case basis.
- A two-to-one opinion was expressed in favor of retaining the current first come - first served arrangement for reserving launch slots.
- On-orbit operations were generally ranked third most expensive behind launch costs and pre-launch preparation costs for both NASA and the customer.
- A general perception exists that planning for satellite servicing will decline as a result of the Challenger accident.
- But the survey also indicates that one to three servicing flights per year will still be required.

SURVEY SECTION 1: GENERAL ISSUES (CONCLUDED)

- IMPORTANT RESULTS FROM THIS SECTION
  - MORE EXPOSURE OF CURRENT POLICIES IS NEEDED
  - THESE POLICIES SHOULD BE EXPANDED AND UPDATED TO REFLECT THE CURRENT STATE OF AFFAIRS
  - ESTABLISH SATELLITE SERVICING COSTS AS A RANGE (MINIMUM, MAXIMUM) FOR EACH ACTIVITY; NEGOTIATE FINAL COST ON A CASE-BY-CASE BASIS
  - LAUNCH ON A FIRST COME - FIRST SERVED BASIS IS PREFERRED BY TWO OUT OF THREE OF THOSE WHO RESPONDED
  - THE COST OF ON-ORBIT OPERATIONS IS PERCEIVED TO BE LOWER THAN EITHER LAUNCH COSTS OR PRE-LAUNCH PREPARATION COSTS
  - THE CHALLENGER ACCIDENT AND REMOVAL OF COMMERCIAL PAYLOADS FROM THE SHUTTLE ARE SEEN AS CONTRIBUTING TO A REDUCTION IN PLANNING FOR FUTURE SATELLITE SERVICING MISSIONS
  - IN SPITE OF THIS A NEED FOR ONE TO THREE SERVICING FLIGHTS PER YEAR IS STILL ANTICIPATED

SURVEY SECTION 2: HARDWARE DEVELOPMENT AND PROCUREMENT

The second section of the survey addressed issues regarding the development and procurement of satellite servicing-related hardware and the operational use of this hardware. These questions attempted to identify those factors or incentives which will draw more users into this process, from designing to meet standard interfaces to non-NASA development and procurement of major hardware items. None of the specific suggestions (see the appendix) made in this regard elicited anything more than a lukewarm response from either the civilian or military groups. However, both groups did express a strong desire to share in the responsibility for hardware development. Thus, further dialogue on this issue will be needed to determine what form this cooperation should take.

SURVEY SECTION 2: HARDWARE DEVELOPMENT AND PROCUREMENT

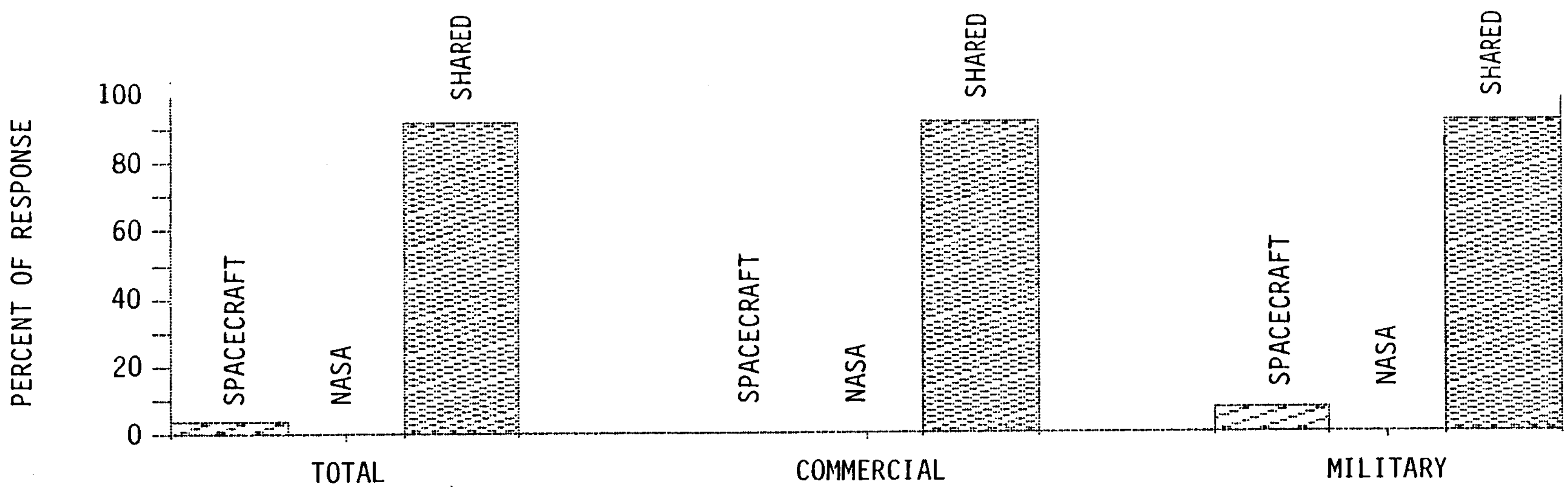
- ATTEMPT TO LEARN WHAT FACTORS OR INCENTIVES WOULD INCREASE PARTICIPATION IN SATELLITE SERVICING ACTIVITIES
- THESE ACTIVITIES RANGE FROM DESIGNING FOR CERTAIN STANDARD INTERFACES TO NON-NASA DEVELOPMENT AND PROCUREMENT OF HARDWARE
- NONE OF THE SUGGESTIONS DREW AN ENTHUSIASTIC RESPONSE
- BOTH CIVILIAN AND MILITARY GROUPS DID EXPRESS A STRONG INTEREST IN SHARED RESPONSIBILITY FOR HARDWARE DEVELOPMENT

SERVICING HARDWARE DEVELOPMENT RESPONSIBILITY

Question 2.1 of the survey asked the participants whether hardware development responsibility should lie entirely with the spacecraft owner, be assumed entirely by NASA, or be shared by the spacecraft owner and NASA. The clear choice by both the commercial and military groups was that this responsibility should be shared. The responses to the next question indicate how this shared responsibility might be handled.

SERVICING HARDWARE DEVELOPMENT RESPONSIBILITY

- PARTICIPANTS ASKED WHERE DEVELOPMENT RESPONSIBILITY SHOULD LIE
  - ENTIRELY WITH THE SPACECRAFT OWNER
  - ENTIRELY WITH NASA
  - SHARED BY NASA, THE SPACECRAFT OWNER, AND APPROPRIATE THIRD PARTIES



SERVICING HARDWARE OWNERSHIP

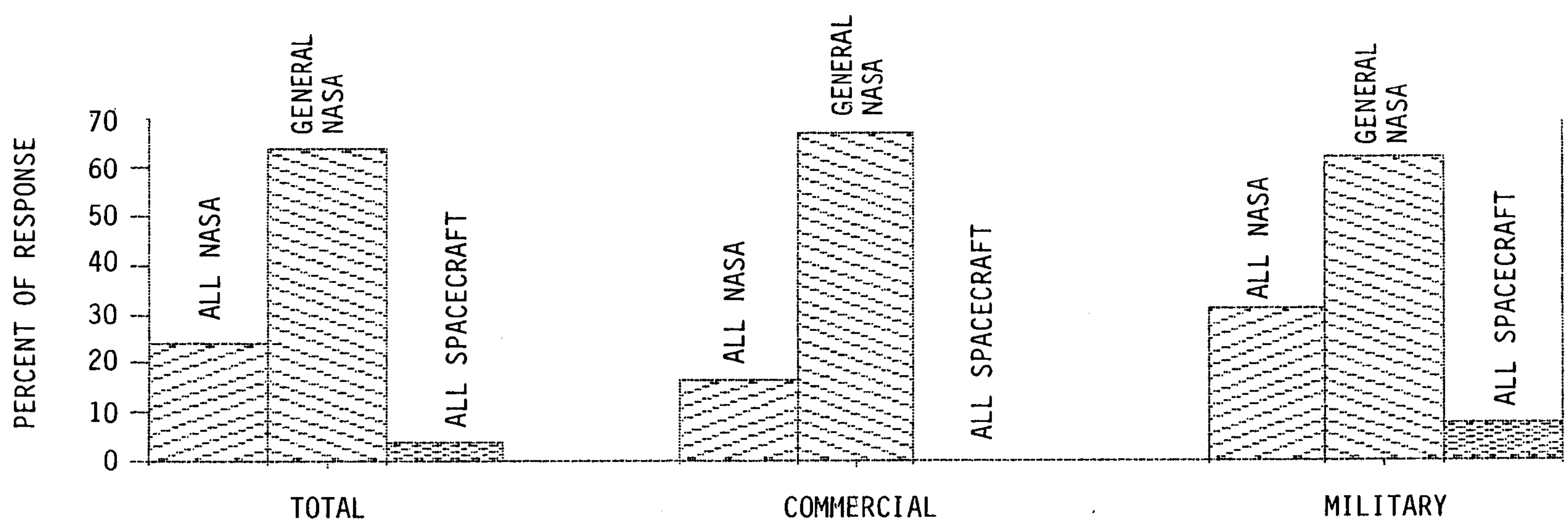
Results from the previous question indicated that the user community would like to share in the development of servicing hardware. The responses to this question also indicated how the user community would like to divide this responsibility. The participants were provided with three options regarding the ownership of servicing hardware, including:

- NASA owning all hardware but with availability to STS users
- NASA owning general purpose hardware (e.g., satellite holding devices, propellant tankers, etc.) with unique hardware supplied by the user
- Each spacecraft owner procuring its own required hardware.

The clear choice by both the commercial and military groups was that NASA should own the general purpose items while the spacecraft owner should provide unique items. A cooperative effort by all parties will be required to ensure that all interfaces are compatible.

SERVICING HARDWARE OWNERSHIP

- WHO SHOULD OWN SERVICING-RELATED HARDWARE?
  - NASA OWNS ALL, HARDWARE "POOL" AVAILABLE TO STS CUSTOMERS
  - NASA OWNS GENERAL PURPOSE ITEMS, UNIQUE ITEMS SUPPLIED BY SPACECRAFT OWNER
  - EACH SPACECRAFT OWNER WOULD OBTAIN ALL REQUIRED HARDWARE



SURVEY SECTION 2: HARDWARE DEVELOPMENT AND PROCUREMENT (concluded)

Of the suggested alternatives presented in this section, the greatest interest was shown in the following:

- NASA should procure general hardware (e.g., satellite holding device, propellant tanker, etc.) while individual customers should be responsible for unique hardware

- Private development of servicing hardware may be encouraged if an eventual buy-back by NASA can be arranged and/or a guaranteed minimum level of usage by NASA or some other organization can be identified.

SURVEY SECTION 2: HARDWARE DEVELOPMENT AND PROCUREMENT (CONCLUDED)

- OF THE SUGGESTIONS MADE, TWO DREW THE MOST INTEREST
  - NASA SHOULD PROCURE GENERAL HARDWARE AND CUSTOMERS SHOULD PROCURE UNIQUE HARDWARE
  - PRIVATE DEVELOPMENT OF SERVICING HARDWARE MAY BE ENCOURAGED IF:
    - AN EVENTUAL BUY-BACK BY NASA CAN BE ARRANGED
    - A GUARANTEED MINIMUM LEVEL OF USAGE CAN BE IDENTIFIED

SURVEY SECTION 3: SERVICING OPERATIONS AND REIMBURSEMENT OPTIONS

This section contained a dozen questions whose purpose was to characterize how the non-NASA user community would like to interface with NASA in the areas of operations and reimbursement. The responses to several of these questions indicated a strong and consistent preference as to how this interface should be handled.

Three of the questions addressed the issue of what level of cost information should be available to the customer when performing trade studies and when presented with an "invoice" for services rendered. For planning purposes, a range (minimum, maximum) of costs was seen as sufficient but when the actual operations and activities had been decided upon, then a detailed accounting of all aspects of the mission was preferred.

Two of the questions examined the most preferred method of reimbursing NASA for a satellite servicing mission. The consistent choice of both the commercial and military groups, as a matter of practicality, was for the cost to be paid in part before flight and the remainder on completion of the mission. One other interesting point is that, when asked which options were desirable (as opposed to practical), the commercial group chose the percentage of future revenues as often as the option just discussed.

SURVEY SECTION 3: SERVICING OPERATIONS AND REIMBURSEMENT OPTIONS

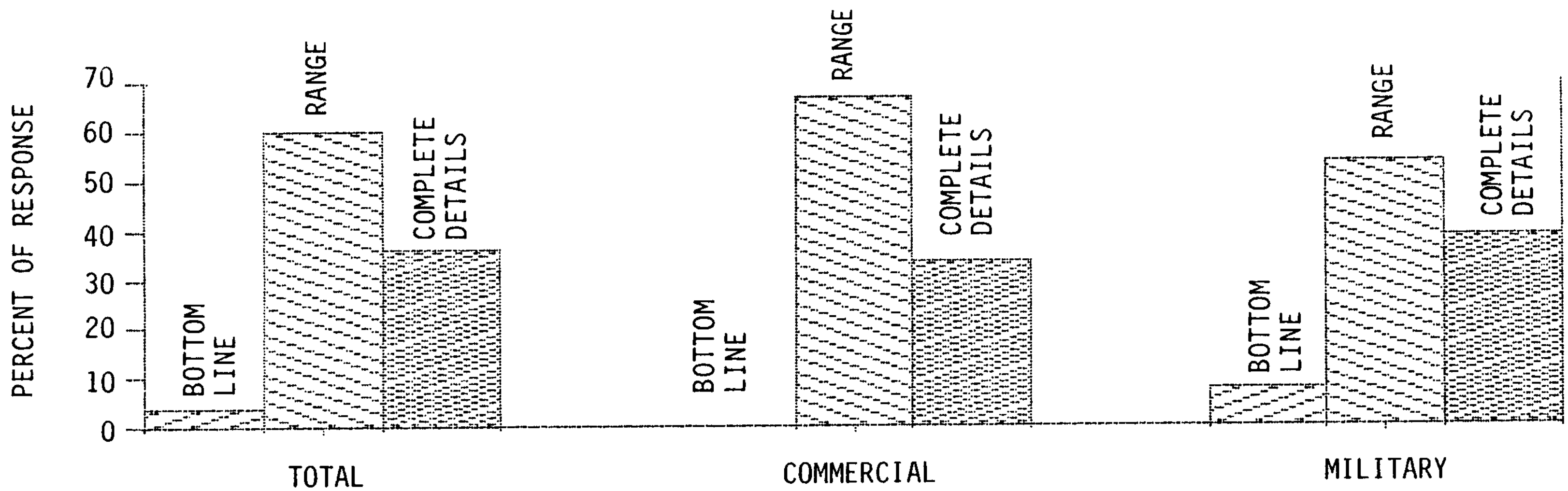
- QUESTIONS ADDRESSED HOW THE OPERATIONS AND REIMBURSEMENT INTERFACES SHOULD BE STRUCTURED
- FOR PLANNING PURPOSES, A COST RANGE (MINIMUM, MAXIMUM) WAS AN ACCEPTABLE LEVEL OF INFORMATION
- THE FINAL "INVOICE" SHOULD BE AS DETAILED AS POSSIBLE
- THE PREFERRED METHOD OF REIMBURSEMENT WAS FOR A PARTIAL PAYMENT BEFORE THE FLIGHT AND THE REMAINDER UPON COMPLETION OF THE MISSION

COST CRITERIA DETAILS FOR TRADE STUDIES

Question 3.1 paralleled Question 1.4 in seeking to understand the level of detail required by the customer in order to conduct reasonable trade studies during the course of spacecraft development. Consistent with the response from Question 1.4, the desirable level of information consisted of a cost range for any particular servicing activity. Results from Question 3.5 indicated that once actual negotiations had begun, a more detailed level of cost information would be sought by the customer.

COST CRITERIA DETAILS FOR TRADE STUDIES

- WHAT LEVEL OF DETAIL IS REQUIRED FOR MACROSCOPIC TRADE STUDIES?
  - BOTTOM LINE, TOTAL COST NUMBER ONLY FOR EACH SERVICING MISSION TYPE
  - THE RANGE (MINIMUM, MAXIMUM) FOR A PARTICULAR SERVICING ACTIVITY WITH THE FINAL COST SUBJECT TO MISSION REQUIREMENTS AND NEGOTIATIONS WITH NASA
  - A COMPLETE AND DETAILED COST BREAKDOWN FOR EVERY ASPECT OF A PARTICULAR SERVICING ACTIVITY



PRACTICAL REIMBURSEMENT OPTIONS

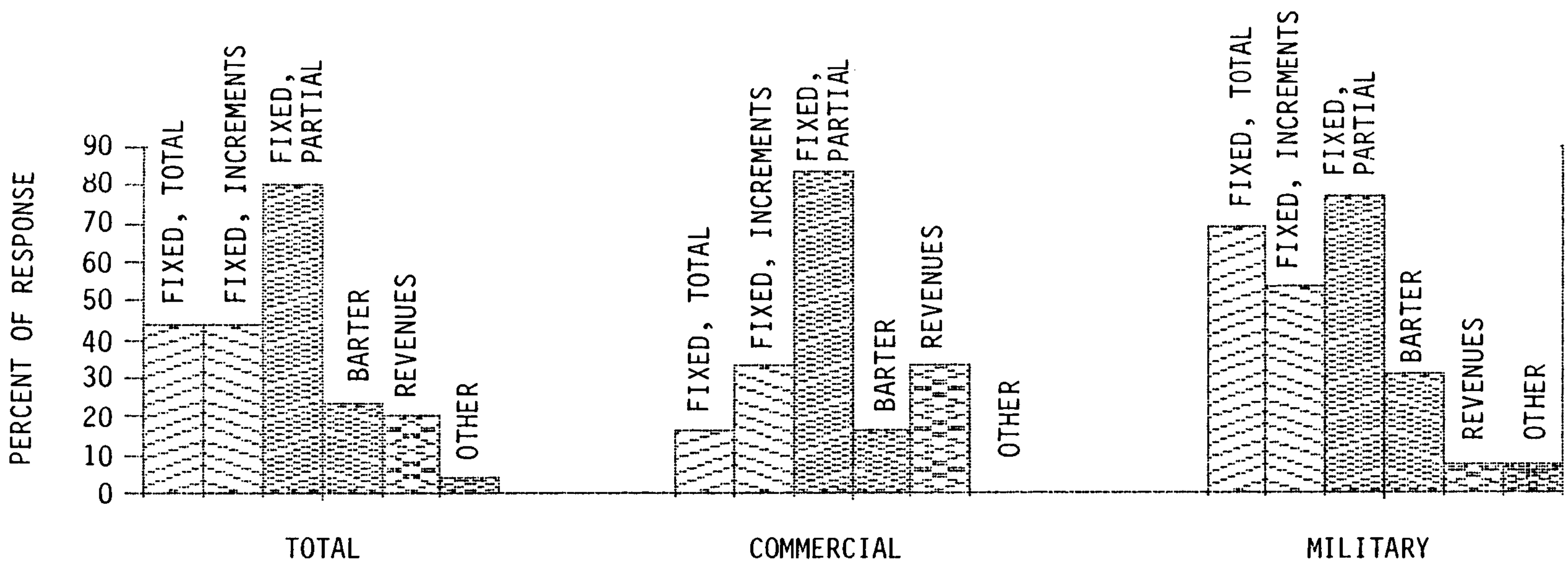
Question 3.2 asked the participants to select as many of the following reimbursement options as were either desirable or practical:

- Fixed fee payable in a lump sum prior to launch
- Fixed fee payable in increments prior to launch
- Fixed fee partially paid in advance, the remainder paid (possibly with interest) after the mission
- Barter; type and quantity of bartered items negotiated on a case-by-case basis
- Percentage of future revenues generated by the vehicle being serviced
- Other (specify)

The results shown below indicate that both the commercial and military groups found the third option (a fixed fee partially paid in advance, the remainder paid after the mission) to be acceptable and practical. This was consistent with the response obtained from Question 3.12 which paralleled this question in the information being sought.

PRACTICAL REIMBURSEMENT OPTIONS

- SEVERAL REIMBURSEMENT OPTIONS WERE PROPOSED FOR CONSIDERATION
- PARTICIPANTS ASKED TO INDICATE WHICH ARE DESIRABLE AND WHICH ARE PRACTICAL
- PRACTICAL RESULTS SHOWN BELOW



COST ACCOUNTABILITY FOR ON-ORBIT OPERATIONS

The last results addressed in this section focus on the level of cost accountability for on-orbit operations. Several approaches were proposed for this situation, ranging from a single, bottom line cost to a detailed accounting for each activity. These suggestions were summarized into the following four options for consideration by the participants:

(1) A single charge based solely on the number of hours the crew is actively involved with the spacecraft regardless of the total time the spacecraft is docked to the Shuttle

(2) A single charge based solely on the total time required to complete the servicing mission, beginning at initiation of the rendezvous sequence and ending at redeployment

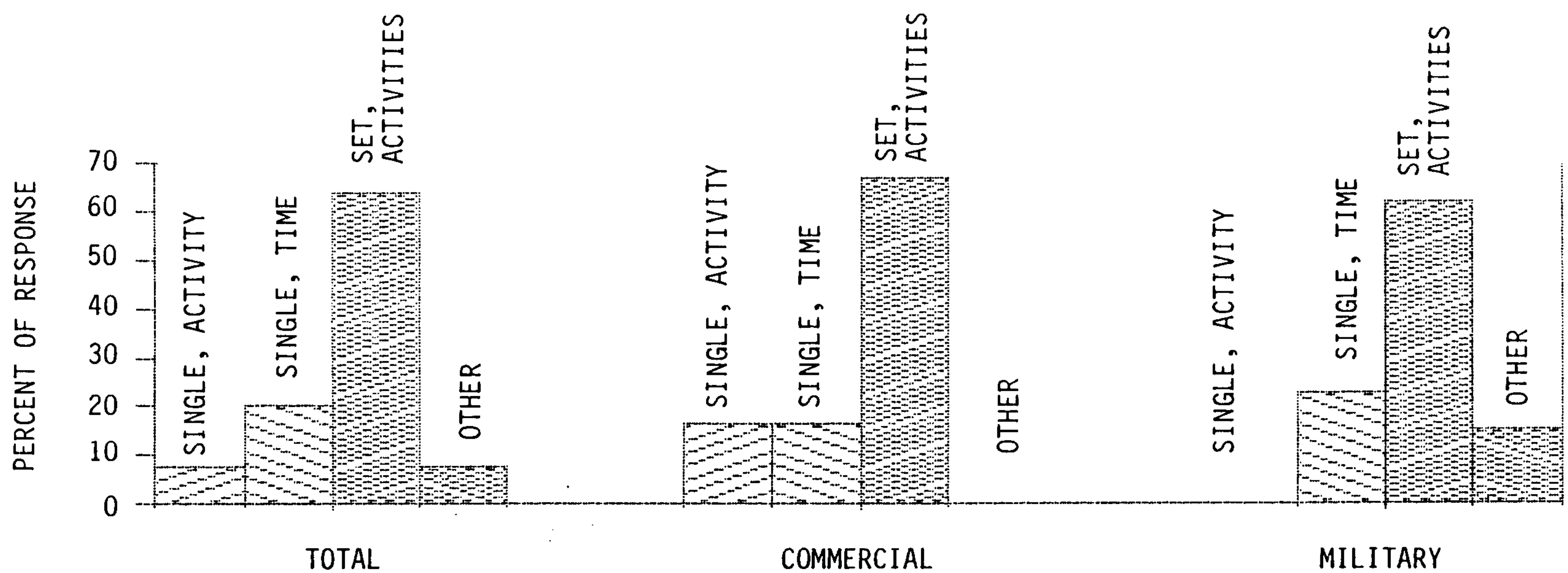
(3) A set of charges based on definable activities: EVA workhours, IVA workhours, and total time from rendezvous to redeployment

(4) Other (specified by participant).

Consistent with earlier results, the most detailed level of accountability was the option sought by both the commercial and military groups.

COST ACCOUNTABILITY FOR ON-ORBIT OPERATIONS

- WHAT IS THE PREFERRED METHOD OF COMPENSATION FOR ON-ORBIT OPERATIONS?
  - A SINGLE COST BASED ON THE NUMBER OF HOURS THE CREW IS WORKING ON THE SPACECRAFT
  - A SINGLE COST BASED ON THE NUMBER OF HOURS THE SPACECRAFT IS DOCKED TO THE SHUTTLE
  - A SET OF CHARGES BASED ON INDIVIDUAL ACTIVITIES



SURVEY SECTION 3: SERVICING OPERATIONS AND REIMBURSEMENT OPTIONS (concluded)

One of the questions in this section asked the participant to indicate which activities associated with a servicing mission should be charged to the customer and which should be carried as part of the NASA overhead. This list, while not exhaustive, was assembled to cover the major phases of a mission (from initial contact with NASA through completion of the flight) and was organized into categories which could be easily identified by the customer.

The responses to this question are summarized below (see the appendix for detailed percentages). The majority of both commercial and military users agreed with the results shown. Significant results were:

- Mission design should be paid for by the customer, but ground and flight crew training should be picked up by NASA
- Usage fees for hardware are acceptable to these users, but they also feel that development costs should be paid by NASA
- Fees for on-orbit activities are also acceptable and, consistent with previous answers, it is more desirable to pay for these activities on an individual basis rather than as one lump sum based on total time for the servicing.

SERVICING OPERATIONS AND REIMBURSEMENT OPTIONS (CONCLUDED)

	MANIFEST FEE	MISSION DESIGN	DOCUMENT PREPARATION	GROUND CREW TRAINING	FLIGHT CREW TRAINING	HARDWARE USAGE FEE	EXPENDABLES	LAUNCH COSTS	ON-ORBIT OPS (ACTIVITIES)	ON-ORBIT OPS (TIME)	SECURE DATA LINK	PAYLOAD RETURN	HARDWARE DEVELOPMENT COSTS
NASA			X	X	X						X		X
CUSTOMER	X	X				X	X	X	X	X		X	

SUMMARY

The results just presented were assembled from a survey which queried the user community about cost-related issues for on-orbit satellite servicing. This survey was split into three categories, covering: various general issues, hardware development and procurement, and finally, servicing operations and reimbursement options. Twenty-five responses were obtained from ten different commercial companies and from various organizations within the U.S. Air Force Space Division and Space Command. Several important conclusions were drawn from these responses, which were uniform across both the civilian and military groups. First, cost criteria were rated at least as important as or more important than knowing the engineering capabilities of servicing hardware. Second, no strong interest was shown in developing servicing hardware by either group unless it was unique to a specific mission. NASA was seen as responsible for developing and procuring generic servicing hardware. Third, a general perception existed among these participants that planning for on-orbit servicing will decline as a result of the Challenger accident. However, a need for at least one and possibly three servicing flights per year was still foreseen. Finally, a strong interest was shown in several features which could be incorporated into a future satellite servicing pricing policy which would be equitable from the users' perspective.

SUMMARY

- NON-NASA USER COMMUNITY HAS BEEN QUERIED ABOUT COST ISSUES RELATED TO SATELLITE SERVICING
- A SURVEY WAS USED TO GATHER THIS INFORMATION AND COVERED THREE BROAD CATEGORIES
  - GENERAL ISSUES
  - HARDWARE DEVELOPMENT AND PROCUREMENT
  - SERVICING OPERATIONS AND REIMBURSEMENT OPTIONS
- SEVERAL IMPORTANT RESULTS CAN BE SUMMARIZED
  - COST CRITERIA ARE AT LEAST AS IMPORTANT OR MORE IMPORTANT THAN KNQWLEDGE OF HARDWARE CAPABILITIES
  - NO STRONG INTEREST WAS SHOWN IN DEVELOPMENT OF HARDWARE UNLESS MISSION UNIQUE
  - PLANNING FOR SERVICING IS SEEN AS DECLINING DUE TO THE CHALLENGER ACCIDENT BUT SEVERAL SERVICING FLIGHTS PER YEAR ARE STILL ANTICIPATED
  - A STRONG INTEREST IN SEVERAL FEATURES WAS INDICATED WHICH COULD BE INCORPORATED INTO A FUTURE SERVICING PRICING POLICY

EQUITABLE PRICING POLICY FEATURES

The key features which the survey results indicated would be desirable in a future pricing policy can be summarized as follows:

(1) Costs for individual servicing activities would be published as a range of values for use in planning and to serve as a starting point for a final, negotiated mission cost.

(2) A high level of accountability was desired for the final mission cost (i.e., an itemized list of cost components broken down into as much detail as possible).

(3) The general elements of a servicing mission for which these participants felt NASA should be compensated include:

- Manifest Fee
- Expendables
- Payload Return
- Mission Design
- Launch Costs
- Hardware Usage
- On-Orbit Operations

(4) Launch slots on the STS manifest should be awarded on a first come - first served basis with allowances made for emergency situations.

(5) Mission costs should be paid in part before and the remainder at the conclusion of the servicing activity.

EQUITABLE PRICING POLICY FEATURES

- A STRONG INTEREST WAS SHOWN BY BOTH CIVILIAN AND MILITARY GROUPS IN THE FOLLOWING FEATURES
  - PUBLISH COSTS AS A RANGE OF VALUES
  - A HIGH LEVEL OF ACCOUNTABILITY FOR THE FINAL MISSION COST
  - MISSION ELEMENTS FOR WHICH NASA SHOULD BE COMPENSATED
    - MANIFEST FEE
    - EXPENDABLES
    - PAYLOAD RETURN
    - MISSION DESIGN
    - LAUNCH COSTS
    - HARDWARE USAGE
    - ON-ORBIT OPERATIONS
  - LAUNCH ON A FIRST COME - FIRST SERVED BASIS
  - MISSION COSTS PAID IN PART BEFORE AND THE REMAINDER AT COMPLETION OF SERVICING

RECOMMENDATIONS

Participation by both the civilian and military groups was generally enthusiastic, as indicated by the number and timeliness of the responses. This seems to indicate a willingness to discuss issues involved in a subject which is considered of great importance. NASA should establish and promote a means of continuing this dialogue to help reach a reasonable and equitable solution. In light of the Challenger accident, NASA needs to restate and clarify its position regarding satellite servicing from the present time through the Space Station IOC to permit adequate planning and preparations. Related to this, NASA must further refine its requirements and policies regarding satellite servicing at the Space Station so that an appropriate transition from STS-based servicing to Space Station-based servicing can be made.

RECOMMENDATIONS

- ESTABLISH AND PROMOTE A MEANS OF CONTINUING THE DIALOGUE REGARDING SERVICING COST CRITERIA
  - WILL HELP REACH A REASONABLE AND EQUITABLE SOLUTION
- RESTATE AND CLARIFY THE NASA POSITION ON SATELLITE SERVICING IN LIGHT OF THE CHALLENGER ACCIDENT
- REFINE REQUIREMENTS AND POLICIES FOR SPACE STATION-BASED SATELLITE SERVICING
  - WILL ALLOW FOR AN APPROPRIATE TRANSITION FROM STS-BASED SERVICING

TASK 2

STS SATELLITE SERVICING DURING THE SPACE STATION ERA

INTRODUCTION

During the initial phase of this contract, a program plan for Space Transportation System (STS) satellite servicing hardware was formulated to meet identified requirements through 1995. This date was chosen because it corresponds roughly to the time when the Space Station would begin servicing satellites, thus introducing a new variable into STS program planning. At the conclusion of that effort, a recommendation was made to examine the post-1995 time period for on-orbit servicing requirements and evaluate the servicing role of the STS during this era. The emphasis of this new task was to be placed on the type and quantity of servicing to be provided by the STS. Hardware identified during the first phase of this contract would then be compared with these new requirements to determine the level of compatibility and need for additional equipment. Because the Space Station is assumed to be the primary location for servicing vehicles with access to the Station, analyses done here focused on those missions with orbits that do not bring them within servicing range of the Space Station.

INTRODUCTION

- STS SATELLITE SERVICING DURING THE SPACE STATION ERA
  - THE OBJECTIVE OF THIS TASK WAS TO EXAMINE AND EVALUATE THE SERVICING ROLE OF THE SPACE TRANSPORTATION SYSTEM (STS) DURING THE SPACE STATION ERA
  - EMPHASIS WAS PLACED ON THE TYPE AND QUANTITY OF SERVICING TO BE PROVIDED
  - ANALYSES FOCUSED ON THOSE MISSIONS WITH ORBITS AND INCLINATIONS DIFFERENT FROM THE SPACE STATION

STUDY GROUND RULES AND CONSTRAINTS

To maintain a degree of commonality with the results from the first phase of this contract, this particular task examined only those servicing requirements which could be accomplished at the Shuttle. This implies that no large Orbital Transfer Vehicle (OTV) would be available to retrieve spacecraft from high-energy orbits. In addition, no servicing of Geosynchronous Earth Orbit (GEO) type vehicles was assumed, either _in situ_ (using a robotic servicer) or at the Shuttle (since no OTV is available). The Orbital Maneuvering Vehicle (OMV) was assumed to be available during this era, but as a transfer vehicle only. In this role the OMV would expand the range of orbits accessible to the STS, but again no robotic servicer would be available for _in situ_ servicing. As mentioned before, it was assumed that those spacecraft which could use the Space Station for servicing would choose to do so. However, there may still be opportunities for the STS in Space Station-compatible orbits. The exchange of a raw materials module for a finished products module at some unmanned or man-tended vehicle is but one example.

STUDY GROUND RULES AND CONSTRAINTS

- EXAMINE ONLY THOSE SERVICING REQUIREMENTS ADDRESSABLE BY THE STS
  - NO OTV AVAILABLE
  - NO GEO SERVICING
- OMV AVAILABLE TO EXPAND THE RANGE OF ORBITS ACCESSIBLE BY THE STS
- THOSE SPACECRAFT WHICH CAN USE THE SPACE STATION FOR SERVICING WILL DO SO

ANALYSIS PROCEDURE

A three-step process was used to meet the objective of this task. First, the mission model constructed for the pre-Space Station era was extended through the year 2010. This was accomplished by using existing data base models which extend into this time period and through the use of analytical projection techniques. Perhaps the best example of related data bases can be found in a study performed by SAIC for the Fairchild Space Company addressing on-orbit fluid resupply requirements. This was the most extensive study from which data were gathered to expand the existing SAIC mission model. The results from this study for Fairchild will be discussed in some detail on the next several pages to illustrate the process used by SAIC to account for other types of servicing missions and other vehicle types.

The second step was to determine the number and type of missions in this expanded data base which could be serviced at the Shuttle if an OMV were available for retrieval and deployment. This includes the possibility of multiple servicings on each STS flight by using the OMV to retrieve spacecraft with orbit inclinations and/or nodes different from the Shuttle.

Finally, hardware capabilities and/or specific hardware items necessary to service the vehicles accessible to the STS were identified. Wherever possible, previous reports and personal contacts, particularly those made during the first phase of this contract, were used to gather and correlate information for specific vehicles. This was an important factor in making the best possible estimate of servicing requirements through the year 2010.

ANALYSIS PROCEDURE

- THE TASK OBJECTIVE WAS MET THROUGH SEPARATE ANALYSES OF THE FOLLOWING TOPICS:

  - EXPANSION OF THE PREVIOUS SAIC MISSION MODEL INTO THE SPACE STATION ERA (APPROXIMATELY 10 TO 15 YEARS POST-IOC) USING EXISTING DATA BASE MODELS AND ANALYTICAL PROJECTION TECHNIQUES

  - DETERMINATION OF THE NUMBER AND TYPE OF MISSIONS WHICH CAN BE CAPTURED BY THE MODEL IF THE OMV IS USED FOR RETRIEVAL AND DEPLOYMENT

  - EXAMINATION OF THE POTENTIAL FOR MULTIPLE SERVICINGS PER STS SORTIE USING THE OMV FOR RETRIEVAL OF SPACECRAFT WITH DIFFERENT ORBIT INCLINATIONS AND/OR NODES

  - IDENTIFICATION OF HARDWARE CAPABILITIES AND/OR SPECIFIC HARDWARE ITEMS REQUIRED TO CARRY OUT THE SERVICING MISSIONS IDENTIFIED

- WHEREVER POSSIBLE, PREVIOUS REPORTS AND PERSONAL CONTACTS WERE USED TO GATHER AND CORRELATE INFORMATION FOR SPECIFIC VEHICLES

ANALYSIS PROCEDURE (concluded)

Due to the extended period of time under consideration for satellite servicing, and the uncertainty this introduces into any analysis, development of a single projection of the number of future servicing missions would be inappropriate. Thus, a high activity model/low activity model approach was used to capture the range of possible growth patterns. Where a general class of vehicle was included in this model (a materials processing satellite is one example) a representative spacecraft and a mission profile were developed to permit servicing requirements to be estimated. The following section discusses in more detail the content of this expanded data base. However, a summary of the vehicle types which were examined includes:

- Earth Observation (8/8)
- Scientific Observation (7/6)
- Materials Processing (7/4)
- Planetary (5/5)
- Other (8/6)

The values in parentheses indicate the number of individual spacecraft from the high and low models, respectively.

ANALYSIS PROCEDURE (CONCLUDED)

- DEVELOPMENT OF A SINGLE PROJECTION WOULD BE INAPPROPRIATE FOR THE TIME PERIOD UNDER CONSIDERATION
- A HIGH ACTIVITY MODEL/LOW ACTIVITY MODEL APPROACH WAS USED HERE TO CAPTURE THE RANGE OF POSSIBILITIES
- WHERE A GENERAL CLASS OF VEHICLE WAS INCLUDED, A REPRESENTATIVE SPACECRAFT AND A MISSION PROFILE WERE DEVELOPED TO PERMIT SERVICING REQUIREMENTS TO BE ESTIMATED
- VEHICLE TYPES EXAMINED (HIGH/LOW)
    - EARTH OBSERVATION (8/8)
    - SCIENTIFIC OBSERVATION (7/6)
    - MATERIALS PROCESSING (7/4)
    - PLANETARY (5/5)
    - OTHER (8/6)

REVIEW OF ON-ORBIT FLUIDS RESUPPLY SURVEY*

The purpose of this study was to estimate the on-orbit fluids resupply demand for spacecraft operating during the period 1990 through 2010.

The scope of this demand study includes all fluid types, with a focus on Earth-storable fluids. Potential users of this fluids resupply service are limited to spacecraft either in Space Shuttle-compatible orbits or in Orbital Maneuvering Vehicle (OMV)-compatible orbits with the OMV operated in a retrieve/deploy mode or a tanker mode. Results of this study may best be used to assess trends of overall need and to formulate design options, rather than to identify the portion of fluids resupply demand captured by a particular system.

* This work was performed for Fairchild Space Company under contract SC00075 with results summarized in report number SAIC-86/1047.

REVIEW OF ON-ORBIT FLUIDS RESUPPLY SURVEY*

- THE PURPOSE OF THIS STUDY WAS TO ESTIMATE THE ON-ORBIT FLUID RESUPPLY DEMAND DURING THE PERIOD 1990 THROUGH 2010

- THE SCOPE FOR THIS DEMAND STUDY INCLUDES:

  - ALL FLUID TYPES, WITH A FOCUS ON EARTH-STORABLE FLUIDS
  - FLUID RESUPPLY LIMITED TO
    - SPACE SHUTTLE-COMPATIBLE ORBITS
    - OMV-COMPATIBLE ORBITS WITH THE OMV USED IN A RETRIEVE/DEPLOY OR TANKER MODE
  - ASSESSMENT OF OVERALL NEED, NOT THE PORTION OF THIS DEMAND CAPTURED BY A PARTICULAR SYSTEM

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* THIS WORK WAS PERFORMED FOR FAIRCHILD SPACE COMPANY UNDER CONTRACT SC00075 WITH RESULTS SUMMARIZED IN REPORT NUMBER SAIC-86/1047.

MISSION MODEL PROJECTION*

Due to the time period addressed in this analysis and the indefinite nature of specific events in that period, it would be inappropriate to develop a single projection of fluid resupply demand for the time period studied. This approach was replaced by a high activity model/low activity model approach which was used to represent the range of possible events.

Wherever possible, previous reports and personal contacts were used to gather and correlate information for specific vehicles for inclusion in both the high model and the low model. For the most distant portion of the time period under consideration (where the need for a general class of vehicle, such as a materials processing spacecraft, was predicted) representative spacecraft and mission profiles were developed to permit approximate estimates of fluid usage.

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* This work was performed for Fairchild Space Company under contract SC00075 with results summarized in report number SAIC-86/1047.

MISSION MODEL PROJECTION*

- DEVELOPMENT OF A SINGLE PROJECTION WOULD BE INAPPROPRIATE FOR THE TIME PERIOD UNDER CONSIDERATION

- A HIGH ACTIVITY MODEL/LOW ACTIVITY MODEL APPROACH WAS USED HERE TO CAPTURE THE RANGE OF POSSIBILITIES

- WHEREVER POSSIBLE, PREVIOUS REPORTS AND PERSONAL CONTACTS WERE USED TO GATHER AND CORRELATE INFORMATION FOR SPECIFIC VEHICLES

- WHERE A GENERAL CLASS OF VEHICLE WAS INCLUDED, A REPRESENTATIVE SPACECRAFT AND A MISSION PROFILE WERE DEVELOPED TO PERMIT FLUID USAGE TO BE ESTIMATED

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* THIS WORK WAS PERFORMED FOR FAIRCHILD SPACE COMPANY UNDER CONTRACT SC00075 WITH RESULTS SUMMARIZED IN REPORT NUMBER SAIC-86/1047.

ASSUMED IOC DATES FOR MAJOR SYSTEMS*

Several types of assumptions were required to complete the high model and low model data bases. These assumptions included:

1. Initial operational capability (IOC) date;
2. On-orbit operation strategy such as how and where the resupply rendezvous will occur and the frequency of resupply activity;
3. Vehicle characteristics related to fluid type(s) and spacecraft life; and
4. Space Transportation System (STS), Orbital Transfer Vehicle (OTV), and OMV usage requirements and sortie rates.

The figure on the facing page illustrates the assumed IOC dates for several of the major systems included in both data bases. While the high model assumes a rapid growth in space activities, especially in materials processing, the low model assumes a more conservative but steady increase in space activities. Systems with more than one date marked, such as Space Industries, Inc. (SII), are represented in this manner to show when replacement vehicles become operational.

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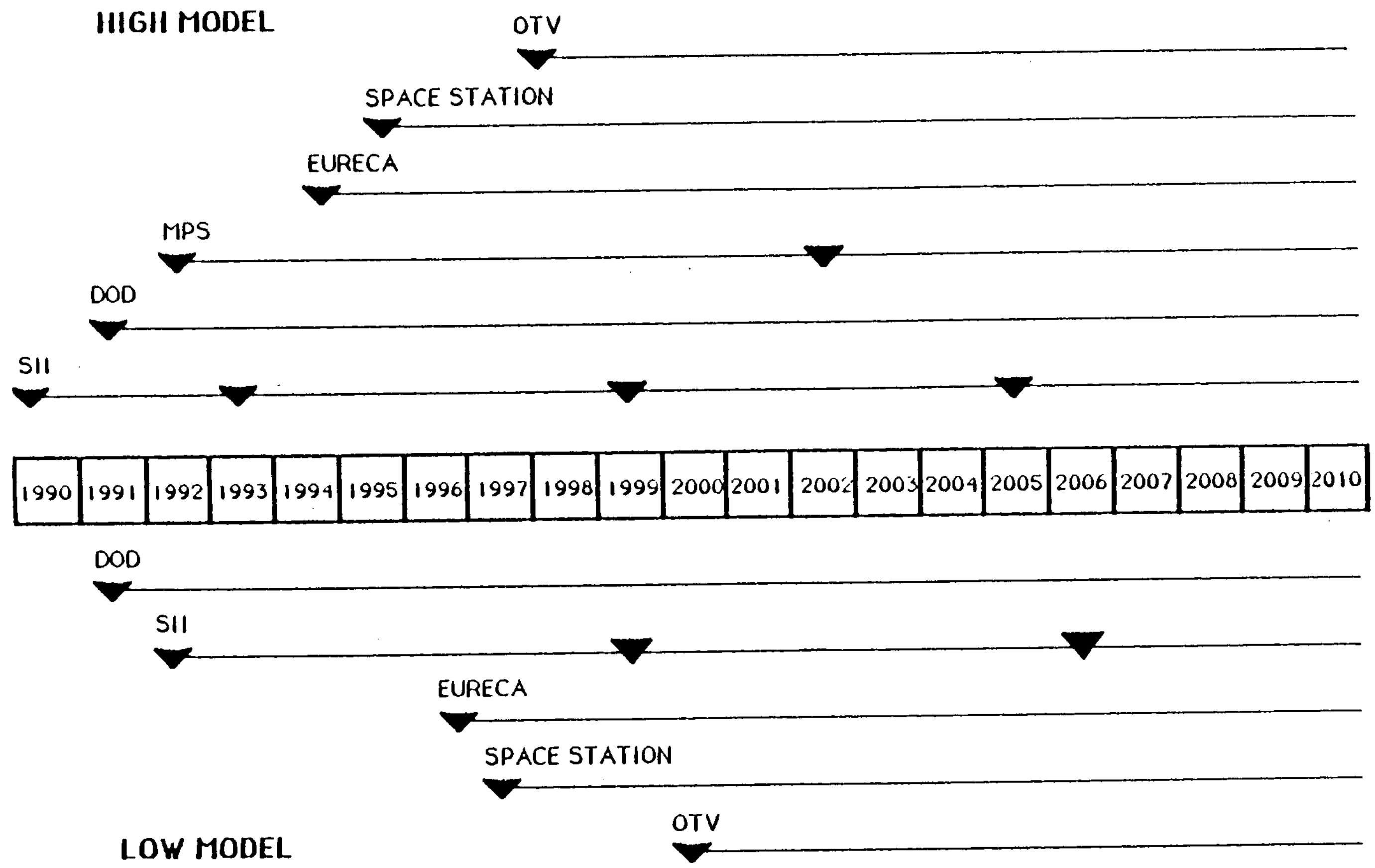
* This work was performed for Fairchild Space Company under contract SC00075 with results summarized in report number SAIC-86/1047.

ASSUMED IOC DATES FOR MAJOR SYSTEMS*



* THIS WORK WAS PERFORMED FOR FAIRCHILD SPACE COMPANY UNDER CONTRACT SC00075 WITH RESULTS SUMMARIZED IN REPORT NUMBER SAIC-86/1047.

DATA BASE STATISTICS - USERS*

Six general user categories were identified among the potential users of an on-orbit resupply system. These user categories are:

1. Scientific observatories
2. Polar orbiting Earth observation satellites (atmosphere, land, and ocean)
3. Unmanned and man-tended materials processing satellites
4. Low-Earth orbit DoD satellites
5. Space Station
6. Transportation system elements (OTV, OMV).

Within these six categories, 61 unique vehicles are included. However, several of these consist of multiple copies of the same vehicle where multiple vehicle constellations were required or where the nominal lifetime of a spacecraft had been exceeded. Over the 20-year time period, the high model contains 406 resupply events while the low model has 301 resupply events. A resupply event occurs each time fluids are transferred to a spacecraft. Therefore, one Space Shuttle resupply mission could provide several resupply events.

* This work was performed for Fairchild Space Company under contract SC00075 with results summarized in report number SAIC-86/1047.

DATA BASE STATISTICS - USERS*

- SIX GENERAL USER CATEGORIES HAVE BEEN IDENTIFIED:
  - SCIENTIFIC OBSERVATORIES
  - POLAR ORBITING EARTH OBSERVATION SATELLITES (ATMOSPHERIC, LAND, AND OCEAN)
  - UNMANNED AND MAN-TENDED MATERIALS PROCESSING SATELLITES
  - LOW-EARTH ORBIT DoD SATELLITES
  - SPACE STATION
  - TRANSPORTATION SYSTEM ELEMENTS (OTV, OMV)
- 61 UNIQUE VEHICLES ARE INCLUDED BUT SEVERAL CONSIST OF MULTIPLE COPIES OF THE SAME VEHICLE
- OVER THE 20-YEAR TIME PERIOD, THE HIGH MODEL CONTAINS 406 RESUPPLY EVENTS WHILE THE LOW MODEL CONTAINS 301

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* THIS WORK WAS PERFORMED FOR FAIRCHILD SPACE COMPANY UNDER CONTRACT SC00075 WITH RESULTS SUMMARIZED IN REPORT NUMBER SAIC-86/1047.

DATA BASE STATISTICS - FLUID TYPES*

A total of 16 fluid types were identified as necessary for various resupply events. These fluids are (in alphabetical order):

1. Aerozine-50 (MMH/N_2O_4)
2. Ammonia (NH_4)
3. Argon (gas)
4. Carbon Dioxide (gas)
5. Helium (gas)
6. Helium (liquid)
7. Helium (superfluid)
8. Hydrazine (N_2H_4)
9. Hydrogen (liquid)
10. Monomethylhydrazine (MMH)
11. Nitrogen (gas)
12. Nitrogen Tetroxide (N_2O_4)
13. Oxygen (gas)
14. Oxygen (liquid)
15. Water (H_2O)
16. Xenon

Space Station IOC operations require resupply of 13 of these fluids, more fluid types than any other system.

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DATA BASE STATISTICS - FLUID TYPES*

- 16 FLUID TYPES IDENTIFIED
  - AEROZINE-50 (MMH/N_2O_4)
  - AMMONIA (NH_4)
  - ARGON (GAS)
  - CARBON DIOXIDE (GAS)
  - HELIUM (GAS)
  - HELIUM (LIQUID)
  - HELIUM (SUPERFLUID)
  - HYDRAZINE (N_2H_4)
  - HYDROGEN (LIQUID)
  - MONOMETHYLHYDRAZINE (MMH)
  - NITROGEN (GAS)
  - NITROGEN TETROXIDE (N_2O_4)
  - OXYGEN (GAS)
  - OXYGEN (LIQUID)
  - WATER (H_2O)
  - XENON

* THIS WORK WAS PERFORMED FOR FAIRCHILD SPACE COMPANY UNDER CONTRACT SC00075 WITH RESULTS SUMMARIZED IN REPORT NUMBER SAIC-86/1047.

ON-ORBIT FLUIDS RESUPPLY SURVEY SUMMARY AND CONCLUSIONS*

In completing this survey study SAIC developed an on-orbit fluids resupply model to cover the 1990 through 2010 time period. This model consists of a high model (with 406 events) and a low model (with 301 events) which cover the range of possibilities for this period of time.

Most missions after 1995 in this model are speculative and dependent on assumptions due to a lack of committed on-orbit servicing users. Although the user community assumes that they will have access to on-orbit servicing in general, and fluid resupply in particular, most users are unwilling to be the first to commit to systems requiring on-orbit fluids resupply. Therefore, any on-orbit fluid resupply system will drive future demand for such a service as well as be driven by it.

Studies in progress which may be used to update the results of this model include:

1. Current Space Station studies (NASA)
2. National Space Transportation Architecture Study (NASA & DoD)
3. Space Assembly, Maintenance, and Servicing (USAF).

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* This work was performed for Fairchild Space Company under contract SC00075 with results summarized in report number SAIC-86/1047.

ON-ORBIT FLUIDS RESUPPLY SURVEY SUMMARY AND CONCLUSIONS*

- MOST MISSIONS BEYOND 1995 IN THIS MODEL ARE SPECULATIVE AND DEPENDENT ON ASSUMPTIONS DUE TO LACK OF COMMITTED USERS
- A SERVICING CAPABILITY IN GENERAL, AND FLUID RESUPPLY IN PARTICULAR, ARE USUALLY ASSUMED BY THE USER COMMUNITY BUT MOST ARE UNWILLING TO BE THE FIRST TO COMMIT
- THUS, ANY ON-ORBIT FLUID RESUPPLY SYSTEM WILL DRIVE FUTURE DEMAND FOR SUCH A SERVICE AS WELL AS BE DRIVEN BY IT
- SEVERAL STUDIES UNDER WAY WHICH MAY BE USED TO UPDATE THE RESULTS PRESENTED IN THIS MODEL:
  - CURRENT SPACE STATION STUDIES (NASA)
  - NATIONAL SPACE TRANSPORTATION ARCHITECTURE STUDY (NASA & DoD)
  - SPACE ASSEMBLY, MAINTENANCE, AND SERVICING (USAF)

* THIS WORK WAS PERFORMED FOR FAIRCHILD SPACE COMPANY UNDER CONTRACT SC00075 WITH RESULTS SUMMARIZED IN REPORT NUMBER SAIC-86/1047.

DATA BASE MODIFICATION AND EXPANSION

Lessons learned from the fluids resupply effort described in the preceding pages were applied to this task. The data base used here was expanded in scope from a fluid-specific model to a general servicing model. As a result of the ground rules discussed, any entries related to servicing at the Space Station were not included. In addition, the prediction capabilities developed for the fluid resupply study were refined to allow improvements to be made for the data base used in this task and to allow for expansion into other categories of servicing.

DATA BASE MODIFICATION AND EXPANSION

- THE CURRENT DATA BASE WAS CHANGED FROM A FLUID-SPECIFIC MODEL TO A GENERAL SERVICING MODEL

- ALL ENTRIES RELATED TO SPACE STATION-BASED SERVICING WERE EXCLUDED

- CURRENT PREDICTION CAPABILITIES WERE REFINED TO ALLOW IMPROVEMENTS TO BE MADE FOR THE PRESENT DATA BASE AND TO ALLOW FOR EXPANSION INTO OTHER CATEGORIES OF SERVICING

THE STATISTICAL APPROACH

One approach to forecasting future satellite servicing requirements is to create a mission model from the bottom up; i.e., the data for discrete payloads are summed to generate an overall demand model. One example of this type of model is the Battelle Outside User's Payload Model (OUPM). A different approach is to forecast future demand based upon a statistical analysis of historical data. We have chosen to perform an analysis of the second type to complement existing forecasts in the open literature (such as the Battelle OUPM). The results of this statistical analysis are presented here.

Plotted in the figure on the facing page is a time series of the cumulative number of communication satellites launched since the beginning of the Space Age.* Communication satellites were chosen for this analysis since they represent, as a category, the single largest sample of historical data points. As is evident in the figure, the data are trending upward, with a steep increase in the past three years. This ramp-up corresponds to the time period when Shuttle began deploying multiple satellites per mission.

Statistical modeling of historic data for forecasting purposes has been used quite successfully for a variety of applications in a wide range of disciplines. However, it should be noted that models based solely upon historical data will not include any current economic or other market factors. If the sample size is large enough, underlying past economic factors will be inherent in the historical data. However, specific to the example at hand, modeling historical data may not accurately account for increased satellite lifetime, increased number of transponders/channels per satellite, or previously unexperienced point upsets such as the recent Shuttle tragedy.

Nevertheless, a combination trend line/autoregressive model provides a reasonable fit to the data, and can be used with confidence to predict a value for 1986. Since the model is a first-order autoregressive model ($x_t = f(x_{t-1})$), it is applicable for one-step-ahead prediction only.

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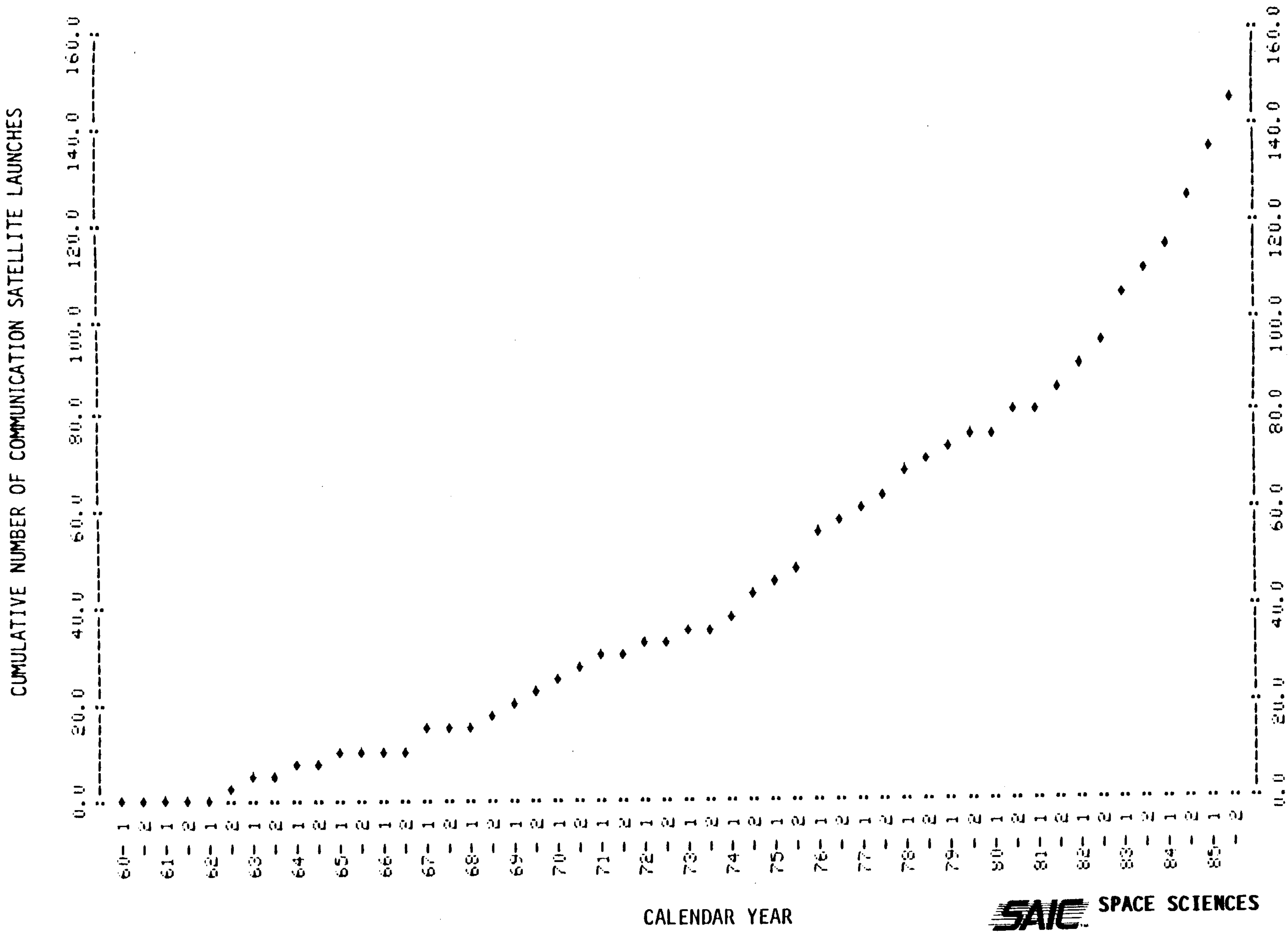
* The data include all known NASA, commercial, DoD, and foreign non-Soviet bloc satellites. The data include all launches, even those that failed to reach orbit.

CUMULATIVE NUMBER OF COMMUNICATION SATELLITES LAUNCHED SINCE 1960



SAIC SPACE SCIENCES

ESTIMATES OF FUTURE VALUES*

Since the preceding model is applicable for one-step-ahead prediction only, forecasting a launch demand for communication satellites through the year 2010 will require another model. On the facing page is a sequence plot of the number of communication satellites launched per year since 1960. (Technically, these are the first differences from the time series on the previous page.) Note that this series is trending upward and that there is also a wave-like pattern in the data. A linear trend line and a quadratic trend line have been fit to the data using ordinary least-squares as shown in the figure. The data point for 1985 (22 launches) is over three standard deviations from the mean of the linear fit. Whether this point is an outlier to the linear fit, or the data are best modeled by a quadratic trend is open to speculation.

This series can be modeled as a random walk with an upward drift of 0.9. This means that the best guess for 1986 is simply the value for 1985 (22) plus 0.9. The point estimate for 1986 using the model generated based upon the data in the preceding figure is 167 (total cumulative launches), which translates to 23 launches also.

The random walk representation of these data is also not sufficient for forecasting to the year 2010. Further analysis of these data is recommended; specifically, an attempt should be made to understand the underlying cause of the wave-like distribution of data points. Given the analysis completed to date, a conservative estimate for communication satellite launches per year would simply be the linear trend $\pm$ two standard deviations, and the quadratic trend will not be considered further.

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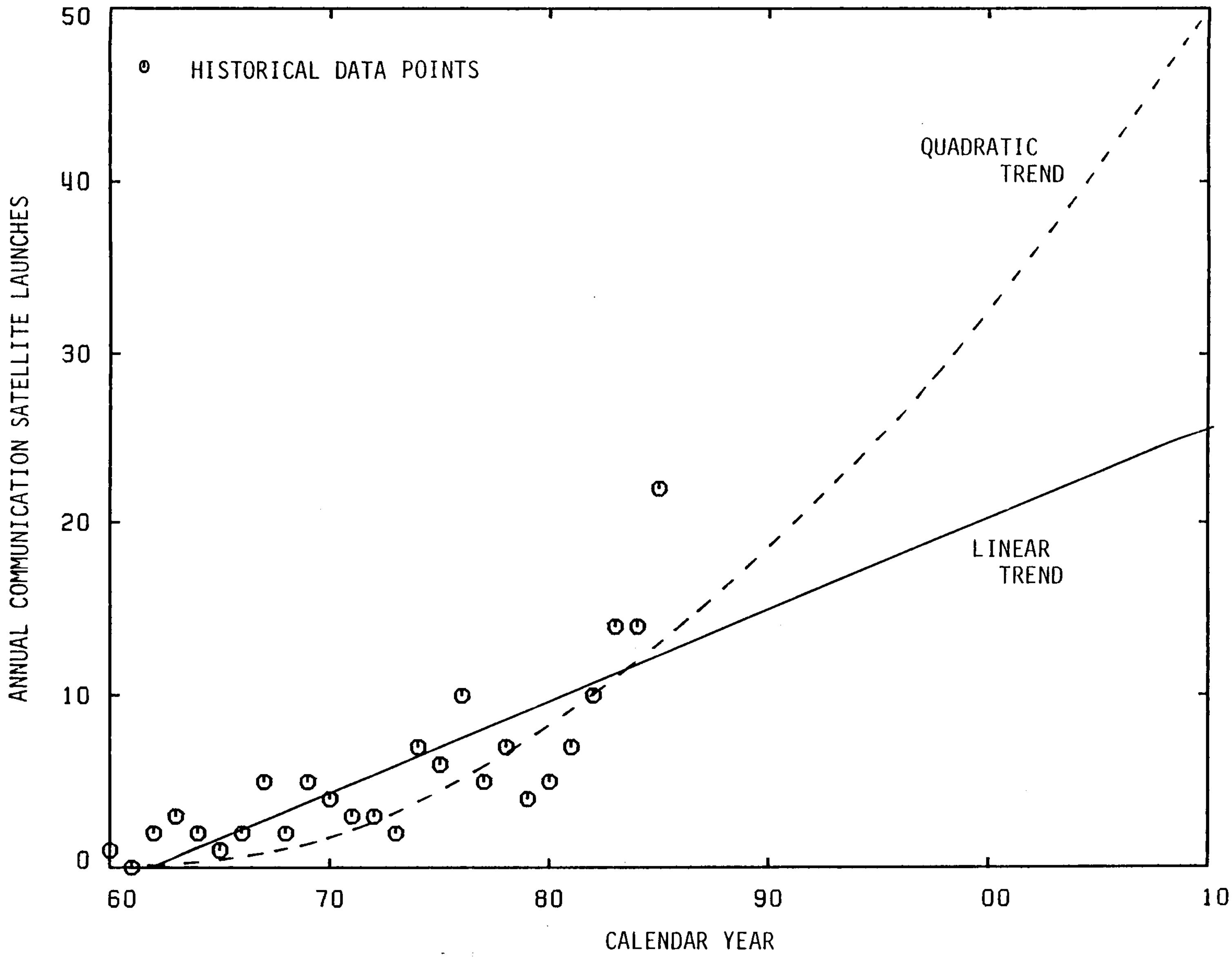
* This work was performed for Fairchild Space Company under contract SC00075 with results summarized in report number SAIC-86/1047.

HISTORICAL RECORD OF THE NUMBER OF COMMUNICATION SATELLITES LAUNCHED PER YEAR SINCE 1960



* THIS WORK WAS PERFORMED FOR FAIRCHILD SPACE COMPANY UNDER CONTRACT SC00075 WITH RESULTS SUMMARIZED IN REPORT NUMBER SAIC-86/1047.

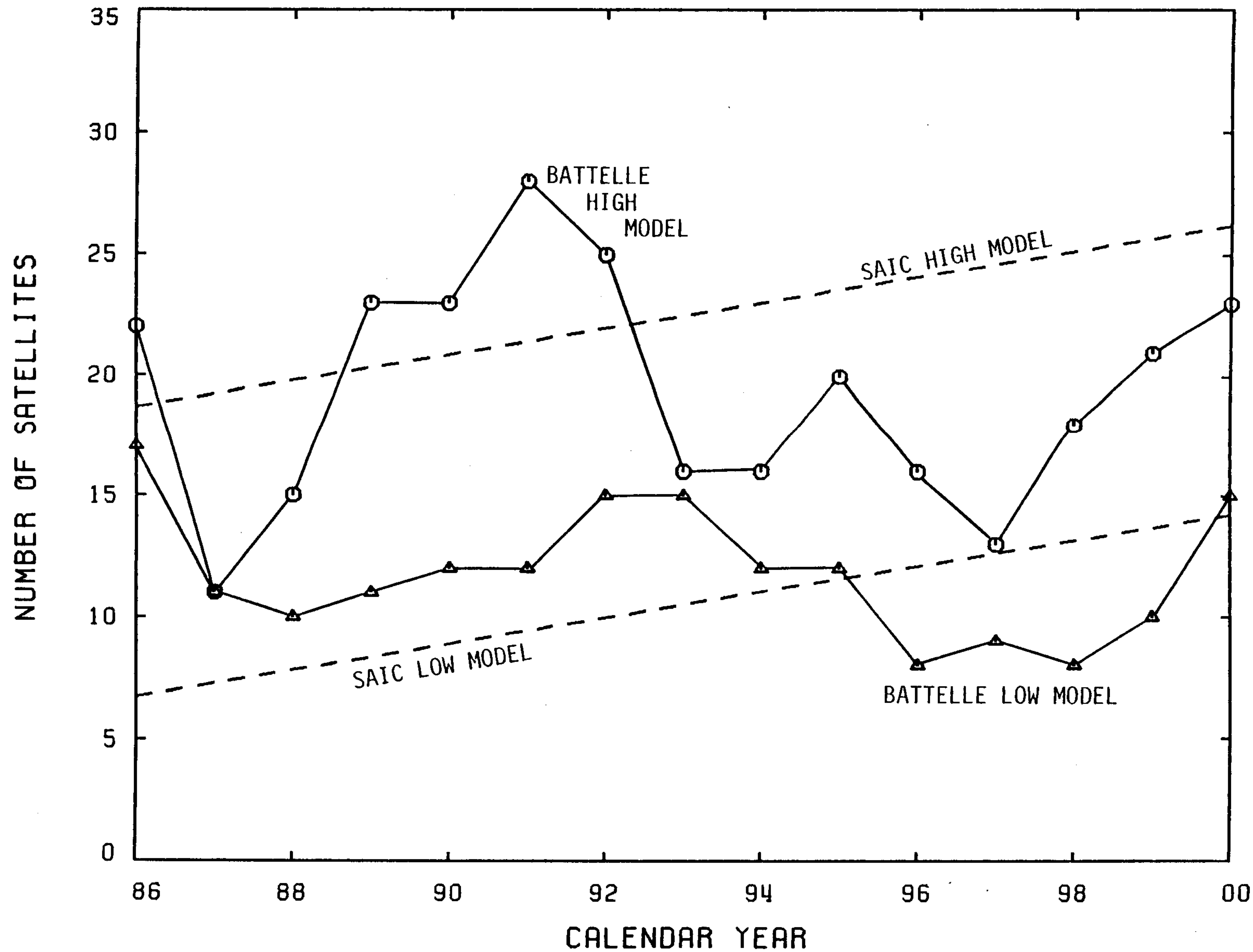
COMPARISON OF SAIC PRELIMINARY MODEL TO BATTELLE OUPM FORECAST

The SAIC model for forecasting future yearly communication satellite launches, a simple linear fit of historical data $\pm$ two standard deviations, is shown on the facing page. To determine whether this model would be valid for predicting future traffic, a comparison of the SAIC model to two existing models in the literature was performed. The results of these comparisons are presented in the following two figures.

On the facing page is shown the comparison of the SAIC statistical model to the bottom-up projection of the Battelle OUPM. It is clear that the SAIC model generally captures the Battelle information, but the trend in the Battelle data shows a lower rate of increase over time. For the purposes of this study*, the SAIC model was retained as representative and was used to generate propellant requirements for a space-borne OTV.

* This work was performed for Fairchild Space Company under contract SC00075 with results summarized in report number SAIC-86/1047.

COMPARISON OF SAIC PRELIMINARY MODEL AND BATTELLE'S OUTSIDE USERS PAYLOAD MODEL FORECAST OF COMMUNICATION SATELLITES FLOWN PER YEAR THROUGH 2000



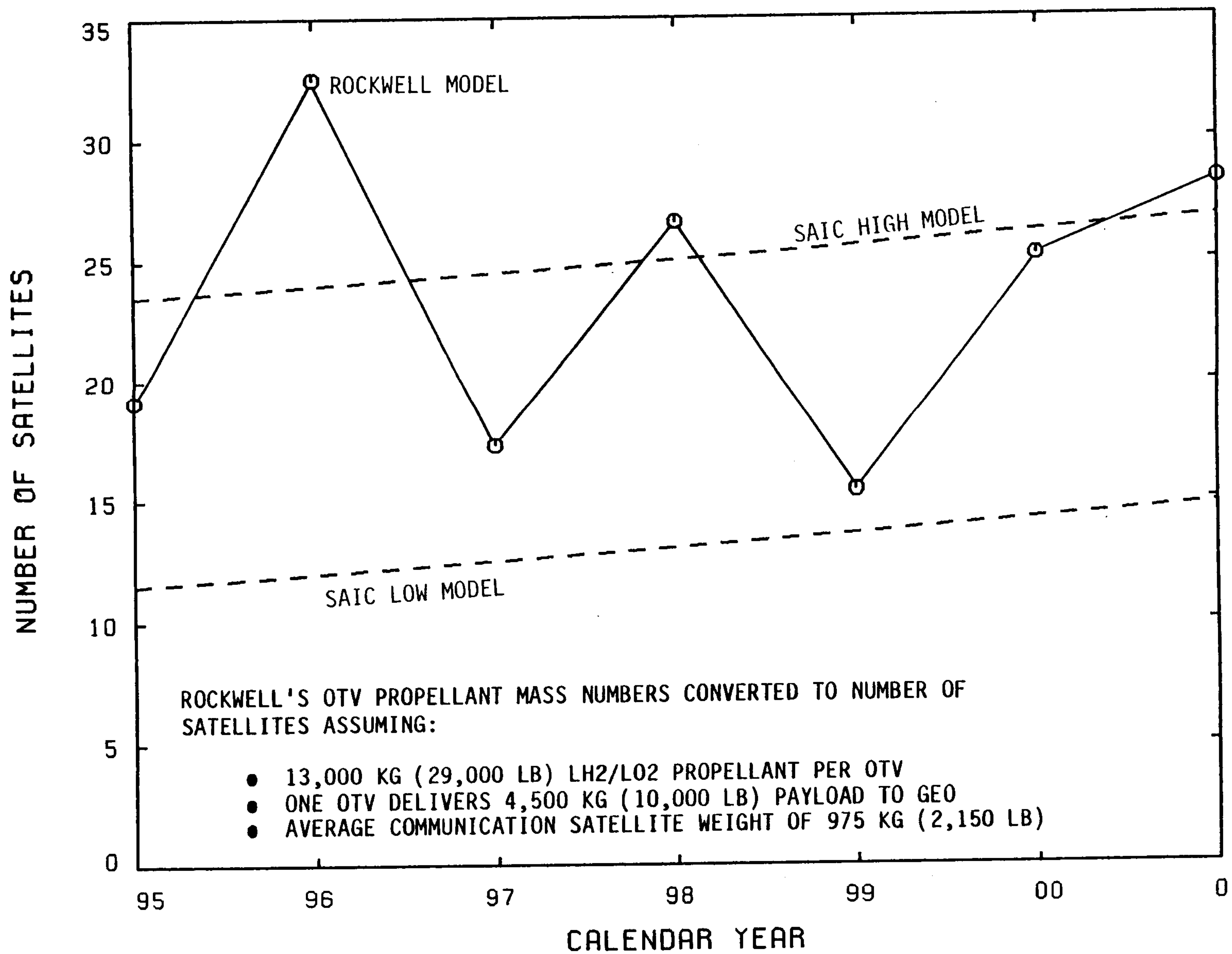
* THIS WORK WAS PERFORMED FOR FAIRCHILD SPACE COMPANY UNDER CONTRACT SC00075 WITH RESULTS SUMMARIZED IN REPORT NUMBER SAIC-86/1047.

COMPARISON OF SAIC MODEL WITH ROCKWELL DATA

To further validate the SAIC model for forecasting future yearly communication satellite launches, a comparison of the SAIC forecasts was made against data from the Rockwell Space Platform Expendable Resupply Supplemental Study. The Rockwell study estimated propellant usage rates through the year 2001. Their OTV LO2/LH2 forecasts were converted to number of satellites by assuming 13,000 kg (29,000 pounds) LO2/LH2 propellant per OTV; one OTV delivers 4,500 kg (10,000 pounds) payload to GEO; and an average communication satellite weight of 975 kg (2,150 pounds). The vehicle data for the OTV were derived from NASA/Marshall Space Flight Center information, and the average satellite weight was calculated from the Batelle OUPM.

As shown in the figure on the facing page, the SAIC model generally captures the Rockwell information. These two comparisons gave us confidence that the statistical approach to forecasting future satellite servicing requirements was a promising tool. However, these tests were performed only on the communication satellite category, and future refinement is necessary before implementing the procedure on LEO spacecraft categories.

COMPARISON OF SAIC'S PRELIMINARY MODEL AND ROCKWELL'S SPACE PLATFORM EXPENDABLE RESUPPLY SUPPLEMENTAL STUDY FORECAST OF COMMUNICATION SATELLITES LAUNCHED PER YEAR THROUGH 2001



OTHER CONSIDERATIONS AFFECTING PREDICTION CAPABILITY

Several of the predicted servicing demand requirements used in this study were based on assumptions regarding the growth in several market areas. For far-term predictions these assumptions are probably adequate due to the uncertainty inovlved in long range forecasts. However, in the near term (i.e., approximately 10 years into the future) specific market growth requires an identified need and low technical risk for commercial companies to make any sort of substantial investment. Examples where these market criteria have been met include those targeted by Arianespace and Spacehab, Inc. Both have focused on markets with a proven demand (launch of communications satellites and small, STS mid-deck locker-sized experiments) and use technology developed by other programs (expendable launch vehicle technology with a 20-30 year experience base and Spacelab module technology). Juxtaposed onto this is the Leasecraft program. This is one example of a concept which provided a capability for which there was as yet no well-established, identifiable market.

OTHER CONSIDERATIONS AFFECTING PREDICTION CAPABILITY

- NEAR-TERM GROWTH OR NEW PRODUCT START-UP REQUIRES AN IDENTIFIED NEED AND LOW TECHNICAL RISK

- EXAMPLE OF SUCCESSES OR POTENTIAL SUCCESSES WHICH MEET THESE CRITERIA INCLUDE:
  - ARIANESPACE
  - SPACEHAB, INC.

- LEASECRAFT IS ONE EXAMPLE OF A CONCEPT WHICH PROVIDED A CAPABILITY FOR WHICH THERE WAS AS YET NO WELL-ESTABLISHED, IDENTIFIABLE MARKET

OTHER CONSIDERATIONS AFFECTING PREDICTION CAPABILITY (continued)

Any growth of space-based ventures in the far term (i.e., post-1995) and the development of completely new markets will require an extended period of basic research and/or a firm commitment decision by the leadership of the organization involved. This generally requires extensive financial resources and the capability to sustain long-term research and development programs which may have no financial payback for 10 to 15 years. Currently the only United States organizations which possess these capabilities are the Federal government, universities (to a limited degree), and Fortune 500 companies. McDonnell Douglas and 3M are two examples of corporations willing to make this investment. On the other hand, the venture capital market is probably not a good source for the funds needed for this kind of activity. Space-related products and services are competing against other Earth-based projects with lower investment costs, lower technical risk, and shorter return-on-investment times. This concludes the discussion of mission model development for use in this task. The ability of the OMV to capture some fraction of these missions, which may have been otherwise inaccessible, must now be determined. The next section will discuss the results of an analysis addressing this question.

OTHER CONSIDERATIONS AFFECTING PREDICTION CAPABILITY (CONTINUED)

- FAR-TERM GROWTH AND COMPLETELY NEW MARKETS WILL REQUIRE AN EXTENDED PERIOD OF BASIC RESEARCH AND/OR A COMMITMENT DECISION BY THE ORGANIZATION LEADERSHIP

- THIS GENERALLY REQUIRES EXTENSIVE FINANCIAL RESOURCES AND THE CAPABILITY TO SUSTAIN A LONG-TERM RESEARCH AND DEVELOPMENT PROGRAM. FOR EXAMPLE,
  - U.S. GOVERNMENT
  - FORTUNE 500 COMPANIES (McDONNELL DOUGLAS, 3M, ETC.)

- THE VENTURE CAPITAL MARKET IS PROBABLY NOT A GOOD SOURCE FOR FUNDING
  - NEW PROJECTS ARE COMPETING AGAINST OTHER PROJECTS WITH LOWER INVESTMENT COST ($3-5M VERSUS $10-20M), LOWER TECHNICAL RISK, AND SHORTER RETURN-ON-INVESTMENT TIME (5 YEARS VERSUS 10-12 YEARS)

OMV CAPABILITY

The Office of Space Flight's OMV is a reusable, remotely controlled, free-flying vehicle capable of performing a wide range of on-orbit services in support of orbiting spacecraft. It is projected to be an important element of the Space Transportation System (STS), designed to operate from either the Shuttle or the Space Station.

The multiple propulsion systems and on-board avionics enable the OMV to economically deliver and retrieve satellites at orbits not otherwise accessible. Precision maneuvering for proximity operations, including docking with an orbiting satellite, is accomplished by man-in-the-loop control of the OMV control station. Limited resources are available for payloads while attached to the OMV, and more extensive services can be considered on a case-by-case basis.

Initial operational capability for the OMV is projected for the 1991 time frame. Delivery and retrieval of payloads at orbits considerably higher than the nominal orbits of the Shuttle and the Space Station will be routine services offered by the operational OMV. The broad spectrum of OMV LEO mission applications offers an expanded range of capability for STS servicing missions, including the number of single, and possibly multiple, vehicles which can be serviced during a single STS mission. One of the more demanding missions for the OMV is the retrieval of a large observatory-class payload for servicing at the Shuttle or Space Station and its return to the same or higher orbit.

OMV CAPABILITY

- THE OMV OFFERS AN EXPANDED RANGE OF CAPABILITY TO THE STS FOR RETRIEVAL AND DEPLOYMENT, ESPECIALLY IN POLAR ORBIT

- THIS INCREASES THE NUMBER OF SINGLE, AND POSSIBLY MULTIPLE, VEHICLES WHICH CAN BE SERVICED DURING A SINGLE STS MISSION

- OMV CHARACTERISTICS (MSFC DATA; DEC. 1985)

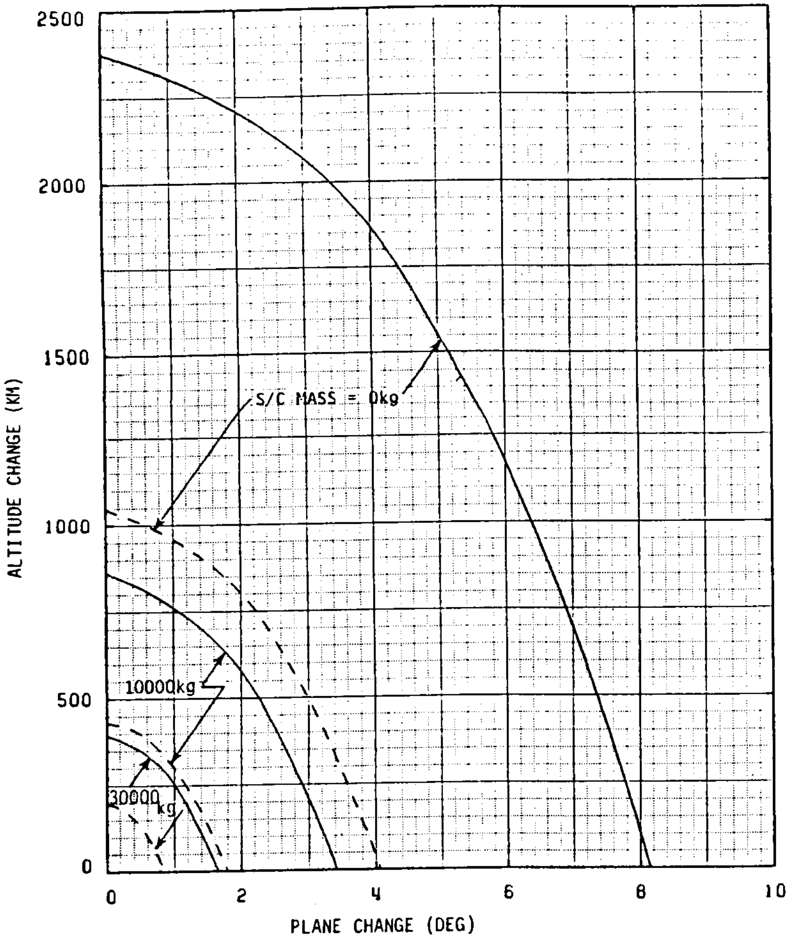
  - DRY MASS = 2,631 KG
  - MAXIMUM PROPELLANT MASS = 3,175 KG
  - I_{SP} = 285 SEC

OMV RETRIEVE AND DEPLOY CAPABILITY

OMV performance in retrieving and deploying payloads, as a function of plane change and altitude change capability, is summarized in the contours displayed on the facing page. The performance stated assumes the STS is in a 200 km altitude circular orbit. The scenario begins with OMV departure from the Space Shuttle, followed by rendezvous with the payload, return of the payload to the Shuttle for servicing, subsequent redeployment by the OMV to the payload's operational orbit, and finally, return of the OMV to the Space Shuttle. The performance contours correspond to spacecraft payload masses of 0 kg, 10,000 kg, and 30,000 kg. The performance for each case is also shown with and without intermediate refueling at the Space Shuttle.

Note the rapid fall-off in performance in both payload and altitude capability as the plane change requirement increases. For example, the OMV can retrieve and deploy a 10,000 kg spacecraft to a Δ altitude of 850 km if no plane change is required. However, the Δ altitude decreases to less than 250 km if a modest plane change of only 3 degrees is required.

OMV RETRIEVE AND DEPLOY CAPABILITY



——— RETRIEVE AND DEPLOY SPACECRAFT **WITH** INTERMEDIATE REFUELING AT THE SPACE SHUTTLE

- - - - - - RETRIEVE AND DEPLOY SPACECRAFT **WITHOUT** INTERMEDIATE REFUELING AT THE SPACE SHUTTLE

* OMV DRY MASS = 2,631 KG

OMV PROPELLANT CAPACITY = 3,175 KG

OMV I_{SP} = 285 SEC

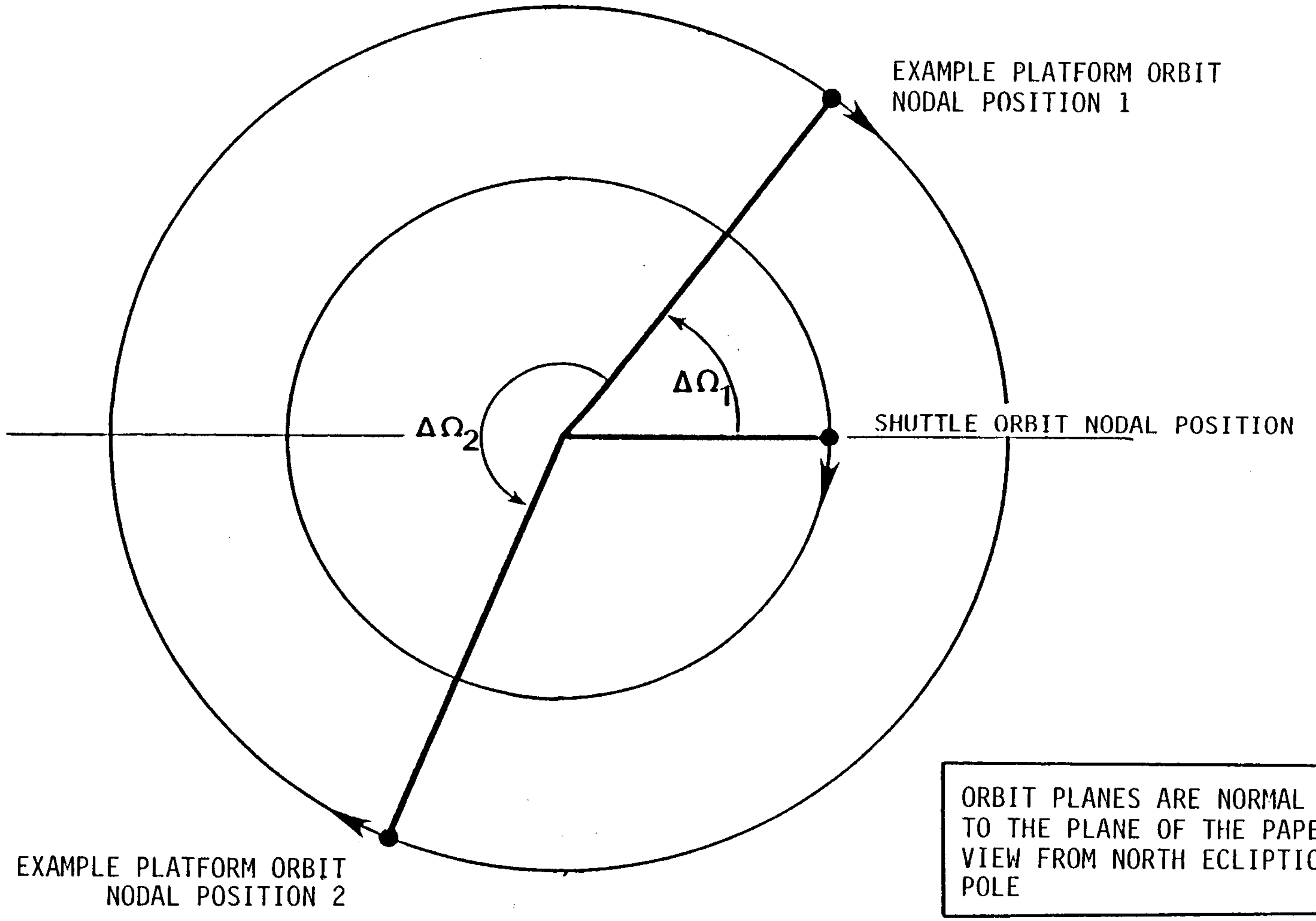
* STS AT 200 KM ALTITUDE

SATELLITE SERVICING USING THE OMV

If the Space Shuttle and the satellite to be serviced are initially in coplanar orbits, but at different altitudes, over time an angular displacement between the orbit's ascending nodes will occur. This is due to the relative difference of the respective orbits' nodal regression rates caused by Earth's oblateness. The problem addressed in the next several pages is the OMV capability to perform round-trip sorties between the STS and a target satellite, when they are in the same inclination orbit, but at different altitudes. The ΔV requirements and corresponding mass performance were analyzed over the complete range of initial nodal offset ($\Delta\Omega_0$) of 0-360 degrees.

The orbit geometry is defined in the figure on the facing page. $\Delta\Omega$ is defined as $\Omega_{satellite} - \Omega_{Shuttle}$. With $\Delta\Omega$ thus defined, the Shuttle leads the satellite by the angle $\Delta\Omega$. This is illustrated on the facing page by $\Delta\Omega_1$ when the satellite nodal location is position 1. To further illustrate the point, if $180° < \Delta\Omega < 360°$, as represented by the satellite node at position 2, then the satellite node actually leads the Shuttle node, since motion is clockwise (westward).

INITIAL ORBIT NODAL GEOMETRY



ORBIT PLANES ARE NORMAL TO THE PLANE OF THE PAPER, VIEW FROM NORTH ECLIPTIC POLE

ROUND-TRIP ΔV REQUIREMENTS FOR SATELLITE SERVICING MISSIONS

Maps of round-trip ΔV versus $\Delta\Omega_0$ are shown in the next three pages for representative servicing missions in which the Shuttle and satellite are in orbits with inclinations of 28.5, 57, and 98.9 degrees. There are three different strategies represented by the curves in these figures, as discussed below.

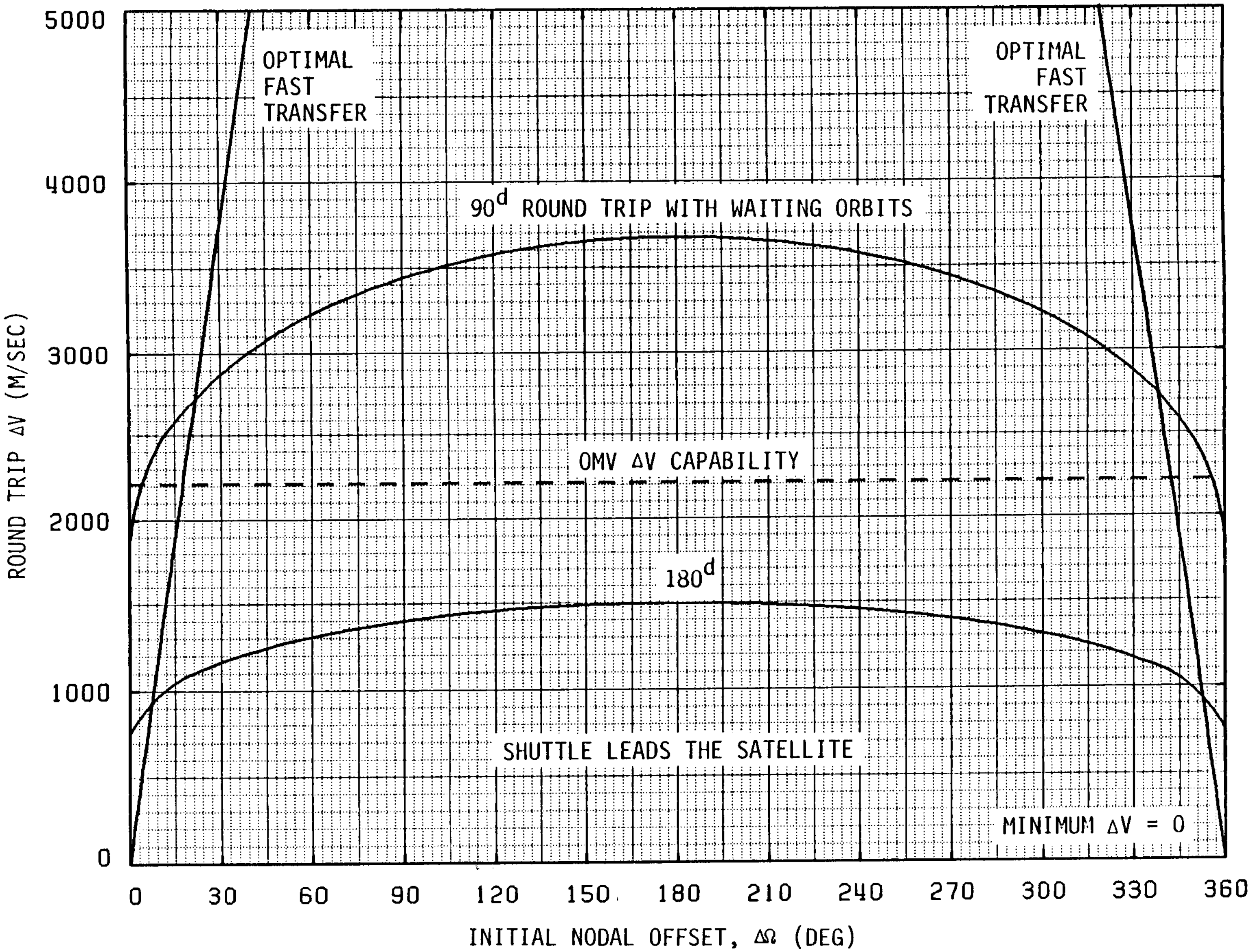
1. **Total Passive Strategy.** This strategy is applicable only to the two cases where the Shuttle and satellite are at different altitudes, such that $|\Delta\dot{\Omega}|$ between the two orbits is greater than 0. Therefore, by remaining at the Shuttle one could simply wait for the planes to align themselves due to the natural nodal regression. A minimum round-trip ΔV is then possible using a two-impulse coplanar Hohmann transfer outbound and return. Any slight orbit plane misalignment occurring during the transfers or operation at the platform is ignored in this analysis. The corresponding ΔV requirement for this strategy is shown as the minimum ΔV (solid horizontal line) in the figures. The waiting times (in days) required for this passive alignment strategy are noted on this line.

2. **Waiting Orbit Strategy.** This strategy also employs a passive waiting strategy, but by means of transferring to a waiting orbit at a different altitude. For example, the OMV transfers from the Shuttle to a higher altitude circular orbit via a two-impulse Hohmann transfer. At this higher altitude the nodal regression rate is less than the satellite's rate, so the orbit planes will align in time. The OMV then transfers from the waiting orbit to the satellite orbit via another two-impulse Hohmann transfer. However, the Shuttle orbit is now some $\Delta\Omega_2$ removed from the platform orbit and the process is repeated for the return leg. Note that this strategy requires a total of eight impulses. Again, the relatively short transfer times were ignored; the total trip time refers to the time spent in the waiting orbits. Note that depending upon the initial $\Delta\Omega$ and total trip time it may be optimal to simply wait at the Shuttle for the orbit planes to align, at which time a minimum ΔV round-trip mission is possible.

3. **Optimal Fast Transfer.** In this strategy, the plane change maneuver required due to the initial nodal offset is performed by the OMV. This is represented by curves of rapidly increasing ΔV requirement with increasing $\Delta\Omega$, which is a further indication of the limited plane change capability of the OMV. For the range of $\Delta\Omega$ of interest here, constrained due to the OMV ΔV capability, the optimal fast transfer is simply an inclined Hohmann transfer.

SPACE SHUTTLE ORBIT: 500 KM (270 N. MI.) ALT., 28.5° INC., CIRCULAR

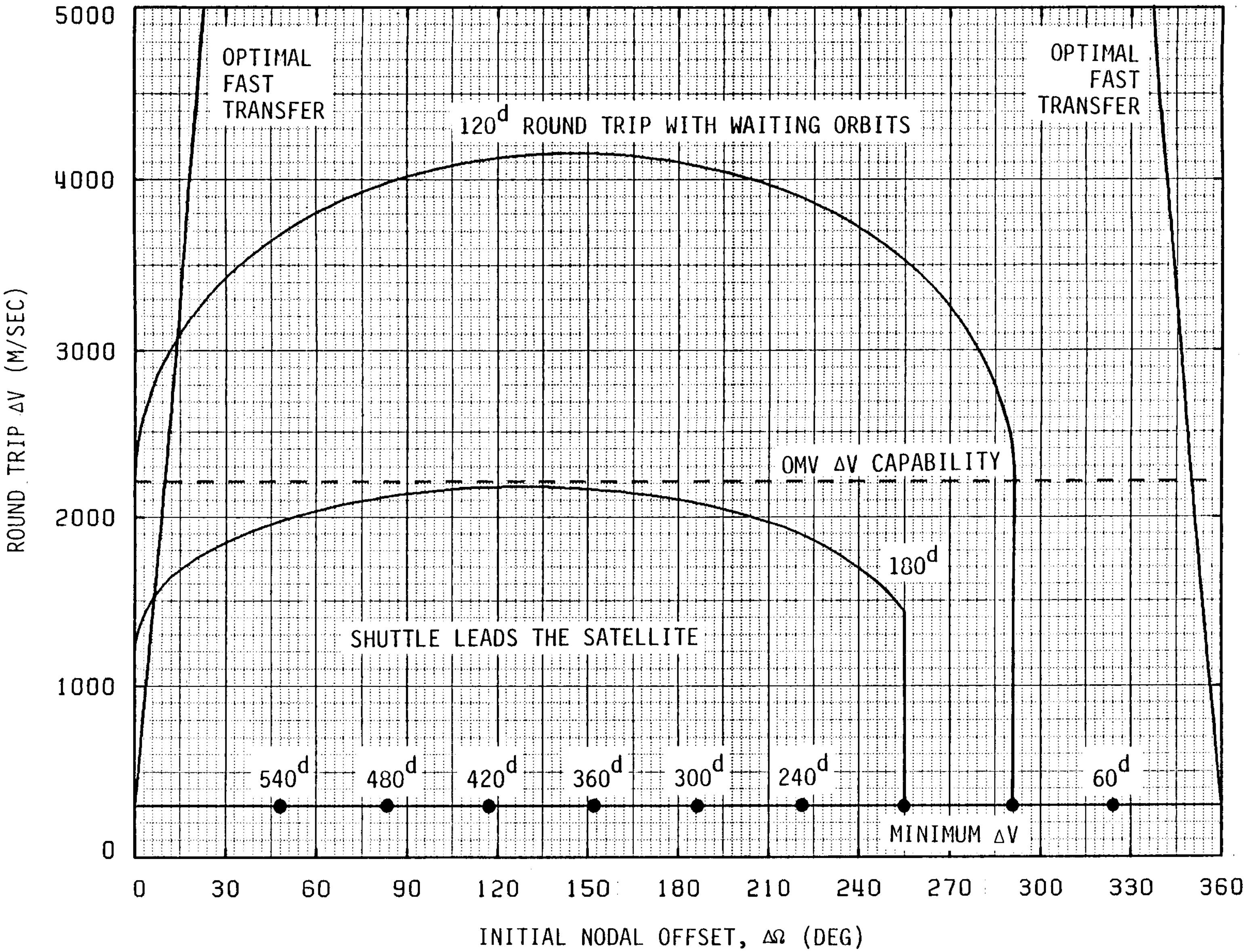
SATELLITE ORBIT: 500 KM (270 N. MI.) ALT., 28.5° INC., CIRCULAR



ROUND TRIP ΔV REQUIREMENTS FOR TRANSFER BETWEEN ORBITS WITH INITIAL NODAL OFFSET

SPACE SHUTTLE ORBIT: 334 KM (180 N. MI.) ALT., 57° INC., CIRCULAR

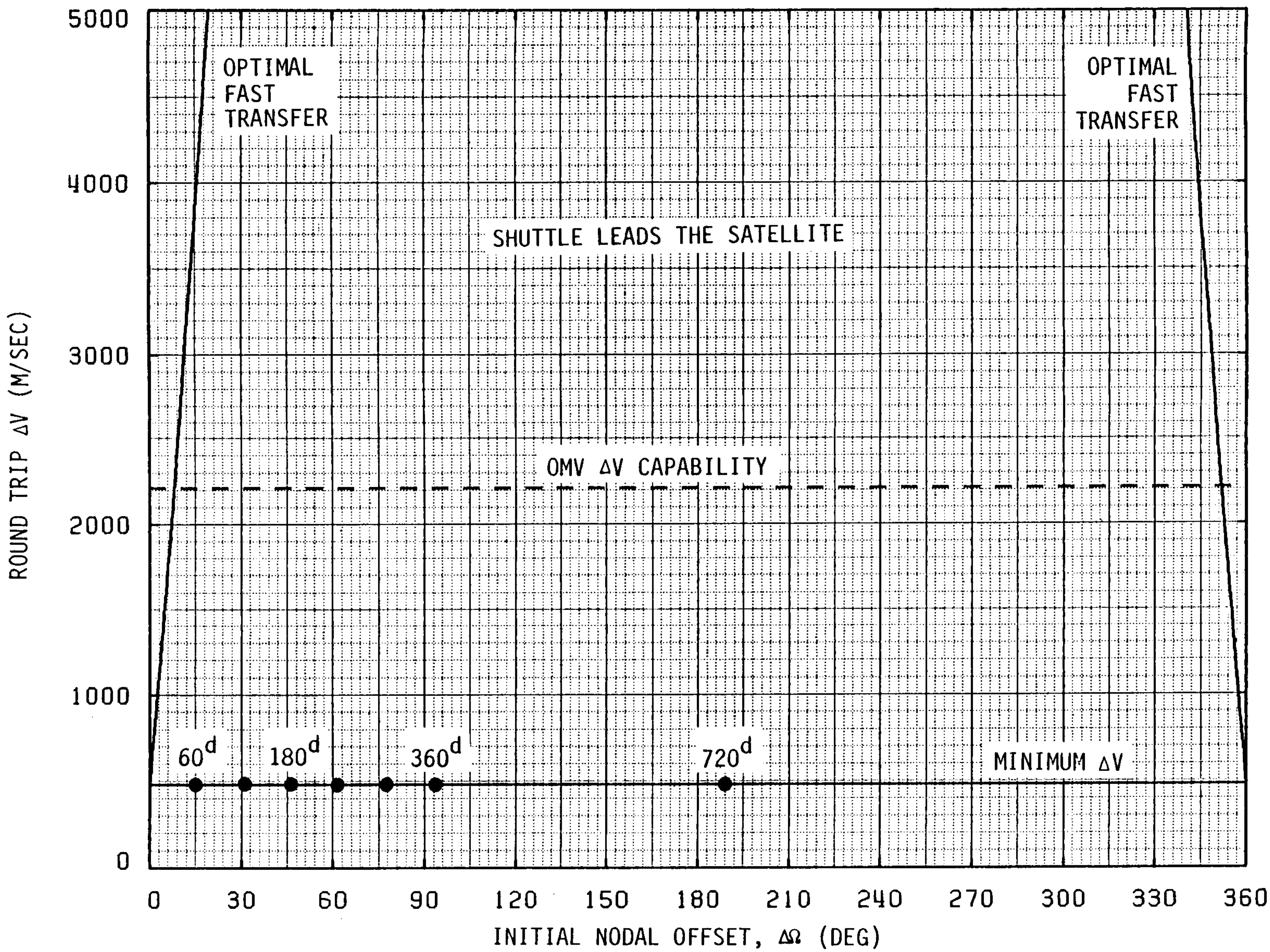
SATELLITE ORBIT: 600 KM (324 N. MI.) ALT., 57° INC., CIRCULAR



ROUND TRIP ΔV REQUIREMENTS FOR TRANSFER BETWEEN ORBITS WITH INITIAL NODAL OFFSET

SPACE SHUTTLE ORBIT: 278 KM (150 N. MI.) ALT., 98.9° INC., CIRCULAR

SATELLITE ORBIT: 710 KM (383 N. MI.) ALT., 98.9° INC., CIRCULAR



ROUND TRIP ΔV REQUIREMENTS FOR TRANSFER BETWEEN ORBITS WITH INITIAL NODAL OFFSET

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SUMMARY OF EXPANDED STS SERVICING CAPABILITIES TO BE DERIVED FROM OMV

In summary, the principal advantage the OMV offers to the STS servicing infrastructure is the added capability to retrieve and/or deploy spacecraft in orbits at altitudes higher than the Shuttle orbiter capability. Analysis has shown, however, that this capability does not extend to orbits whose inclinations are more than one or two degrees different from the Space Shuttle's orbit inclination. Likewise, greater propellant capabilities and longer on-orbit times are needed to visit multiple spacecraft not in the same orbit plane.

In response to the limited OMV plane change capability, scenarios were studied which use the natural nodal regression perturbation combined with waiting strategies to perform round-trip missions between coplanar orbits with initial nodal offsets. The ΔV requirements were found to be within the OMV capability only when total trip times approached a significant fraction of a year (i.e., > 180 days).

Remote servicing of satellites, including changeout of modules and resupply of consumables, will become available as the OMV program matures and mission kits become available. The cold gas Reaction Control System (RCS) may be used during proximity operations if the satellite being accommodated is contamination sensitive.

The following pages will use this information, along with the mission model data developed in the first part of this task, to derive satellite servicing hardware requirements.

SUMMARY OF EXPANDED STS CAPABILITIES TO BE DERIVED FROM OMV

- THE PRINCIPAL ADVANTAGE OF THE OMV IS THE ABILITY TO RETRIEVE OR DEPLOY SPACECRAFT IN HIGH ORBITS
- THE OMV'S CAPABILITY IS NOT SUFFICIENT TO RETRIEVE OR DEPLOY SPACECRAFT MORE THAN A FEW DEGREES AWAY FROM THE SPACE SHUTTLE'S ORBIT PLANE
- LONGER ON-ORBIT TIMES OR GREATER PROPELLANT CAPABILITIES ARE NEEDED TO VISIT MULTIPLE SPACECRAFT NOT IN THE SAME ORBIT PLANE
- AN ENHANCED SERVICING CAPABILITY MAY BE POSSIBLE USING A SPACE-BASED ROBOTIC SERVICER AND STORAGE DEPOT

HARDWARE REQUIREMENTS

In order to assess satellite servicing hardware requirements, the following servicing activities were identified from the expanded mission model:

1. Manufactured materials retrieval
2. Propellant transfer (Earth-storable and cryogenic)
3. Other consumables replenishment (instrument cryogens, gases, etc.)
4. On-orbit assembly
5. ORU replacement (repairs and/or upgrade)
6. Planetary sample return canister retrieval and quarantine.

Although some of these servicing activities have never been practiced in space, no completely new servicing activities were identified. Because these servicing activities are variations or expansions of near-term servicing activities, the previous hardware list* remains valid.

* This hardware list may be found in "Satellite Services System Program Plan" prepared by SAIC for NASA/JSC in July, 1985.

HARDWARE REQUIREMENTS

- SERVICING ACTIVITIES IDENTIFIED
  - MANUFACTURED MATERIALS RETRIEVAL
  - PROPELLANT TRANSFER (EARTH-STORABLE AND CRYOGENIC)
  - OTHER CONSUMABLES REPLENISHMENT (INSTRUMENT CRYOGENS, GASES, ETC.)
  - ON-ORBIT ASSEMBLY
  - ORU REPLACEMENT (REPAIR AND/OR UPGRADE)
  - PLANETARY SAMPLE RETURN CANISTER RETRIEVAL AND QUARANTINE
- NO COMPLETELY NEW SERVICING ACTIVITIES APPARENT
- GENERALLY VARIATIONS OR EXPANSIONS OF PRESENT AND NEAR-TERM ACTIVITIES
- PREVIOUS HARDWARE LIST STILL VALID

NEAR-TERM SERVICING HARDWARE

Several key results from the July 1985 pre-IOC Space Station satellite servicing report ("Satellite Services System Program Plan") indicated a strong preference for the following hardware items:

1. A payload interface panel which will allow more direct and sophisticated communication with the spacecraft being serviced by those on board the Space Shuttle. This will allow vehicle monitoring during servicing and vehicle checking after servicing.

2. A second arm either in the form of a second (preferred) RMS (Remote Manipulator System) or an HPA (Handling and Positioning Aid) mounted on a cradle. This will allow servicing of vehicles outside the payload bay envelope while eliminating a potential launch cost to reserve clearance space within the payload bay.

3. Remote controlled fluids coupling. This would avoid EVA time for connecting and disconnecting such a coupling.

4. A large, 2,300 kg (5,000 pounds) minimum capacity monopropellant tanker. Most vehicles which potentially need refueling require 900 to 2,200 kg (2,000 to 5,000 pounds) of propellant.

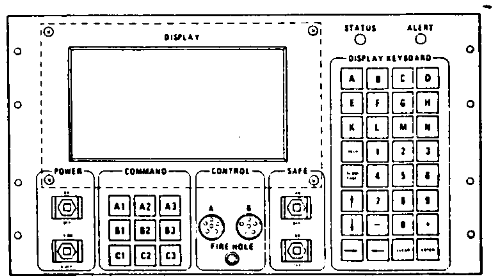
5. Large spacecraft berthing device. This device was identified for massive vehicles of 13,600 to 18,000 kg (30,000 to 40,000 pounds) which would be berthed to the orbiter for extended periods of time (6 to 8 hours or more).

C-2

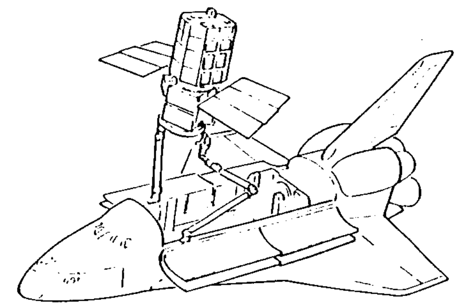
NEAR-TERM SERVICING HARDWARE

- RESULTS FROM 1985 REPORT FOR SERVICING PRIOR TO SPACE STATION IOC

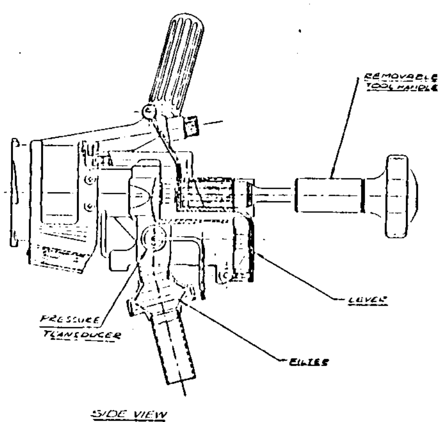
PAYLOAD INTERFACE PANEL



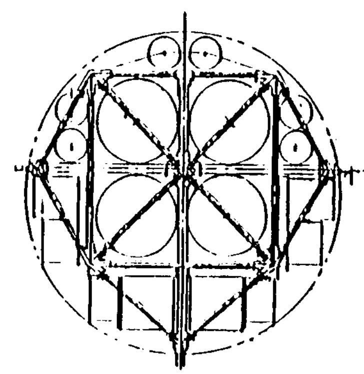
2ND ARM



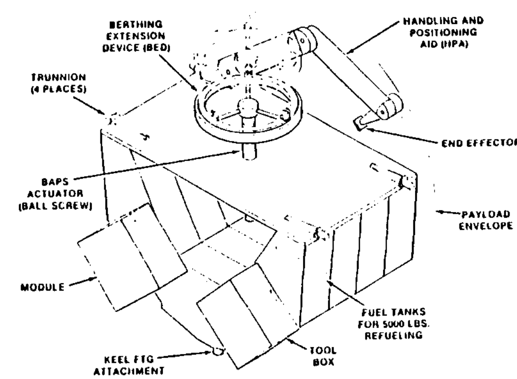
FLUIDS COUPLING



LARGE TANKER



LARGE SPACECRAFT BERTHING DEVICE



EXPANDED CAPABILITY SERVICING HARDWARE

To meet the needs of the post-IOC Space Station satellite servicing user community, the following expanded capability servicing hardware has been identified:

1. Satellite checkout equipment. This computerized system will not only determine the functional status of the satellite at deployment and retrieval, but also isolate faults by ORU location.

2. Liquid tankers and transfer lines. Appropriately insulated for the fluid carried, these hardware items will store and transport primarily superfluid helium, hydrazine, hydrogen, oxygen, and bipropellants.

3. Payload environmental control system. This system, attached to the orbiter cargo bay wall, would control the temperature of ORUs or experiments which require cooling or heating.

4. Remotely operated umbilicals. These systems will provide a convenient method of monitoring information concerning propellant and pressurants (e.g., temperature, pressure, flow rate) as well as provide power and communications links between the orbiter and satellite being serviced.

5. Laser docking system. This automated rendezvous and docking device will allow quicker, safer, and more accurate docking. By utilizing this system, plume impingement and environment contamination will be minimized.

EXPANDED CAPABILITY SERVICING HARDWARE

SATELLITE CHECKOUT EQUIPMENT

- A COMPUTERIZED SYSTEM USED TO DETERMINE THE FUNCTIONAL STATUS OF SATELLITE AT BOTH DEPLOYMENT AND RETRIEVAL
- SHOULD HAVE THE CAPABILITY TO ISOLATE FAULTS BY ORU LOCATION

LIQUID TANKERS AND TRANSFER LINES

- SUPERFLUID HELIUM
- HYDRAZINE
- HYDROGEN
- OXYGEN
- BIPROPELLANT

PAYLOAD ENVIRONMENTAL CONTROL SYSTEM

- A COOLING/HEATING SYSTEM ATTACHED TO THE ORBITER CARGO BAY WALL
- SHOULD BE ABLE TO CONTROL TEMPERATURE OF ORUs OR EXPERIMENTS WHICH REQUIRE COOLING OR HEATING

REMOTELY OPERATED UMBILICALS

- PROPELLANT/ PRESSURE
- POWER/COMMUNICATIONS

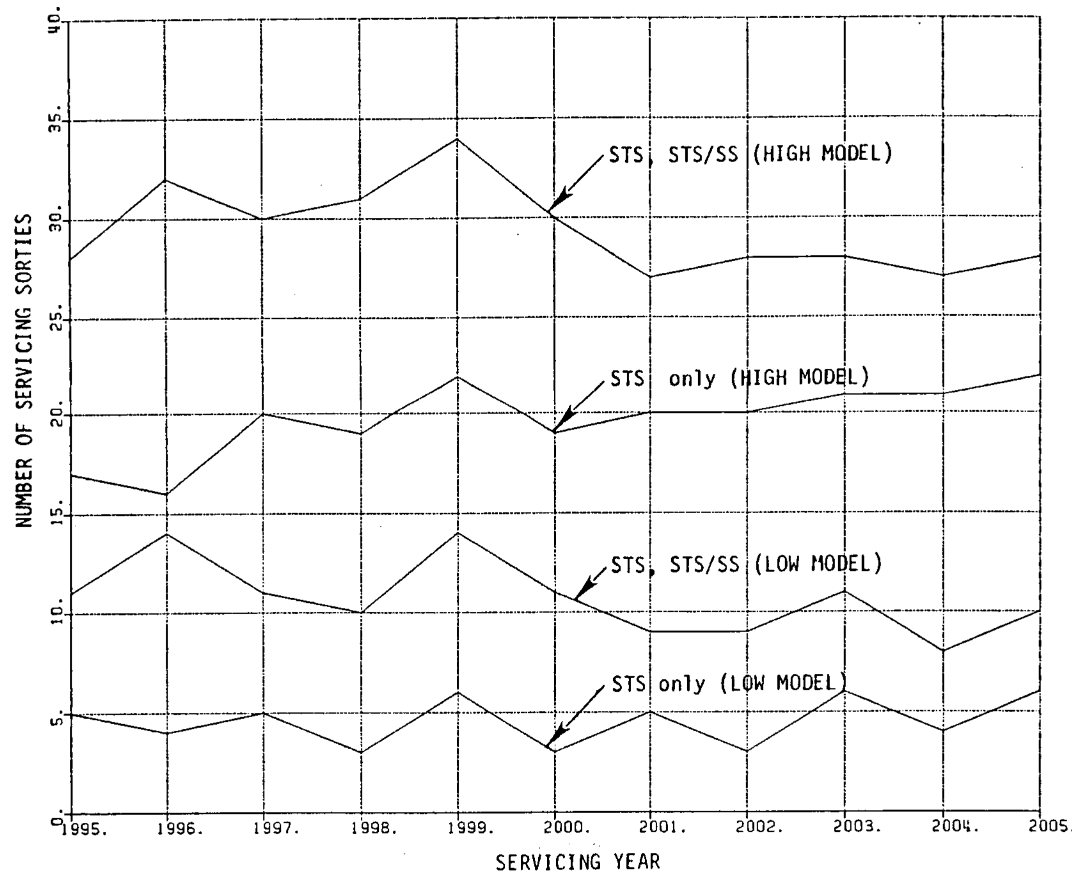
LASER DOCKING SYSTEM

- AUTOMATED RENDEZVOUS AND DOCKING DEVICE USED FOR QUICKER, SAFER, MORE ACCURATE DOCKING
- MINIMIZES PLUME IMPINGEMENT AND ENVIRONMENT CONTAMINATION

STS LOW-INCLINATION SORTIE RATE

The sortie rate for serviceable satellites in low-inclination orbits (less than 30°) accessible by STS only or accessible by either STS or Space Station (STS, STS/SS) depends on both OMV capability and activity levels predicted from the fluid resupply study data bases. For STS, STS/SS type servicing sorties a large percentage is for MPS satellites (e.g., 15 to 20 sorties per year for the high model). One key assumption used in forming the plot on the facing page is that the European equivalent of the Space Shuttle (HERMES) would likely be used to service many foreign satellites beginning with the year 2000. The plot shows the effect of this assumption by decreased sortie rates on and after the year 2000.

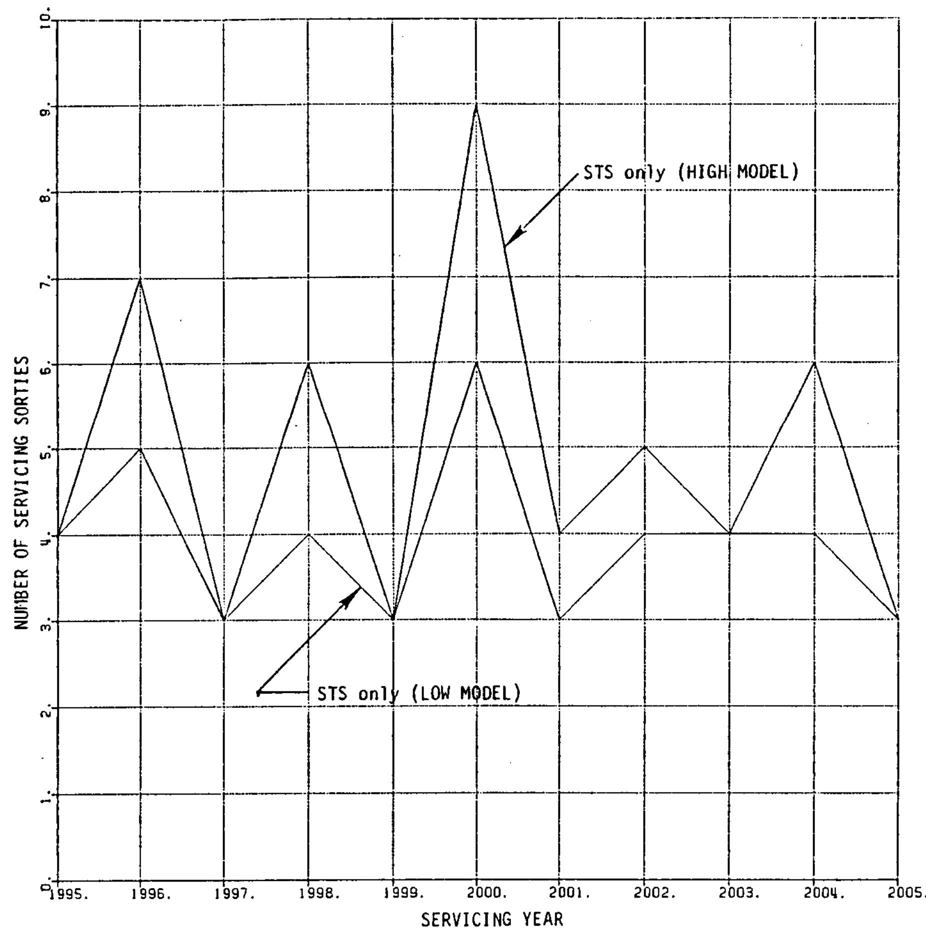
STS LOW-INCLINATION SORTIE RATE



STS HIGH-INCLINATION SORTIE RATE

The sortie rate for serviceable satellites in high-inclination orbits (greater than 60°), accessible by STS only, depends on both OMV capability and activity levels predicted from the fluid resupply study data bases. It was determined that all high-inclination, STS-accessible, serviceable spacecraft will have orbital inclinations between 90° and 100°. A significant percentage of future, high-inclination, serviceable spacecraft will belong to the Department of Defense (especially after the year 2000).

STS HIGH-INCLINATION SORTIE RATE



SUMMARY

This task has developed a mission model for satellite servicing requirements extending from 1995 through 2010. The hardware items needed to meet these requirements are basically the same as those identified during the first phase of this contract which looked at servicing requirements prior to 1995. One aspect of the identified hardware which affects both NASA and servicing customers during this time period are the interfaces between STS hardware and the vehicle being serviced. These interfaces include all types of connections between the STS and the spacecraft: mechanical, power, fluids, and data, to name a few. The definition of these interfaces is the current concern of those organizations now beginning to design vehicles for use in the late 1990s and early 2000s. What makes this problem amenable to solution at this time is the fact that these interfaces are independent of the hardware characteristics on either side of the connection. Unfortunately, the current method of defining these interfaces is usually ad hoc: the first version designed and built becomes the standard without regard for a wider range of users.

SUMMARY

- A COMMON ASPECT OF THE IDENTIFIED HARDWARE WHICH AFFECTS BOTH NASA AND CUSTOMERS DURING THIS TIME PERIOD INVOLVES INTERFACES (MECHANICAL, POWER, FLUIDS, DATA, ETC.)

- THIS IS THE CURRENT CONCERN OF THOSE BEGINNING TO DESIGN NEW VEHICLES FOR THE 1990s AND 2000s

- THESE INTERFACES ARE INDEPENDENT OF THE CHARACTERISTICS ON EITHER SIDE OF THE INTERFACE AND CAN BE ADDRESSED NOW

- THE CURRENT METHOD OF DEFINING THE INTERFACE IS AD HOC; THE FIRST VERSION DESIGNED AND BUILT BECOMES THE STANDARD

RECOMMENDATIONS

To rectify this situation NASA and the user community should concentrate on developing a base of generic interface standards. One possible approach is to use all available STS flights to validate (on a small scale) the various types of interfaces proposed by the servicing community. This approach would also be useful in obtaining astronaut feedback regarding the utility of the interface hardware and in developing a base of experience for future operational activities. All specifications developed during this process should then be made available to appropriate personnel by means of an easily accessible data base. This will accelerate the introduction of these standards into operational vehicles.

RECOMMENDATIONS

- CONCENTRATE ON DEVELOPING A BASE OF GENERIC INTERFACE STANDARDS
  - POSSIBLE APPROACH: USE ALL STS FLIGHTS TO VALIDATE (ON A SMALL SCALE) THE VARIOUS TYPES OF INTERFACES PROPOSED BY THE SERVICING COMMUNITY
  - USEFUL IN OBTAINING ASTRONAUT FEEDBACK AND DEVELOPING EXPERIENCE
- MAKE SPECIFICATIONS AVAILABLE TO APPROPRIATE PERSONNEL THROUGH EASILY ACCESSIBLE DATA BASE

TASK 3

ON-ORBIT HANDLING OF LARGE MODULES

INTRODUCTION

The three-body problem as used in this study refers to the on-orbit exchange of very large payload modules from a free-flying support bus. Thus, the three bodies include the large on-orbit payload, the exchange payload, and the support bus. Each of these modules must be manipulated in one way or another by the Shuttle orbiter and crew.

The payload modules have been defined here as having a length of approximately 9.1 meters (30 feet) and/or a weight in the 9,000 to 13,600 kg (20,000 to 30,000 pounds) range. The free-flying support bus would have a weight of 4,500 to 9,000 kg (10,000 to 20,000 pounds) depending upon the propellant load, and would provide on-orbit services such as electrical power, environmental control, pointing, and communications.

The need for a solution to this problem arose from two different sources. The near-term application of such a solution would be commercial materials processing payloads. With a commercial payload of this size, the desire to limit costs associated with the payload exchange has become a driving factor. A long-term application of this concept will be to support the Space Station unmanned platforms. The polar platform will obviously require the Shuttle orbiter to conduct any exchange with existing platform payloads. The co-orbiting platform will generally be serviced at the Space Station. However, some of the larger NASA payloads and future commercial microgravity factories may find it more suitable to conduct such an exchange at the Shuttle orbiter rather than go through the intermediate step of transferring the payload at the Space Station.

INTRODUCTION

- 3 BODIES: LARGE, ON-ORBIT MODULE; REPLACEMENT MODULE; SUPPORT BUS
- LARGE MODULE: 9,000 TO 13,600 KG (20,000 TO 30,000 POUNDS) WEIGHT
  UP TO 9.1 METERS (30 FEET) IN LENGTH
- SUPPORT BUS: 4,500 TO 9,000 KG (10,000 TO 20,000 POUNDS) WEIGHT
- SOLUTION NEEDED BY: NEAR TERM - MATERIALS PROCESSING FACTORIES
  FAR TERM - SPACE STATION UNMANNED PLATFORMS

TASK OBJECTIVES AND SCOPE

Three major objectives have been set for this task. The first of these is to gather servicing requirements from potential users. This set of requirements can thus serve as a starting point for any future studies in this area. These requirements will also serve as a starting point for this task, indicating the type of hardware and exchange procedures which are viable from the user's perspective.

The second objective is to take these servicing requirements, along with the general description of the mission to be accomplished, and formulate possible scenarios for conducting the module exchange. Each of these scenarios will require certain hardware items to complete the task. Part of this objective, then, is to identify generic hardware concepts which could meet the exchange scenario requirements. Both the scenario and hardware options should cover the range of possibilities in a general sense. Any fine tuning of a particular concept or procedure can be made in future efforts.

The final objective of this task is to gather and summarize the reactions of potential users to both the hardware and procedures. This will serve to narrow the range of possible options for any future study.

The scope of this task covers only the exchange of large payload modules. Other types of servicing, such as subsystem module replacement or support bus refueling, which may occur as part of the module exchange mission, have not been addressed. In addition, hardware capabilities will be derived primarily from near-term user requirements. Far-term users will presumably adapt to, or make minor adjustments to, these capabilities.

TASK OBJECTIVES AND SCOPE

- OBJECTIVES
  - GATHER POTENTIAL USER INPUT REGARDING SERVICING REQUIREMENTS
  - FORMULATE EXCHANGE SCENARIOS AND NECESSARY HARDWARE
  - SUMMARIZE USER PREFERENCES REGARDING SCENARIOS AND HARDWARE
- SCOPE
  - EXAMINE HARDWARE AND PROCEDURE OPTIONS FOR MODULE EXCHANGE ONLY
  - FOCUS ON REQUIREMENTS FROM NEAR-TERM USERS

POTENTIAL VEHICLE AND MISSION CANDIDATES

At the present time three vehicles have been identified as possible users for this type of large module exchange. Two of these are commercially operated spacecraft whose primary customers will probably be materials processing payloads. The third vehicle is the NASA unmanned platform being developed in conjunction with the Space Station. Most of the currently identified users of this platform are large NASA science payloads.

Both Fairchild Space Company and RCA AstroElectronics have proposed spacecraft which would lease on-orbit services (i.e., electrical power, environmental control, communications, etc.) to various payloads. The vehicle itself would weigh in the range of 4,500 to 9,000 kg (10,000 to 20,000 pounds) depending upon the propellant load. A typical payload for this type of spacecraft would be a continuous flow electrophoresis factory being developed by McDonnell Douglas Astronautics Corp. and the Ortho Division of Johnson & Johnson. This factory would weigh approximately 11,000 kg (25,000 pounds) and would require a payload exchange every three to six months.

The third vehicle in this category is the NASA unmanned platform. NASA's reference configuration for this spacecraft has an estimated dry weight of 5,400 kg (12,000 pounds). Accommodations have been made for up to 2,700 kg (6,000 pounds) of propellant, which would be used basically to raise and lower the vehicle's orbit altitude. This yields a total platform weight of 8,100 kg (18,000 pounds) without a payload. The larger payloads identified for this vehicle thus far are NASA science observatories. These include the Advanced Solar Observatory at 9,000 kg (20,000 pounds), 28.5° inclination, the High Throughput Experiment at 10,000 kg (22,000 pounds), 28.5° inclination, and the Polar C collection of instruments at 4,500 kg (10,000 pounds), 98° inclination.

POTENTIAL VEHICLE AND MISSION CANDIDATES

- LEASECRAFT (FSC)
  - SUPPORT BUS: APPROXIMATELY 9,000 KG (20,000 POUNDS) TOTAL WEIGHT; 2,200 KG (5,000 POUNDS) PROPELLANT
  - TYPICAL PAYLOAD: MATERIALS PROCESSING FACTORY; APPROXIMATELY 11,300 KG (25,000 POUNDS) TOTAL WEIGHT
- OMNISTAR (RCA)
  - COMPARABLE TO LEASECRAFT IN SIZE AND PAYLOAD
- SPACE STATION UNMANNED PLATFORMS
  - NASA REFERENCE CONFIGURATION: 5,400 KG (12,000 POUNDS) DRY WEIGHT; UP TO 2,700 KG (6,000 POUNDS) PROPELLANT
  - BOTH HIGH AND LOW INCLINATION ORBIT LOCATIONS
  - POTENTIAL LARGE PAYLOAD: ADVANCED SOLAR OBSERVATORY 9,000 KG (20,000 POUNDS)

INITIAL USER REQUIREMENTS FOR THE THREE-BODY PROBLEM

In addition to the already available RMS arm, a berthing/docking interface for any large platform, preferably outside of the revenue-generating Shuttle payload bay envelope, has been indicated by potential users as a minimum requirement. A temporary storage location for the exchange module is also required. This hardware could be located in the payload bay, or could be an additional out-of-bay berthing device. In-bay berthing devices are constrained by requirements for clear access to the exchange modules during grappling, berthing, and redeployment operations. Further, attention must be given to visibility considerations for operations using in-bay hardware, and especially for out-of-bay operations which may occur during orbit "nighttime."

All mechanical interfaces must be compatible as well as simple and inexpensive. Standard trunnion/latch interfaces would be desirable. Both communications and power must be supplied to the platform and modules during changeout operations. As they are currently understood, these changeout operations should be completed in approximately three hours and no module should be without power for longer than approximately one hour. During a module exchange mission, it may also be necessary or prudent to replenish the platform propulsion system modules, and therefore a capability for fluid exchange may be required. Potential users also indicated that operations should be designed to minimize crew activity, which will in turn minimize crew training. The platform/module exchange system should also be designed to take full advantage of the STS nominal launch manifest and attempt to avoid any requirement for unscheduled launches.

The purpose of the out-of-bay preference for missions of this type is to keep the costs low. Hardware development costs can be lowered by using existing flight support equipment such as the RMS, FSS, and Spacelab pallets. Transportation (launch) costs could be minimized by careful optimization of weight load factors, length load factors, crew interaction (minimize EVAs and crew training) and mission-unique flight plans. For example, the flight support equipment could be packaged with the new module in such a way that its launch cost is included in the weight and length load factors attributed to the new module alone.

INITIAL USER REQUIREMENTS FOR THE THREE-BODY PROBLEM

- HARDWARE REQUIREMENTS
  - PROVIDE A BERTHING/DOCKING INTERFACE FOR THE PLATFORM
  - PROVIDE A TEMPORARY STORAGE LOCATION FOR THE EXCHANGE MODULE
- HANDLING, BERTHING, AND DOCKING PROVISIONS
  - SIMPLE (AND INEXPENSIVE) MECHANICAL INTERFACES
  - ELECTRICAL INTERFACE: PROVIDE POWER TO THE MODULE
PROVIDE COMMAND/MONITORING OF THE MODULE
  - POSSIBLE FLUID EXCHANGE
  - VISIBILITY AND FREE ACCESS CONSIDERATIONS
- OPERATIONAL REQUIREMENTS
  - PERFORM CHANGEOUT IN APPROXIMATELY THREE HOURS
  - TAKE ADVANTAGE OF NOMINAL STS LAUNCH MANIFEST
  - MINIMIZE CREW ACTIVITY
- COSTS
  - LOW LAUNCH COSTS
  - LOW HARDWARE DEVELOPMENT COSTS

SERVICING HARDWARE DESCRIPTIONS

1. REMOTE MANIPULATOR SYSTEM (RMS) - LENGTH = 15M (50 FEET), WEIGHT = 400 KG (905 POUNDS), TRANS COST = $1.76M* (FOR 2ND RMS)

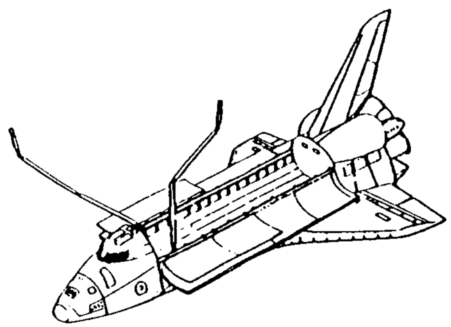
2. HANDLING AND POSITIONING AID (HPA)
   - OPTION A: RMS-BASED — LENGTH = 6.7M (22 FEET), WEIGHT = 360 KG (802 POUNDS), TRANS COST = $1.51M
   - OPTION B: "STRONG-ARM" — LENGTH = 6.1M (20 FEET), WEIGHT = 830 KG (1,820 POUNDS), TRANS COST = $3.43M
   - OPTIONS C & D: A & B WITH CRADLE — REQUIRED PAYLOAD BAY LENGTH = 1.2M (4 FEET), WEIGHT = 450 KG (1,000 POUNDS), TRANS COST = $9.19M

3. IN-BAY DOCKING FIXTURES
   - OPTION A: FLIGHT SUPPORT SYSTEM (FSS) — REQUIRED PAYLOAD BAY LENGTH = .5M (1.5 FEET), WEIGHT = 1,500 KG (3,300 POUNDS), TRANS COST = $6.22M
   - OPTION B: LIGHTWEIGHT FSS — REQUIRED PAYLOAD BAY LENGTH = .6M (2 FEET), WEIGHT = 900 KG (2,000 LB), TRANS COST = $5.1M

4. OUT-OF-BAY DOCKING FIXTURES
   - OPTION A: PAYLOAD BERTHING SYSTEM (PBS) — REQUIRED PAYLOAD BAY LENGTH = 2.6M (8.5 FEET), WEIGHT = 260 KG (570 POUNDS), TRANS COST = $18.38M
   - OPTION B: RECONFIGURABLE SATELLITE SERVICING SYSTEM (RSSS) — REQUIRED PAYLOAD BAY LENGTH = 1.5M (5 FEET), WEIGHT = 1,100 KG (2,400 POUNDS), TRANS COST = $11.23M

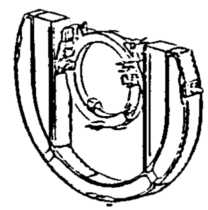
* TRANSPORTATION COSTS CALCULATED USING STANDARD STS PRICING FORMULA AND DEDICATED SHUTTLE PRICE OF $92M (FY86)

SERVICING HARDWARE DESCRIPTIONS



2ND RMS ARM

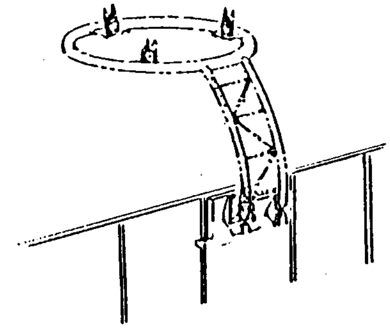
IN-BAY DOCKING FIXTURES



OPTION A: FSS

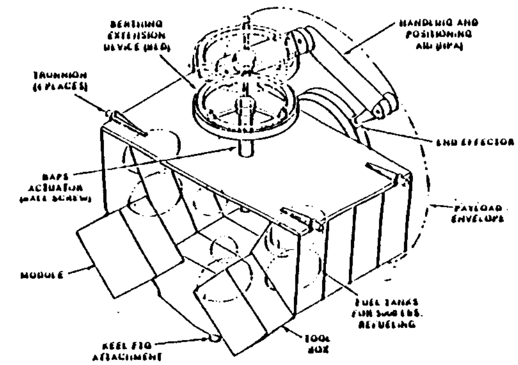
OPTION B: LIGHT-WEIGHT FSS

OUT-OF-BAY DOCKING FIXTURES



OPTION A: PBS

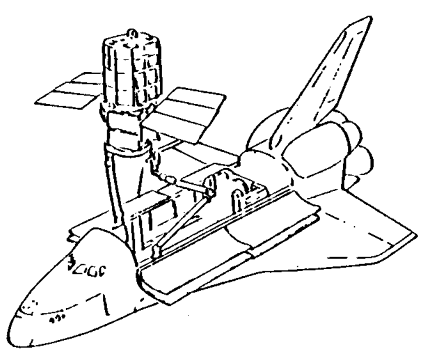
(ROCKWELL INT'L.)



OPTION B: RSSS

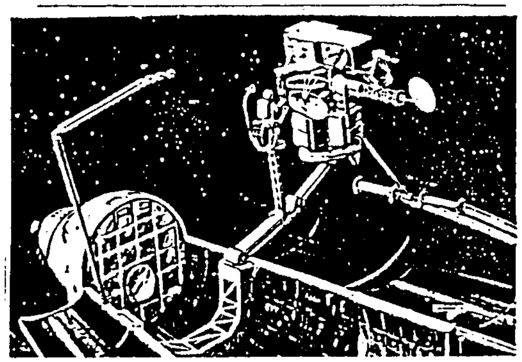
(FAIRCHILD)

HANDLING AND POSITIONING AIDS



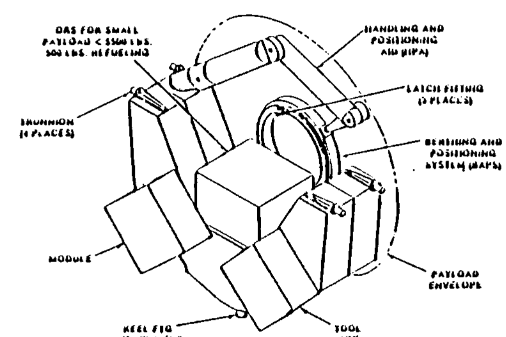
OPTION A: RMS-BASED

(SPAR)



OPTION B: "STRONG ARM"

(GRUMMAN)



OPTIONS C & D: OPTIONS A & B WITH CRADLE

SERVICING HARDWARE OPTIONS

The questionnaire was basically concerned with exchange scenarios and the hardware to be used for the exchange. It was assumed that there would always be at least one RMS arm available in each scenario. To further assist in the payload exchange, the Shuttle orbiter could have a second RMS arm and/or zero, one, or two other docking fixtures as described on the preceding page. A four-digit numbering system was developed to indicate the specific hardware combinations available from the usable options; the explanation of this numbering system is as follows:

FIRST DIGIT	-	Number of RMS-type arms (1 or 2)
SECOND DIGIT	-	Number of Handling and Positioning Aid-type arms (0, 1, or 2)
THIRD DIGIT	-	Number of in-bay docking fixtures (0, 1, or 2)
FOURTH DIGIT	-	Number of out-of-bay docking fixtures (0, 1, or 2)

Due to the nature of this problem, there will never be a need to carry more than three hardware items on any exchange mission. Thus, if the four digits in the numbering scheme are added together, the total will be three or less. This numbering system will be used on subsequent pages as part of the explanation of questionnaire results.

SERVICING HARDWARE OPTIONS

- ALWAYS AT LEAST ONE RMS-TYPE ARM

- ADDITIONAL HARDWARE OPTIONS INCLUDE:
  - SECOND RMS-TYPE ARM
  - HANDLING AND POSITIONING AID-TYPE ARM
  - IN-BAY DOCKING FIXTURES
  - OUT-OF-BAY DOCKING FIXTURES

- MAXIMUM OF THREE HARDWARE ITEMS TOTAL FOR EXCHANGE MISSIONS

- FOUR-DIGIT NUMBERING SYSTEM DEVELOPED TO INDICATE SPECIFIC HARDWARE COMBINATIONS USED IN EACH SCENARIO

SURVEY DESCRIPTION

In order to gain a sense of what are generally acceptable methods to accomplish this type of payload exchange, a survey of potential options was constructed. This survey was divided into two sections, the first dealing with representative hardware concepts and the second focusing on scenarios to conduct the necessary exchange. Within each section the participant was asked to rate each hardware concept or exchange scenario in three different categories. These categories for the hardware and exchange scenario sections are shown on the facing page. A numerical scale from 1 (lowest ranking) to 5 (highest ranking) was used for each category and a weighted average across all three categories was calculated for each item (hardware and exchange scenario). The participants were also asked to match the most useful hardware concept to each scenario in the second section. Results obtained from Fairchild Space Company and RCA AstroElectronics will be discussed on the following pages.

SURVEY DESCRIPTION

- SURVEY DIVIDED INTO TWO SECTIONS
  - (1) REPRESENTATIVE HARDWARE CONCEPTS
  - (2) MODULE EXCHANGE SCENARIOS
- CONCEPTS IN EACH SECTION RATED IN THREE DIFFERENT CATEGORIES
  - (1) HARDWARE
    - IMPORTANCE OF EQUIPMENT TO ANTICIPATED NEEDS
    - FREQUENCY OR DURATION OF EQUIPMENT USE
    - QUALITY OF TOOL AS A SOLUTION TO ANTICIPATED NEEDS
  - (2) EXCHANGE SCENARIOS
    - EFFICIENT UTILIZATION OF STS ASSETS
    - UTILIZATION OF ON-ORBIT PERSONNEL
    - QUALITY OF EXCHANGE SCENARIO AS A SOLUTION TO ANTICIPATED NEEDS
- HARDWARE CONCEPTS MATCHED TO SCENARIOS AS PART OF RATING PROCESS
- PARTICIPANTS: FAIRCHILD SPACE COMPANY AND RCA ASTROELECTRONICS

HARDWARE RESULTS

The facing page lists all hardware examples included in the survey along with the estimated transportation costs and participant response to each. As can be seen, RCA places little value on those systems which use payload bay space, since from their perspective this problem can be solved without this equipment. However, RCA does indicate that devices of this type may be useful on a limited basis if the hardware already exists. In contrast, it can be seen that a second arm is considered necessary by RCA and of the choices available, a second RMS located on the starboard longeron is preferable.

Fairchild Space Company (FSC) also considers an additional arm (RMS or HPA) to be necessary and prefers the structural rigidity offered by the HPA. FSC also foresees the need to carry several ORUs into orbit to repair or enhance the orbiting platform. This spacecraft will also require refueling, the amount and timing of which will depend on the rendezvous altitude used by the Shuttle orbiter. Both of these items will require supporting structures for launch and landing. As a result, FSC tends to favor those concepts which include a cradle to which these modules could be attached.

One additional comment regarding the PBS should be noted. This concept was included to represent a means of berthing a payload outside of the orbiter's payload bay envelope. But this particular hardware was applied to a situation for which it was not designed. If this concept were to be applied to a more generic mission set, the specifics of the hardware would undoubtedly be redesigned to reduce transportation costs and increase load capacity.

HARDWARE RESULTS

HARDWARE ITEM	TRANS COST* ($M)	FSC RATING	RCA RATING	COMMENTS
SECOND RMS ON SILL	1.76	2.0	3.5	
HPA ON SILL	3.43	3.3	3.0	
RMS-BASED HPA ON SILL	1.51	2.8	3.0	
HPA WITH CRADLE	9.19	4.3	3.0	CRADLE IMPORTANT FOR CARRYING ORUs
RMS-BASED HPA WITH CRADLE	9.19	3.3	3.0	CRADLE IMPORTANT; RMS MAY BE WEAK
FSS	6.22	4.3	1.0	
LIGHTWEIGHT FSS	5.11	5.0	1.0	
PBS	18.38	1.5	1.0	CANNOT HOLD PAYLOAD MASS WITHOUT MODIFICATION
RSSS	11.23	4.8	1.0	

* ALL COSTS IN FY 1986 DOLLARS; BASED ON STANDARD STS PRICING FORMULA AND DEDICATED SHUTTLE PRICE OF $92M (FY86)

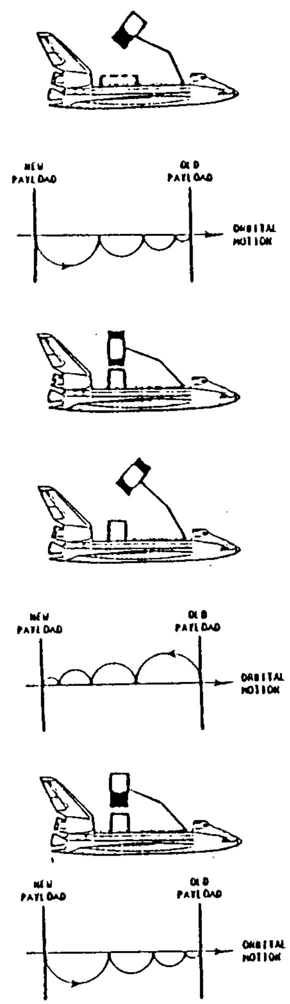
MISSION SCENARIOS FOR ON-ORBIT EXCHANGE OF VERY LARGE PAYLOADS

	MISSION SCENARIO 1	MISSION SCENARIO 2	MISSION SCENARIO 3	MISSION SCENARIO 4, 5*
HARDWARE AVAILABLE	1 RMS ARM	1 RMS ARM AND 1 OTHER DOCKING FIXTURE	1 RMS ARM AND 2 OTHER DOCKING FIXTURES	2 RMS ARMS
SCENARIO** DESCRIPTION	a) DEPLOY NEW PAYLOAD IN FREE DRIFT b) MANEUVER AWAY AND RENDEZVOUS WITH PLATFORM c) BERTH PLATFORM/OLD PAY-LOAD IN PAYLOAD BAY d) REMOVE OLD PAYLOAD AND DEPLOY IN FREE DRIFT e) RETURN TO NEW PAYLOAD f) MATE NEW PAYLOAD TO PLATFORM AND DEPLOY g) RETURN TO OLD PAYLOAD, GRAPPLE AND STOW	a) DEPLOY NEW PAYLOAD IN FREE DRIFT b) MANEUVER AWAY AND RENDEZVOUS WITH PLATFORM c) BERTH PLATFORM/OLD PAY-LOAD IN DOCKING FIXTURE d) REMOVE OLD PAYLOAD AND STOW e) SECURE PLATFORM AND REN-DEZVOUS WITH NEW PAYLOAD f) GRAPPLE NEW PAYLOAD, MATE TO PLATFORM AND DEPLOY	a) GRAPPLE AND SECURE PLATFORM TO FIXTURE 1 b) REMOVE OLD PAYLOAD FROM PLATFORM AND SECURE TO FIXTURE 2 c) SECURE NEW PAYLOAD TO PLATFORM AND DEPLOY d) STOW OLD PAYLOAD IN PAYLOAD BAY	a) GRAPPLE NEW PAYLOAD WITH RMS 1 AND MOVE TO NON-INTERFERING LOCATION b) BERTH PLATFORM IN PAYLOAD BAY WITH RMS 2 c) DETACH OLD PAYLOAD FROM PLATFORM AND MOVE TO NON-INTERFERING LOCATION WITH RMS 2 d) ATTACH NEW PAYLOAD TO PLATFORM WITH RMS 1 e) DEPLOY PLATFORM WITH RMS 1 f) STOW OLD PAYLOAD WITH RMS 2

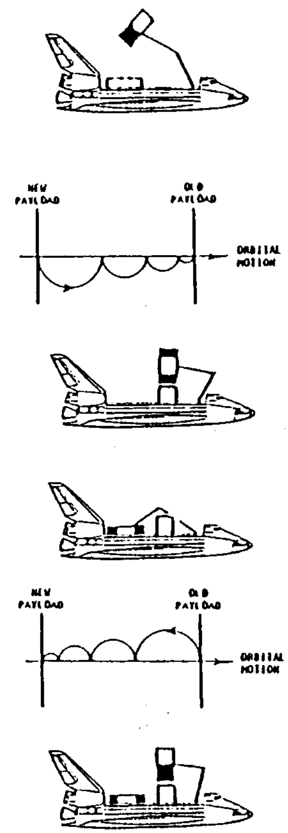
** THE ASSUMPTION WAS MADE IN ALL MISSION SCENARIOS THAT THE PLATFORM CAN BE BERTHED IN THE PAYLOAD BAY, AND THAT THE PLATFORM AND PAYLOADS ARE COMPATIBLE WITH ALL DOCKING FIXTURES

* IN SCENARIO 5 THE PLATFORM IS BERTHED TO A DOCKING FIXTURE RATHER THAN PAYLOAD BAY

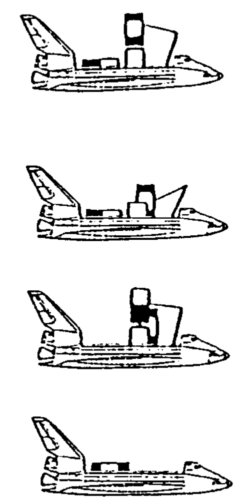
MISSION SCENARIOS FOR ON-ORBIT EXCHANGE OF VERY LARGE PAYLOADS



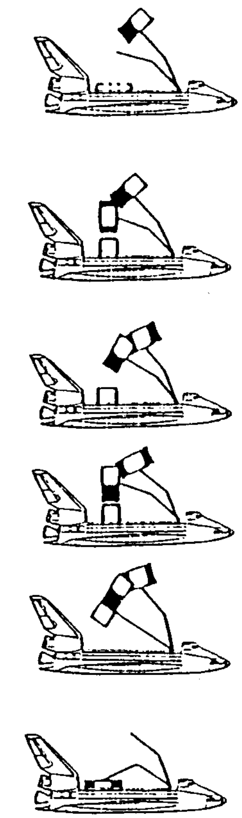
MISSION SCENARIO 1



MISSION SCENARIO 2



MISSION SCENARIO 3



MISSION SCENARIO 4, 5

SCENARIO RESULTS

Of the five scenarios presented, the first two were discounted by both Fairchild and RCA, primarily due to the fact that one or both of the payload modules would be left unattached to the orbiter and thus significantly increase the risk to mission success. This is in spite of the fact that these scenarios offer the opportunity to reduce the amount of hardware needed to carry out the exchange. Of the remaining options, those utilizing two arms were the most highly favored, as suggested by the ratings in the hardware section. A question was again raised regarding the adequacy of the RMS when left in an "unattended" mode with a large, massive payload still attached.

A difference of opinion exists between the two respondents regarding the worth of a berthing device in the payload bay as part of one of these scenarios. As mentioned previously, Fairchild would use this structure both as a berthing device and as a location to support ORUs while RCA foresees no such needs in its operations. Both agree, however, that if such a device is necessary transportation costs should be minimized.

With these caveats in mind, the best compromise solution appears to be the 1110 case using the port RMS, a sill-mounted HPA or RMS-based HPA, and the lightweight FSS.

SCENARIO RESULTS

- ALLOWING EITHER THE OLD OR NEW PAYLOAD MODULE TO DRIFT UNATTACHED SERIOUSLY JEOPARDIZES MISSION SUCCESS; ANY SCENARIO RELYING ON THIS OPTION WAS NOT HIGHLY RATED

- THOSE SCENARIOS WHICH UTILIZE TWO ARMS (STANDARD RMS AND EITHER 2ND RMS, HPA, OR RMS-BASED HPA) WERE RATED MOST HIGHLY; OF THESE 1110, 1101, AND 2100 WERE RATED HIGHEST

- A QUESTION WAS RAISED REGARDING THE ADEQUACY OF THE RMS WHEN USED AS AN "UNATTENDED" BERTHING DEVICE

- A DIFFERENCE OF OPINION EXISTS ON THE WORTH OF A FIXED BERTHING DEVICE IN THE PAYLOAD BAY, BUT IF SUCH A DEVICE IS USED, USER COSTS SHOULD BE MINIMIZED

- ON AVERAGE, THE BEST SCENARIO IS THE 1110 CASE USING THE RMS, A SILL-MOUNTED HPA OR RMS-BASED HPA, AND THE LIGHTWEIGHT FSS

SUMMARY

The results from the scenario evaluations indicate that the temporary free-drift storage of a payload is not an acceptable option. As a result, additional hardware to be provided by either NASA or the customer will be required to carry out this type of payload exchange. A recommendation which follows from this conclusion is that NASA should establish guidelines which delineate the responsibilities of NASA and the customer regarding the development, ownership, and operation of servicing hardware.

At a minimum, this additional hardware should include a second arm capability. Potential users would prefer that this arm be installed on the starboard longeron to minimize payload bay usage. A second RMS arm would be the simplest solution to this desire. However, there is some uncertainty among the potential users regarding the adequacy of the RMS as an "unattended" berthing device during that period of time when the single set of controls is used to operate the other arm. The HPA would provide a safer solution to this problem but would be more expensive in terms of development time and cost. As a result, it is recommended that a study of the RMS in its potential role as a berthing device for large, massive payloads be conducted to answer these user concerns.

CONCLUSIONS

- FREE-DRIFT STORAGE OF PAYLOAD MODULES IS NOT AN ACCEPTABLE OPTION; ADDITIONAL SERVICING HARDWARE IS REQUIRED
- AT A MINIMUM, A 2ND ARM CAPABILITY IS NEEDED
  - USERS PREFER TO MOUNT ARM ON STARBOARD LONGERON TO MINIMIZE PAYLOAD BAY USAGE
  - A SECOND RMS IS SIMPLEST SOLUTION
  - USER UNCERTAINTY EXISTS REGARDING ADEQUACY OF RMS AS AN "UNATTENDED" BERTHING DEVICE
  - HPA PROVIDES A SAFER (BUT MORE EXPENSIVE) OPTION

RECOMMENDATIONS

- NASA SHOULD PROVIDE GUIDELINES REGARDING SERVICING HARDWARE DEVELOPMENT AND OPERATIONS RESPONSIBILITIES OF NASA AND CUSTOMER
- A STUDY OF THE RMS IN A POTENTIAL ROLE AS A BERTHING DEVICE FOR LARGE, MASSIVE PAYLOADS SHOULD BE CONDUCTED TO ANSWER USER CONCERNS

SUMMARY (concluded)

In addition to a two-arm capability, the survey results indicate that a means of securing the third body to the orbiter is needed. Potential users strongly prefer to minimize the number and/or size of any in-bay berthing deivces in order to minimize transportation costs. Several possibilities exist to meet this objective. The first is the use of payload bay sill and keel latches as berthing fixtures. In this situation, existing trunnions used for spacecraft launch would be reused as the berthing interface. However, the current latch design should be evaluated for its acceptability in this role. An alternative would be to leave specially designed berthing hardware attached to the spacecraft bus and thus avoid the recurring cost of transporting equipment to and from orbit. Spacecraft designers should examine this option for its effect on overall mission cost.

If an in-bay device is required, the preferred option is the lightweight FSS. This device has potentially the lowest development and transportation cost of the hardware options presented. It also provides a location for the storage of ORUs during launch and landing. Thus, a study of lightweight cradle designs to support the FSS berthing ring is needed.

SUMMARY (CONCLUDED)

CONCLUSIONS

- A MEANS OF SECURING THE THIRD BODY TO THE ORBITER (IN ADDITION TO THOSE HELD BY THE TWO ARMS) IS NEEDED
- USERS STRONGLY PREFER TO MINIMIZE THE NUMBER AND/OR SIZE OF ANY IN-BAY BERTHING DEVICES TO MINIMIZE COST
  - PAYLOAD BAY SILL AND KEEL LATCHES COULD BE USED AS PART OF A BERTHING FIXTURE
  - ALTERNATIVE IS TO LEAVE BERTHING HARDWARE ATTACHED TO SPACECRAFT BUS
- IF AN IN-BAY DEVICE IS NEEDED, THE LIGHTWEIGHT FSS IS THE PREFERRED OPTION
  - POTENTIALLY THE LOWEST DEVELOPMENT AND TRANSPORTATION COSTS
  - ALSO PROVIDES LOCATION FOR ORU STORAGE

RECOMMENDATIONS

- ACCEPTABILITY OF CURRENT SILL AND KEEL LATCH DESIGN AS PART OF A BERTHING FIXTURE SHOULD BE ASSESSED
- CONCEPTS SHOULD BE DEVELOPED FOR ON-ORBIT STORAGE OF BERTHING HARDWARE BY MODIFICATION OF SPACECRAFT DESIGNS TO INCORPORATE THIS FUNCTION
- STUDY OF LIGHTWEIGHT CRADLE DESIGN FOR THE FSS BERTHING RING IS NEEDED

APPENDIX

This appendix contains two items which will elaborate on the results obtained from the pricing policy survey. The first item is a copy of the survey showing all questions and possible responses as seen by the participants. The second item is a summary of the responses to the survey shown as an overall response, a commercial response, and a military response. The survey questions and an abbreviated form of the possible responses are in the first two columns. Unless otherwise indicated, all results are shown as the percentage of affirmative answers taken over all responses. In some cases, the percentages may not add up to 100 percent, as some of the participants chose not to answer some of the questions. In other cases, the percentages will total more than 100 percent if the participants were asked to select "as many as apply."

Section 1 - General questions regarding overall satellite servicing issues and current NASA pricing policies.

1.1 Do you think your responses to a questionnaire on the topic of reimbursement by a customer to a satellite servicing organization are relevant if specific dollar values are not discussed (Y/N)? ____

1.2 What is the importance of a pricing policy relative to knowledge of servicing hardware availability/capability?

____ More important (i.e., pricing will decide whether servicing will be done at all)

____ Equally important (i.e., servicing will be done but specific design trades cannot be made without pricing information)

____ Less important (i.e., servicing provides the best means of accomplishing a mission; therefore, higher costs can be tolerated)

1.3 Are you familiar with the current "STS Reimbursement Guide" and the "Retrieval/Revisit Policy"?

Reimbursement Guide ____ Yes ____ No

Retrieval/Revisit Policy ____ Yes ____ No

If your answer to either of the above questions is yes, please select one of the responses from the following list:

____ A. The current STS policy is adequate for future satellite servicing needs.

____ B. The current STS policy is basically the correct approach but needs to be expanded and updated.

____ C. The current STS policy is entirely inappropriate and should be replaced.

1.4 If satellite servicing price guidelines exist, how should NASA publish the charges for services it renders?

____ As a single fixed price based on the type of servicing activity.

____ As fixed price ranges with the final price negotiated on a case by case basis.

____ Other (specify) ________________________________

1.5 Should STS launch slots/payload reservations for satellite servicing missions be:

____ Awarded to the highest bidder

____ Assigned on a first come - first served basis

Regardless of the answer selected above, should provisions be made to assign top priority to a servicing mission if the target spacecraft is in danger of being lost should servicing be delayed (Y/N)? ____

1.6 What should be the driving factor behind the costs charged to a customer by NASA?

____ A. Recovery of all NASA costs, both development and operations.

____ B. Recovery of NASA operations costs only.

____ C. User demand: lower than NASA costs charged to encourage startup, higher than NASA costs charged when competition for NASA services begins.

____ D. Other (specify) ________________________________

1.7 How do you perceive the relative costs of basic satellite servicing phases? Please answer by rating the following mission phases from 1 (most costly) to 4 (least costly) for each column.

	NASA Cost	Customer Cost
Prelaunch (R&D, tool usage fees, training, insurance, etc.)	____	____
Launch (standard STS launch cost)	____	____
On-orbit (rendezvous, servicing, product retrieval, etc.)	____	____
Return (reentry preparation, post flight ground operations, etc.)	____	____

1.8 Given the STS launch costs in effect at the time of the Challenger accident, how many existing and proposed LEO spacecraft (at all orbit inclinations) would benefit from on-orbit servicing?

____ None ____ Some ____ Most ____ All

How many Shuttle flights (per year) would be needed to support all of these vehicles?

____ None ____ Fewer than 1 ____ 1 to 3 ____ 4 or more

If other servicing-related charges were added to the existing launch costs, how many of these same spacecraft would still benefit from on-orbit servicing?

____ None ____ Some ____ Most ____ All

How many Shuttle flights (per year) would be needed to support all of these vehicles?

____ None ____ Fewer than 1 ____ 1 to 3 ____ 4 or more

1.9 What effect will the Shuttle accident, the indefinite postponement of future Shuttle flights, and the apparent removal of commercial payloads from near-term flights, have on planning for satellite servicing?

____ A. Eliminate all planning for future satellite servicing missions

____ B. Substantially reduce this planning

____ C. Only moderately affect this planning

____ D. Have no impact on this planning

____ E. Increase planning

Section 2 - Questions concerning hardware development and procurement

2.1 Regarding satellite servicing hardware development, should:

____ the spacecraft owner develop its own hardware, train its own payload specialists, and manage its own satellite servicing

or

____ NASA be reimbursed for handling these tasks

or

____ the responsibility be shared by NASA, the spacecraft owner, and other organizations (as appropriate).

2.2 Would the existence of economic incentives from NASA for satellite servicing operations encourage users to pursue servicing as a viable alternative?

____ A. Yes, if the cost of the actual servicing mission were below some threshold, most users would definitely pursue servicing as an option.

____ B. Possibly; however, there are many more variables to consider in addition to the cost of the actual servicing mission which are of equal importance.

____ C. No, most users have determined that for other reasons, satellite servicing is not an acceptable option.

2.3 What incentives can NASA use to encourage private development and/or procurement of servicing hardware which would be available to the entire user community?

____ A. An eventual buy-back by NASA as an outright purchase or in exchange for NASA services.

____ B. Guarantee by NASA that no competing hardware will be flown on the Shuttle for a fixed period of time.

____ C. Guaranteed usage rate by NASA for NASA missions.

____ D. Other (specify) ____

2.4 Would servicing activity be encouraged if servicing related costs were eliminated for the first several flights and subsequent payments made by installment (with interest)?

____ Yes ____ In some cases ____ No

2.5 Which option will provide for the most timely buildup of satellite servicing hardware?

____ Hardware developed on an as-needed basis by the first user and optimized for the requirements of that first user. This hardware would then be available to other users subject to terms set by the developer.

____ A formal or ad hoc group of interested organizations (both government and industry) would contribute to the development of hardware which is driven by, but not limited to, the requirements of the first user. Priority among members for use of this hardware and/or distribution of revenue generated by usage fees would be based on the initial contribution to the development effort.

____ Other (specify) ____

2.6 Who should own satellite servicing hardware?

____ A. NASA should procure and own all servicing hardware regardless of the number of potential users: all servicing customers would have access to this servicing hardware "pool."

____ B. NASA should procure and own only general purpose items (e.g. satellite holding device, tanker, etc.) while each spacecraft should provide its own small and/or specialized tools.

____ C. Each spacecraft owner should be responsible for procurement of all necessary servicing hardware.

2.7 As an economic incentive for users, NASA should treat the first flight of each servicing activity "type" as a technology demonstration and fly that mission at no cost to the user. Subsequent missions would be charged the "standard" rate for that mission type as determined by NASA.

____ A. This is a good idea and would encourage users to consider satellite servicing as an option.

____ B. This is a reasonable idea and would be practical for some but not all future satellite servicing users.

____ C. Implementing this strategy would have no effect on whether users design their vehicles to include servicing capabilities.

Section 3 - Questions concerning servicing operations and reimbursement options.

3.1 To what level of detail should the NASA reimbursement policy be specified in advance to allow users to conduct macroscopic trade studies of their servicing options?

____ A. Bottom line, total cost number only for each servicing mission type (i.e., refueling mission, an ORU replacement mission, etc.).

____ B. The range (min,max) for a particular servicing activity with the final cost subject to mission requirements and negotiations with NASA.

____ C. A complete and detailed cost breakdown for every aspect of a particular servicing activity.

3.2 Which of the following methods of reimbursement would be desirable from the customer's perspective? As a separate issue, which would be practical to implement? (Mark as many as apply.)

Desirable	Practical	
( )	( )	- Fixed fee payable in a lump sum prior to launch
( )	( )	- Fixed fee payable in increments prior to launch
( )	( )	- Fixed fee partially paid in advance, the remainder paid (possibly with interest) after the mission
( )	( )	- Barter; type and quantity of bartered items negotiated on a case-by-case basis
( )	( )	- Percentage of future revenues generated by the vehicle being serviced
( )	( )	- Other (specify)

3.3 Assume a "standard" set of mission operations (e.g. rendezvous procedure, EVA/IVA timelines for specific activities, predefined location and size for umbilical connections, etc.) were made available at a fixed cost lower than that of a unique mission which accomplishes the same objective. At what percentage of the unique mission cost will customers begin to adapt their spacecraft design and/or operation to meet the standard?

____ 75 - 100 percent

____ 50 - 74 percent

____ 25 - 49 percent

____ less than 25 percent

____ Users will optimize their design and operations for maximum performance while continuing to pay the cost for a unique mission.

3.4 From the customer's perspective, which of these potential charges are reasonable for NASA to levy on the user (as opposed to costs which are part of normal NASA operations):

Charge Customer	NASA Overhead	Uncertain	
( )	( )	( )	- Manifest booking fee (to hold launch slot)
( )	( )	( )	- Mission design and planning (including software development)
( )	( )	( )	- Document preparation and tracking (for PIP, PIP annexes, and ICDs)
( )	( )	( )	- Ground control crew training
( )	( )	( )	- Flight crew training
( )	( )	( )	- Hardware usage fee (i.e., "rent" for NASA owned tools such as a large holding device, tanker, OMV, etc.)
( )	( )	( )	- Government-furnished expendables (OMS propellant, OMV propellant, power, etc.)
( )	( )	( )	- Launch cost (standard STS cost based on length or mass of payload)
( )	( )	( )	- On-orbit operations cost based on specific activities

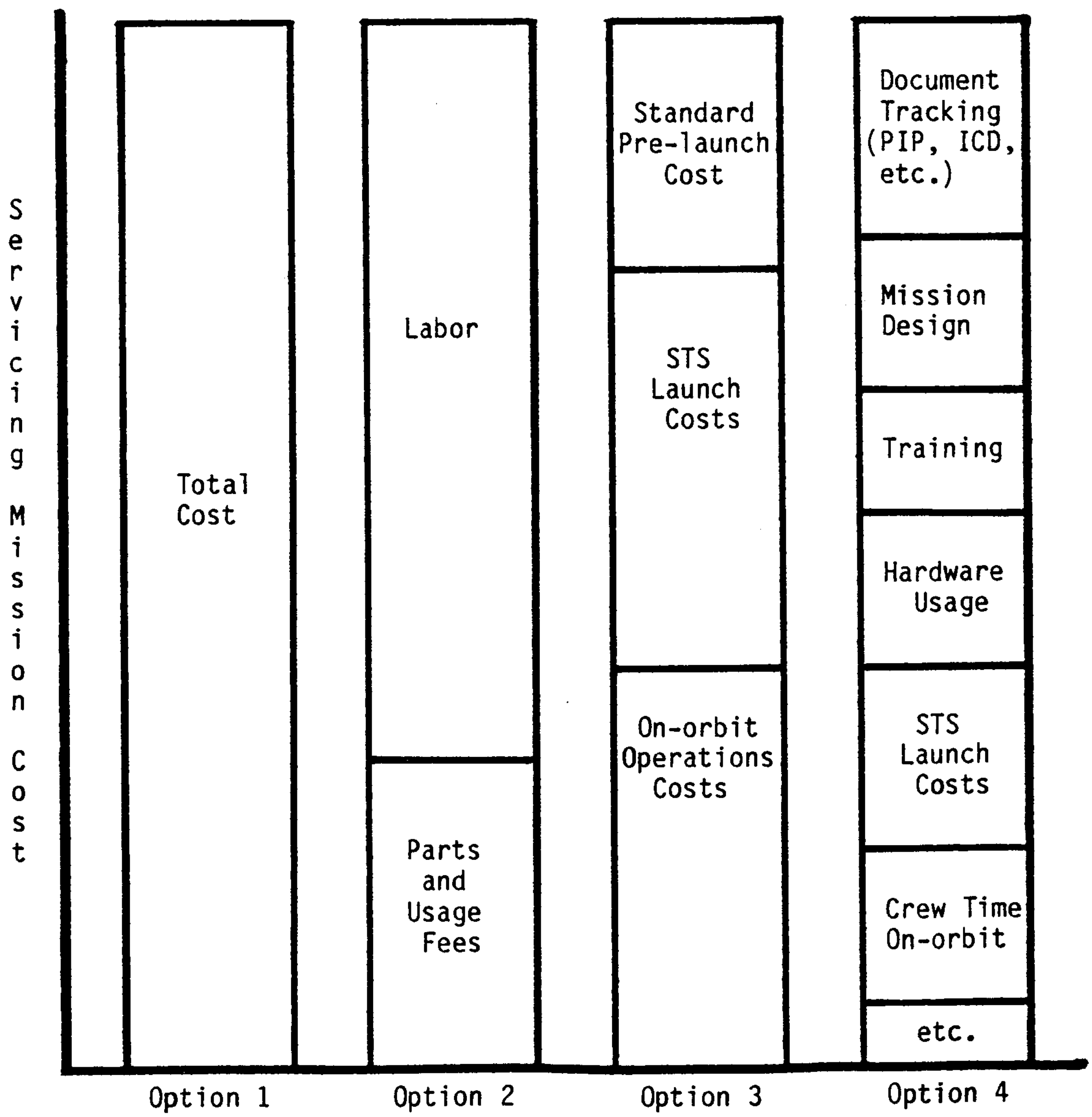
( ) ( ) ( ) - On-orbit operations costs based on the time required to complete the entire servicing mission

( ) ( ) ( ) - Secure payload data link with ground

( ) ( ) ( ) - Payload return (based on length or mass of payload)

( ) ( ) ( ) - Recovery of hardware development costs (independent of "rent" charge described above)

3.5 For this question it has been assumed that NASA has determined a total mission cost to the customer based on customer requirements. Which of the following four options of the planned "invoice" will best help the user to plan and prepare for this mission: ____



3.6 How should the overall organization of satellite servicing be structured:

____ A. Status quo: all missions are processed by NASA or DoD; all costs are negotiated on a case-by-case basis.

____ B. A structure with some of the features of options A and C.

____ C. Arianespace- or Comsat-type corporation: a public or semipublic organization offering on-orbit servicing to its members and to nonmembers; the corporation would be operated on a break-even or for profit basis; new members could buy into the corporation as desired.

____ D. A structure with some of the features of options C and E.

____ E. A private corporation with some TBD level of government backing and/or incentives (e.g., exclusive access to the STS, guaranteed level of usage by the government, etc.)

3.7 Should NASA be financially liable for launch schedule delays or post-launch failures which result in loss of space-manufactured products or damage to a customer's spacecraft? (Y/N) ____

3.8 Should a customer be financially liable for damage to NASA-owned equipment or injury to NASA personnel while servicing the customer's spacecraft? (Y/N) ____

3.9 The current NASA reimbursement guide for optional payload operations states that if the servicing operation is flown at NASA's convenience (i.e., piggybacked with a "primary" mission) then the costs paid by the servicing user are limited to any additional time in orbit for operations and any other additional services as required (e.g., EVA, etc.) In your opinion:

____ A. Most (>75%) satellite operations can (or will) be performed as piggyback missions.

____ B. Some (approximately 50%) will be piggyback missions.

____ C. Few (<25%) will be piggyback missions.

3.10 Given that the Shuttle has a limited amount of time during which it can stay in orbit and that the crew will be available for some smaller fraction of this time (due to activities such as meals and sleep), what is the preferred method of compensation for the on-orbit time devoted to servicing activities by the Shuttle and its crew:

____ A. A single charge based solely on the number of hours the crew is actively involved with the spacecraft regardless of the total time the spacecraft is docked to the Shuttle.

____ B. A single charge based solely on the total time required to complete the servicing mission: beginning at initiation of the rendezvous sequence and ending at redeployment.

____ C. A set of charges based on definable activities: EVA workhours, IVA workhours, and total time from rendezvous to redeployment.

____ D. Other (specify) ______________________________

3.11 Which option best describes the mixture of fixed and negotiable costs which should be established for future servicing missions (choose one only):

____ A. All aspects subject to negotiation; no fixed costs (including launch costs).

____ B. Some combination of options A and C.

____ C. Fixed costs (or minimum and maximum cost range) for those aspects common to all servicing missions (e.g., the existing STS pricing policy for launch, the retrieval/revisit policy, etc.); costs for unique mission aspects negotiated on a case-by-case basis.

____ D. Some combination of options C and E.

____ E. No negotiations; all costs fixed and published in a detailed listing (in $/hr, $/activity, $/kg, etc.) for servicing activities.

3.12 Regarding actual reimbursement procedures, select as many of the following as apply:

NASA should be reimbursed:

____ A. In full before any satellite servicing mission.

____ B. In full before flight but only for dedicated servicing missions.

____ C. In full after any satellite servicing mission.

____ D. In full after flight for those missions conducted at NASA's convenience.

____ E. In part before flight and the balance upon completion of the servicing mission.

____ F. Other (specify) ______________________________

3.13 To which of the survey questions would you have been able to provide more meaningful answers if specific dollar values had been included?

____ 1.2	____ 2.1	____ 3.1
____ 1.3	____ 2.2	____ 3.2
____ 1.4	____ 2.3	____ 3.3
____ 1.5	____ 2.4	____ 3.4
____ 1.6	____ 2.5	____ 3.5
____ 1.7	____ 2.6	____ 3.6
____ 1.8	____ 2.7	____ 3.7
____ 1.9		____ 3.8
		____ 3.9
		____ 3.10
		____ 3.11
		____ 3.12

Total Commercial Responses = 12
Total Military Responses = 13

QUESTION	POSSIBLE RESPONSE	TOTAL RESPONSE	COMMERCIAL RESPONSE	MILITARY RESPONSE
1.1 Do you think your responses to a questionnaire on the topic of reimbursement by a customer to a satellite servicing organization are relevant if specific dollar values are not discussed (Y/N)?	Yes = 1	76.0	83.3	69.2
	No = 0			
	No Response = 0			
1.2 What is the importance of a pricing policy relative to knowledge of servicing hardware availability/capability?	More Important	48.0	58.3	38.5
	Equally Important	40.0	25.0	53.8
	Less Important	12.0	16.7	7.7
1.3 Are you familiar with the current "STS Reimbursement Guide" and the "Retrieval/ Revisit Policy"?	Reimbursement Guide	48.0	58.3	38.5
	Retrieval Policy	24.0	25.0	23.1
If your answer to either of the above options is yes, characterize the adequacy of these policies.	Adequate	0.0	0.0	0.0
	Expand	36.0	41.7	30.8
	Inappropriate	16.0	25.0	7.7
1.4 If satellite servicing price guidelines exist, how should NASA publish the charges for services it renders?	Single, Fixed Price	8.0	8.3	7.7
	Range, Negotiated	76.0	75.0	76.9
	Other	20.0	25.0	15.4
1.5 Should STS launch slots/payload reservations for satellite servicing missions be:	Highest Bidder	28.0	16.7	38.5
	First Come - First Served	60.0	75.0	46.2
Should spacecraft needing immediate repairs be assigned top priority for a servicing mission	Emergency Provision	84.0	83.3	84.6

QUESTION	POSSIBLE RESPONSE	TOTAL RESPONSE	COMMERCIAL RESPONSE	MILITARY RESPONSE
1.6 What should be the driving factor behind the costs charged to a customer by NASA?	Recover All Costs	12.0	0.0	23.1
	Recover Operations Costs	32.0	50.0	15.4
	User Demand	44.0	50.0	38.5
	Other	8.0	0.0	15.4
1.7 How do you perceive the relative costs of basic satellite servicing phases?	NASA Prelaunch	2.2	2.6	1.8
	NASA Launch	1.5	1.3	1.7
(1=Most Costly, 4=Least Costly; results show averaged response over all participants)	NASA On-Orbit	2.8	2.5	3.1
	NASA Return	3.3	3.4	3.3
	Customer Prelaunch	2.2	1.9	2.5
	Customer Launch	1.9	1.8	1.9
	Customer On-Orbit	2.4	2.5	2.3
	Customer Return	3.3	3.3	3.4
1.8 Given the STS launch costs in effect at the time of the Challenger accident, how many existing and proposed LEO spacecraft (at all orbit inclinations) would benefit from on-orbit servicing?	Present Costs	2.6	2.7	2.5
	Flight/Year	3.5	3.3	3.7
	Additional Costs	2.4	2.2	2.5
	Flight/Year	3.5	3.3	3.7

Results show averaged response over all participants. Key to responses:

	Cost	Flights/Yr
1	None	None
2	Some	Fewer than 1
3	Most	1 to 3
4	All	4 or more

	QUESTION	POSSIBLE RESPONSE	TOTAL RESPONSE	COMMERCIAL RESPONSE	MILITARY RESPONSE
1.9	What effect will the Shuttle accident, the indefinite postponement of future Shuttle flights, and the apparent removal of commercial payloads from near-term flights, have on planning for satellite servicing?	Eliminate All	4.0	8.3	0.0
		Substantially Reduce	40.0	41.7	38.5
		Moderately Affect	32.0	41.7	23.1
		No Impact	8.0	8.3	7.7
		Increase Planning	16.0	0.0	30.8
2.1	Regarding satellite servicing hardware development, should the spacecraft owner develop its own hardware, train its own payload specialists, and manage its own satellite servicing, or NASA be reimbursed for handling these tasks, or the responsibility be shared by NASA, the spacecraft owner, and other organizations (as appropriate).	Spacecraft Owner	4.0	0.0	7.7
		NASA	0.0	0.0	0.0
		Shared Responsibility	92.0	91.7	92.3
2.2	Would the existence of economic incentives from NASA for satellite servicing operations encourage users to pursue servicing as a viable alternative?	Yes	32.0	16.7	46.2
		Possibly	64.0	75.0	53.8
		No	0.0	0.0	0.0
2.3	What incentives can NASA use to encourage private development and/or procurement of servicing hardware which would be available to the entire user community?	NASA Buy-back	48.0	58.3	38.5
		No Competition	16.0	16.7	15.4
		Guaranteed Usage	40.0	41.7	38.5
		Other	20.0	25.0	15.4
2.4	Would servicing activity be encouraged if servicing related costs were eliminated for the first several flights and subsequent payments made by installment (with interest)?	Yes	32.0	41.7	23.1
		Some Cases	56.0	41.7	69.2
		No	8.0	8.3	7.7

QUESTION		POSSIBLE RESPONSE	TOTAL RESPONSE	COMMERCIAL RESPONSE	MILITARY RESPONSE
2.5	Which option will provide for the most timely buildup of satellite servicing hardware?	As-needed Basis	36.0	41.7	30.8
		Ad Hoc Group	48.0	33.3	61.5
		Other	20.0	33.3	7.7
2.6	Who should own satellite servicing hardware?	All to NASA	24.0	16.7	30.8
		General NASA	64.0	66.7	61.5
		Spacecraft Owner	4.0	0.0	7.7
2.7	As an economic incentive for users, NASA should treat the first flight of each servicing activity "type" as a technology demonstration and fly that mission at no cost to the user. Subsequent missions would be charged the "standard" rate for that mission type as determined by NASA.	Good Idea	28.0	33.3	23.1
		Reasonable Idea	52.0	50.0	53.8
		No Effect	20.0	16.7	23.1
3.1	To what level of detail should the NASA reimbursement policy be specified in advance to allow users to conduct macroscopic trade studies of their servicing options?	Bottom Line	4.0	0.0	7.7
		Range	60.0	66.7	53.8
		Complete Detail	36.0	33.3	38.5
3.2	Which of the following methods of reimbursement would be desirable from the customer's perspective?	Fixed Total	8.0	8.3	7.7
		Fixed Increment	20.0	8.3	30.8
		Fixed Partial	60.0	58.3	61.5
		Barter	36.0	33.3	38.5
		Percentage of Revenues	40.0	58.3	23.1
		Other	4.0	0.0	7.7

QUESTION	POSSIBLE RESPONSE	TOTAL RESPONSE	COMMERCIAL RESPONSE	MILITARY RESPONSE
As a separate issue, which would be practical to implement?	Fixed Total	44.0	16.7	69.2
	Fixed Increment	44.0	33.3	53.8
	Fixed Partial	80.0	83.3	76.9
	Barter	24.0	16.7	30.8
	Percentage of Revenues	20.0	33.3	7.7
	Other	4.0	0.0	7.7
3.3 Assume a "standard" set of mission operations (e.g., rendezvous procedure, EVA/IVA timelines for specific activities, predefined location and size for umbilical connections, etc.) were made available at a fixed cost lower than that of a unique mission which accomplishes the same objective. At what percentage of the unique mission cost will customers begin to adapt their spacecraft design and/or operation to meet the standard?	75-100%	12.0	8.3	15.4
	50-74%	8.0	8.3	7.7
	25-49%	24.0	25.0	23.1
	< 25%	8.0	8.3	7.7
	None	32.0	41.7	23.1
3.4 From the customer's perspective, which of these potential charges are reasonable for NASA to levy on the user (as opposed to costs which are part of normal NASA operations):				
Manifest Booking Fee	Customer	64.0	58.3	69.2
	NASA	24.0	25.0	23.1
Mission Design	Customer	44.0	41.7	46.2
	NASA	36.0	33.3	38.5
Document Preparation	Customer	16.0	8.3	23.1
	NASA	64.0	66.7	61.5
Ground Control Crew Training	Customer	16.0	16.7	15.4
	NASA	76.0	75.0	76.9

QUESTION	POSSIBLE RESPONSE	TOTAL RESPONSE	COMMERCIAL RESPONSE	MILITARY RESPONSE
Flight Crew Training	Customer	20.0	33.3	7.7
	NASA	64.0	41.7	84.6
Hardware Usage Fee	Customer	68.0	75.0	61.5
	NASA	24.0	16.7	30.8
Expendables	Customer	60.0	58.3	61.5
	NASA	28.0	25.0	30.8
Launch Costs	Customer	72.0	75.0	69.2
	NASA	20.0	16.7	23.1
On-Orbit Operations Costs Based on Activities	Customer	68.0	66.7	69.2
	NASA	8.0	0.0	15.4
On-Orbit Operations Costs Based on Total Time	Customer	52.0	50.0	53.8
	NASA	20.0	8.3	30.8
Secure Payload Data Link	Customer	32.0	25.0	38.5
	NASA	52.0	66.7	38.5
Payload Return	Customer	60.0	58.3	61.5
	NASA	28.0	33.3	23.1
Hardware Development Costs	Customer	8.0	8.3	7.7
	NASA	68.0	58.3	76.9
3.5 For this question it has been assumed that NASA has determined a total mission cost to the customer based on customer requirements. Which of the following four options of the planned "invoice" will best help the user to plan and prepare for this mission. (Results show averaged response over all participants)	1 - 4	3.8	3.8	3.7
3.6 How should the overall organization of satellite servicing be structured?	Status Quo	20.0	8.3	30.8
	Combination of A & C	32.0	33.3	30.8
	Public Corp.	20.0	25.0	15.4
	Combination of C & E	20.0	16.7	23.1
	Private Corp.	4.0	8.3	0.0

QUESTION	POSSIBLE RESPONSE	TOTAL RESPONSE	COMMERCIAL RESPONSE	MILITARY RESPONSE
3.7 Should NASA be financially liable for launch schedule delays or post-launch failures which result in loss of space-manufactured products or damage to a customer's spacecraft?	Yes = 1	60.0	58.3	61.5
	No = 0			
	No Response = 0			
3.8 Should a customer be financially liable for damage to NASA-owned equipment or injury to NASA personnel while servicing the customer's spacecraft?	Yes = 1	40.0	33.3	46.2
	No = 0			
	No Response = 0			
3.9 The current NASA reimbursement guide for optional payload operations states that if the servicing operation is flown at NASA's convenience (i.e., piggybacked with a "primary" mission) then the costs paid by the servicing user are limited to any additional time in orbit for operations and any other additional services as required (e.g., EVA, etc.). What percentage of satellite operations can (or will) be performed as piggyback missions?	Most (> 75%)	44.0	25.0	61.5
	Some (50%)	28.0	33.3	23.1
	Few (< 25%)	20.0	33.3	7.7
3.10 Given that the Shuttle has a limited amount of time during which it can stay in orbit and that the crew will be available for some smaller fraction of this time (due to activities such as meals and sleep), what is the preferred method of compensation for the on-orbit time devoted to servicing activities by the Shuttle and its crew?	Single, Activity	8.0	16.7	0.0
	Single, Time	20.0	16.7	23.1
	Set Charges, Activity	64.0	66.7	61.5
	Other	8.0	0.0	15.4

QUESTION	POSSIBLE RESPONSE	TOTAL RESPONSE	COMMERCIAL RESPONSE	MILITARY RESPONSE
3.11 Which option best describes the mixture of fixed and negotiable costs which should be established for future servicing missions (choose one only).	All Negotiable	4.0	8.3	0.0
	Combination of A & C	36.0	33.3	38.5
	Fixed Costs	40.0	41.7	38.5
	Combination of C & E	12.0	8.3	15.4
	All Fixed Costs	4.0	8.3	0.0
3.12 Regarding actual reimbursement procedures, select as many of the following as apply. NASA should be reimbursed:	In Full Before Any Mission	0.0	0.0	0.0
	In Full Before Dedicated Missions	12.0	0.0	23.1
	In Full After	8.0	0.0	15.4
	In Full After Mission at NASA's Convenience	24.0	8.3	38.5
	In Part Before	80.0	100.0	61.5
	Other	4.0	0.0	7.7
3.13 To which of the survey questions would you have been able to provide more meaningful answers if specific dollar values had been included?	1.2	24.0	25.0	23.1
	1.3	12.0	25.0	0.0
	1.4	16.0	8.3	23.1
	1.5	4.0	0.0	7.7
	1.6	12.0	16.7	7.7
	1.7	36.0	41.7	30.8
	1.8	20.0	33.3	7.7

QUESTION	POSSIBLE RESPONSE	TOTAL RESPONSE	COMMERCIAL RESPONSE	MILITARY RESPONSE
3.13 (continued)	1.9	4.0	8.3	0.0
	2.1	8.0	0.0	15.4
	2.2	36.0	50.0	23.1
	2.3	8.0	0.0	15.4
	2.4	8.0	8.3	7.7
	2.5	4.0	8.3	0.0
	2.6	4.0	8.3	0.0
	2.7	12.0	25.0	0.0
	3.1	20.0	16.7	23.1
	3.2	20.0	25.0	15.4
	3.3	36.0	50.0	23.1
	3.4	32.0	41.7	23.1
	3.5	4.0	0.0	7.7
	3.6	4.0	0.0	7.7
	3.7	4.0	0.0	7.7
	3.8	4.0	0.0	7.7
	3.9	4.0	8.3	0.0
	3.10	20.0	25.0	15.4
	3.11	24.0	25.0	23.1
	3.12	4.0	8.3	0.0