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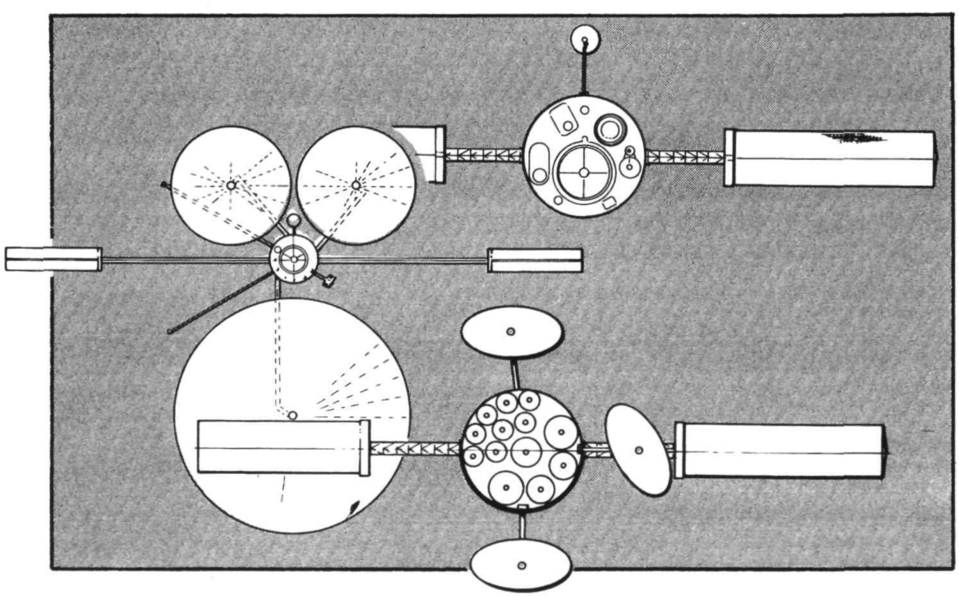
GEOSYNCHRONOUS PLATFORM DEFINITION STUDY

Volume VI

GEOSYNCHRONOUS PROGRAM EVALUATION AND RECOMMENDATIONS



JUNE 1973

Space Division
Rockwell International

12214 Lakewood Boulevard
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H L Myers

H. L. Myers
GPDS STUDY MANAGER

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FOREWORD

The Geosynchronous Platform Definition Study was a pre-Phase A analysis conducted by the Space Division of Rockwell International Corporation (Rockwell) under Contract NAS9-12909 for the Lyndon B. Johnson Space Center of the National Aeronautics and Space Administration. The study explores the scope of geosynchronous traffic, the needs and benefits of multifunction space platforms, transportation system interfaces, and the definition of representative platform conceptual designs. The work was administered under the technical direction of Mr. David Brown (Telephone 713-483-6321) of the Program Planning Office/Future Programs Division of the Lyndon B. Johnson Space Center.

This report consists of the following seven volumes:

Volume I - Executive Summary	SD 73-SA-0036-1
Volume II - Overall Study Summary	SD 73-SA-0036-2
Volume III - Geosynchronous Mission Characteristics	SD 73-SA-0036-3
Volume IV, Part 1 - Traffic Analysis and System Requirements for the Baseline Traffice Model	SD 73-SA-0036-4 Part 1
Volume IV, Part 2 - Traffic Analysis and System Requirements for the New Traffic Model	SD 73-SA-0036-4 Part 2
Volume V - Geosynchronous Platform Synthesis	SD 73-SA-0036-5
Volume VI - Geosynchronous Program Evaluation and Recommendations	*SD 73-SA-0036-6*
Volume VII - Geosynchronous Transportation Requirements	SD 73-SA-0036-7

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E. G. Clegg	Spacecraft Design
K. B. Roberts	Operations Analysis
A. Gianformaggio	Cost Analysis
D. W. Earle	System Integration
R. E. Ogelvie	Guidance and Control
R. P. Arras	Thermal Control
W. C. Schmill	Electrical Power
J. B. Weddell	Astro-Physics Programs
E. F. Kraly	Sensor Systems Analysis

CONTENTS

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ILLUSTRATIONS

TABLES

ABBREVIATIONS

ASCS	Attitude stabilization and control system
ATS	Applications Technology Satellite
CCD	Charge coupled device
CCIR	Consultative Committee for International Radio
CM	Crew module
C/N	Carrier-to-noise ratio
COMM	Communications
Comsat	Communications Satellite
CSM	Common support module
DMS	Data management subsystem
Domsat	Domestic Communications Satellite
ECS	Environmental control subsystem
EIRP	Effective isotropic radiated power
EPS	Electrical power subsystem
FDMA	Frequency division multiplexing
FM	Frequency modulation
GEOPAUSE	Geodetic satellite in polar geosynchronous orbit
Geoseps	Geosynchronous solar electric propulsion stage
Intelsat	International Communication Satellite
IPACS	Integrated power and attitude control system
Mersat	Metrology and Earth Observations Satellite
Navsat	Navigation and Traffic Control Satellite

OTS	Orbital transportation system
PCM	Pulse code modulation
PSK	Phase shift keying
RCS	Reaction control subsystem
RSU	Remote service unit
SATA	Small Application Technology Satellite
SEP	Solar electric propulsion
SGLS	Space-ground link subsystem (part of U.S. Air Force Satellite Control Facility)
SNR	Signal-to-noise ratio
SSM	Spares storage module
STDN	Spaceflight tracking and data network
STS	Space transportation system
TDMA	Time division multiple access
TDRS	Tracking and Data Relay Satellite
TPS	Thermal protection subsystem
TT&C	Tracking, telemetry and command
UHF	Ultra high frequency
VHF	Very high frequency
WARC	World Administrative Radio Conference
XMTR	Transmitter

1.0 INTRODUCTION

This volume, Geosynchronous Program Evaluation and Recommendations, presents the programmatic analyses conducted to achieve the objectives of the Geosynchronous Platform Definition Study. It examines the characteristics of alternate geosynchronous programs based on the servicing concepts, geosynchronous platform configurations, and equipment definitions discussed in Volume V.

The logistics support necessary to carry out programs using these systems are defined considering alternate approaches for on-orbit servicing of defined programs. The costs of the resultant programs are then determined and the alternate program approaches compared. Conventional programs with expendable satellites are also defined to the extent necessary to permit comparison with on-orbit serviced platform programs.

During these analyses, primary emphasis was placed on the examination, comparison, and evaluation of alternate program approaches using a consistent comparison base. This base was provided by defining alternate platform programs which had a time-phased, on-orbit operational capability which was at least equivalent to the operational capabilities of the satellite traffic models defined in Volume IV. In addition, common space transportation systems were used to initiate and support all alternate program approaches examined. Thus, the number of programmatic variables were reduced, permitting a more direct comparison and evaluation of the alternate program approaches.

Independent evaluations were conducted for the baseline and the new traffic models. In this manner, program sensitivity to the number of spacecraft, one element in the program evaluation criteria, was determined.

2.0 SUMMARY

The fundamental purposes of the program evaluation activity were to compare alternate on-orbit serviced platform programs and to develop a recommended geosynchronous platform program approach based on these comparisons and on the platform configurations, and servicing system concepts developed in Volumes IV and V. The basic program approaches considered in the study included on-orbit serviced platform programs for both the baseline and new traffic models. Within this family of possible program approaches, single function and multiple function platforms were examined with both remote and manned servicing. To parametrically assess the impact of the servicing operations on the total program costs, a limited set of alternate servicing levels and frequencies was examined. The values examined were selected for the purpose of establishing the impact and program sensitivity to the servicing level and frequency, and do not necessarily represent the values which will ultimately be required in an operational program. Relatively high servicing levels and frequencies were selected to ensure that the impact of these considerations would be evident. These analyses resulted in the examination of four single-function platform programs and twelve multiple function platform programs. In addition, the characteristics of conventional expendable satellite programs were developed for both the baseline and new traffic models. These programs were developed only to the extent necessary to permit a general comparison of platform programs with conventional satellite programs.

The principal program evaluation activities consisted of the development of spacecraft delivery schedules; spacecraft, shuttle, and tug launch schedules; and program costs. The launch schedules and the program costs provided the basis for selecting the preferred program alternative. These data, plus the spacecraft concept considerations, provided the basis for defining the preferred geosynchronous platform program approach. The basic input data required for these analyses were the traffic models, satellite population histories, and platform and servicing systems defined in Volumes IV and V.

The initial program evaluation task centered on the development of platform delivery schedules which produced the same on-orbit operational capability as that defined by the baseline and new traffic models. These schedules determined when platform deliveries would be required and provided the basis for the subsequent development of shuttle/tug launch schedules. During the development of the platform schedules, the required geographic distribution of platforms was also considered to ensure that world-wide operational capability could be provided. In order to establish total program costs, it was necessary to then define the required shuttle/tug launch schedules for platform delivery, mission equipment updates, and on-orbit servicing of the platforms. The required launch schedules were determined by combining platform deliveries, mission equipment updates, and servicing missions where possible.

The constraints imposed during the development of the shuttle/tug launch schedules were the physical volume within the shuttle cargo bay and the performance capability of a reusable tug. Payloads (or combinations of payloads) up to 290 inches in length can be installed in the shuttle cargo bay with a 35-foot reusable tug, if a docking module is not installed. With a docking module, the maximum length is reduced to 210 inches. The principal reusable tug characteristic considered was the payload delivery and/or return capability. During the assessment of the groupability of missions, the effects of on-orbit maneuvers on the tug payload capability were incorporated. Thus, a pure placement mission would have a lower on-orbit delta-V requirement than a delivery plus servicing mission with corresponding differences in the tug payload capabilitiy.

During the development of the shuttle/tug launch schedules, the required platform deliveries, mission equipment updates, and servicing missions were identified. In addition, the required delivery weights for placement and the required return weights for update and servicing missions were determined. Payload lengths were also identified considering the spares storage volume required for servicing missions. The total logistics requirements for each year were then examined to determine the required number of shuttle/tug launches without exceeding the dimensional and performance capabilities of these systems. For each candidate multiple mission opportunity, the capability to perform the mission was verified by calculating the tug on-orbit maneuver requirements and the resultant impact on the payload capability.

The shuttle/tug launch schedules, plus the definitions of the platforms and servicing systems, provided the basis for the development of total program costs. The resultant costs, plus considerations of the number of hardware end items, the number of operational spacecraft on-orbit, and the program demands placed on the shuttle and tug, provided the basis for defining a preferred program alternative. Of the program alternatives considered during this study, the remotely serviced multiple function platform alternative is preferred. This alternative offers the following advantages:

1. It requires the least number of hardware end items because mission functions have been combined into compatible groupings.

2. It results in the least number of operational spacecraft on-orbit.

3. It requires the lowest shuttle/tug launch requirements due to the reduced number of elements to be delivered and serviced, and, as a result of the above,

4. It has the lowest total program costs.

There are additional factors which must be considered in the final selection of a recommended geosynchronous platform program approach. These include the need for further identification and refinement of geosynchronous traffic characteristics and payload groupability and integrations requirements. Also, the program flexibility offered by the selected platform design approach must be considered, particularly its adaptability to changing traffic needs and servicing modes or operations. Although no significant drivers were identified which require manned servicing of platforms during the program period examined (through 1990), man offers unique capabilities for in situ judgement and adaptability for handling the "unexpected". Thus, it is important to retain the flexibility for this option until more definitive data become available.

Based on the principal study results and insights gained during the conduct of the study, a recommended geosynchronous program approach was formulated. Its important features are summarized below.

- It is recommended that efforts be continued toward the identification and refinement of geosynchronous traffic characteristics. Significant progress was made during this study. Many new functions were identified along with several very advanced concepts offering vast benefits to mankind. A model framework including rationale and construction techniques was also produced. However, new sensors, new technologies. and new populations of users are emerging which require continued attention in updating traffic characteristics.

- It is also recommended that feasible payload grouping options be applied in future program/system definition activities. Additional and/or different groupings may be possible as new and better definitions of geosynchronous traffic become available. Further efforts are required on mission equipment integration issues, particularly as better definitions of equipment configuration and accommodation requirements become known. New functions in the updated and refined traffic models will also require integration analysis.

- It is further recommended that the "tri-mode" platform configuration approach be applied to hold open the option for manned servicing. Much effort is required to determine a preferred servicing mode. Analysis results, design trades, and operational experience must be accumulated on both the spacecraft to be serviced and the systems performing the servicing operations before preferred servicing modes can be selected. The above "tri-mode" approach offers the desired flexibility at virtually no design penalty. Safety considerations would introduce variations in qualification programs, but applying this basic configuration approach to further studies of hardware standardization and subsystems commonality could focus their results to useful products somewhat independent of future decisions on servicing operations.

3.0 PROGRAM EVALUATION METHODOLOGY

This section defines the overall methodology used to conduct the programmatic analyses leading to the definition of a recommended geosynchronous platform program approach. The objective of the program evaluation effort was to compare alternate geosynchronous platform programs using the geosynchronous platform configurations, servicing concepts, and equipment definitions presented in Volume V, Geosynchronous Platform Synthesis. This objective was accomplished using the overall geosynchronous program evaluation logic shown in Figure 3-1. In addition, Figure 3-2 presents a schematic representation of the process used to execute the steps in the evaluation logic. The figure illustrates the data base required for the analyses and the principal products developed in order to achieve the overall evaluation study objectives.

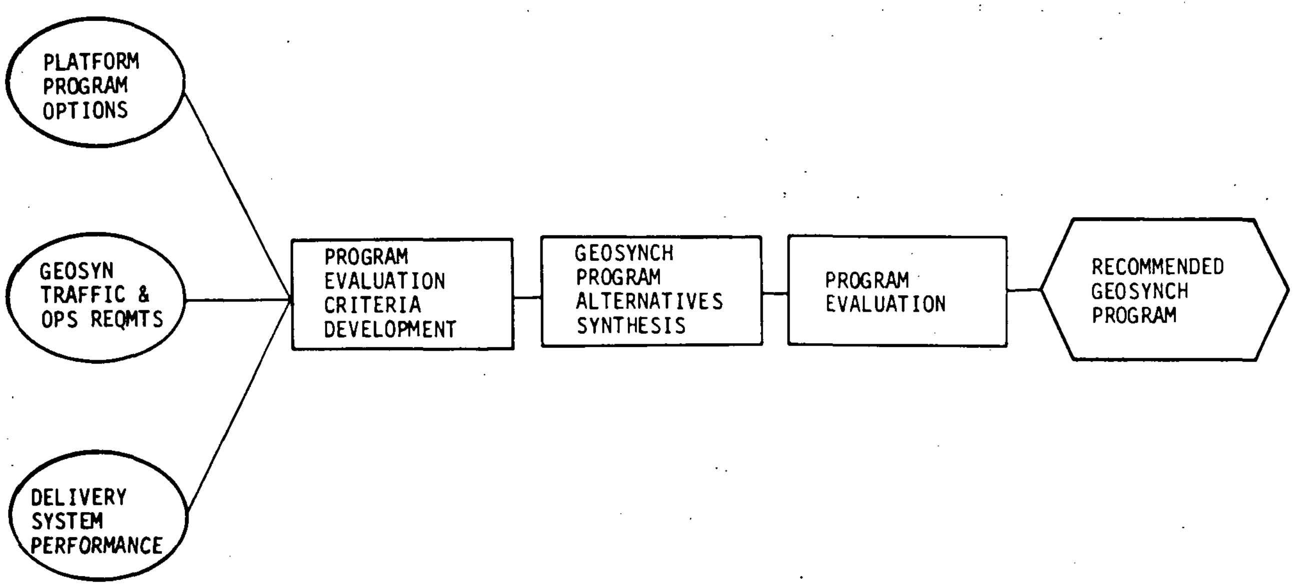

Figure 3-1. Geosynchronous Program Evaluation Logic

3.1 DATA BASE DEFINITION

The fundamental data base element for the geosynchronous platform program evaluation analysis was the definition of the platform configurations, servicing concepts, and equipment definitions presented in Volume V. The defined platforms were scheduled to provide the equivalent operational capability represented by the baseline and new traffic models presented in Volume IV, Parts 1 and 2. During the scheduling of platform deliveries, the geographic distributions of the expendable satellites defined in the traffic models were

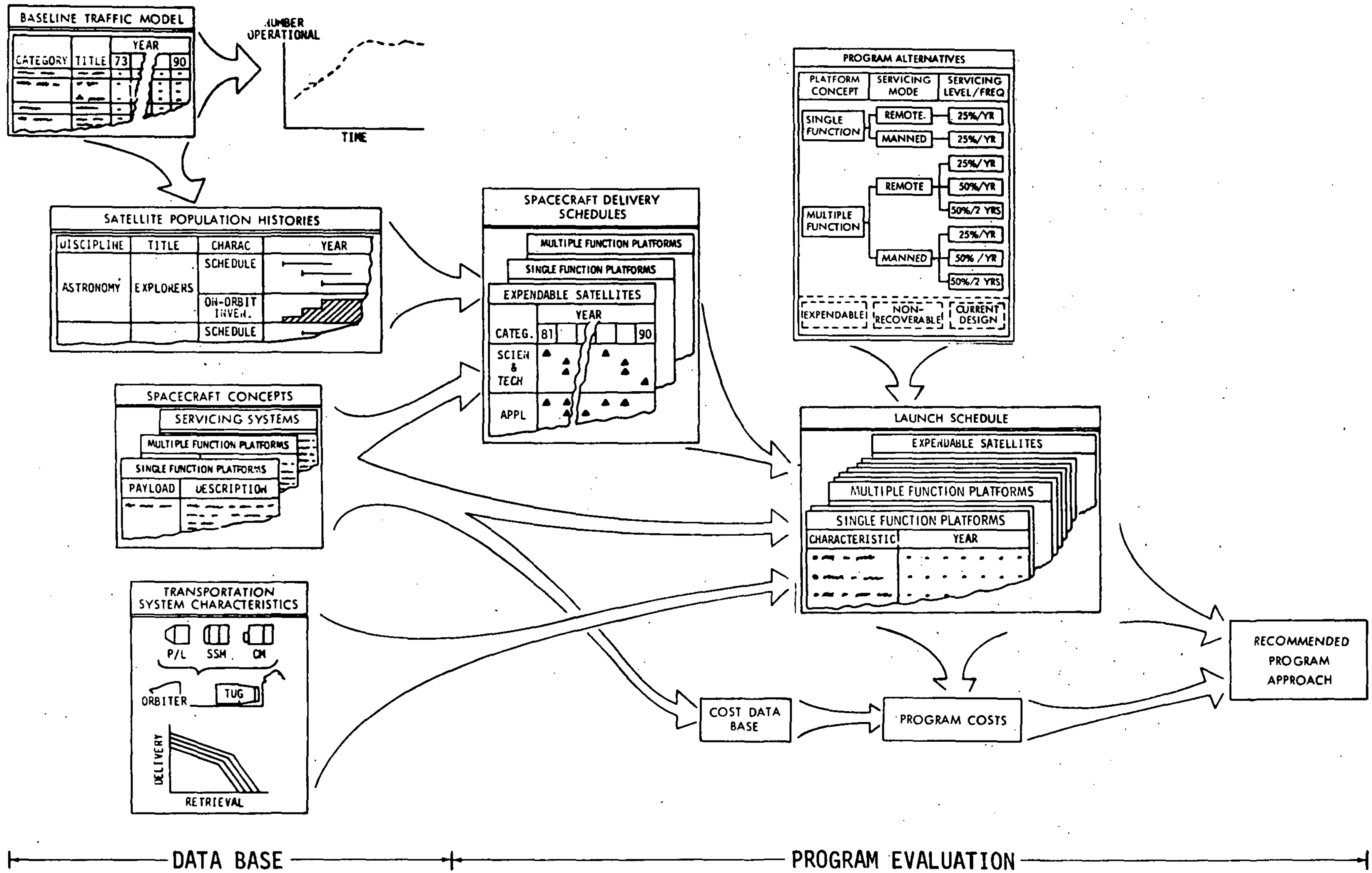

Figure 3-2. Program Evaluation Process

considered to ensure that the on-orbit operational capabilities would satisfy world-wide demands. In addition, the transportation system launch schedules were developed on the basis of the physical and performance characteristics of the transportation systems defined for this study. The performance characteristics were based on the geosynchronous mission operational performance requirements defined in Volume III. The principal operational performance requirements considered were the mission delta-V requirements for placement and servicing of geosynchronous satellites and platforms.

3.2 PROGRAM EVALUATION

The three elements of the data base--baseline traffic model, platform concepts, and transportation system capabilities--are shown schematically in the "Data Base" phase of Figure 3-2. With the baseline traffic model as the definition of operational capability on orbit, the second of these elements, platform concepts, was used to develop platform delivery schedules. Functional capability was the consideration driving the development of these schedules for the placement of single-function and multiple-function platforms. The platform delivery schedules resulted in an on-orbit functional capability equivalent to the conventional expendable satellite programs by replacing expendable satellite deliveries with platform deliveries. Details of these platform delivery schedules are presented in Section 4.1.

Weight and sizing data for the platforms were enumerated in order to determine the transportation system requirements; i.e., the requirements for shuttle/tug flights which would deliver the platforms to geosynchronous orbit.

The number of shuttle/tug flights required to implement the program is also a function of the payload capability, expressed in pounds and constrained by the physical dimensions of the shuttle cargo bay. Nominally, the round-trip payload capability of a single tug is taken to be 3225 pounds. However, the actual capability is a function of orbital maneuvers, which would be dictated by the mission profile; e.g., delivery only, delivery and servicing one platform, servicing two platforms, etc. Rather than use generalized delivery/retrieval payload capability curves, it was decided to take into account this variability in orbital maneuvers which uniquely describes each proposed flight. This was accomplished with the aid of a computerized routine which tracked the propellant consumed during ascent and descent delta-V's, as well as during on-orbit delta-V's for phasing between spacecraft. Input data were main propulsion system (MPS) delta-V's, specific impulse (I_{sp}), stage and payload gross weight, usable MPS, and auxiliary propulsion system (APS) propellants. Among these, the variables which characterized each flight were on-orbit MPS delta-V's, payload gross weight, and usable MPS propellant.

Proposed shuttle flights were loaded with tug, spacecraft, and/or servicing units up to the usable cargo bay envelope of 60 by 15 feet. With a 35-foot tug, 25 feet were available for payload. Opportunities for combining delivery and servicing functions were limited by the dimensions of the servicing unit and the number of spares (and therefore, servicing system tiers) to be delivered.

For a single tug, 56,585 pounds are available for payload, MPS propellant, and APS propellant. The flight was run with the selected payload combination and propellant equal to the difference between 56,585 pounds and the payload weight. Based on the delta-V's contained in Volume III, the sum of MPS propellants required for the mission through rendezvous and docking with the shuttle was calculated. If this sum was greater than the original propellant ($W_{prop} \leq 0$), the flight was disallowed. One of the payload elements was removed; the propellant was increased by that amount, and the flight rerun. This process was repeated until the weight of the excess propellant was greater than zero. This was done region by region, combining flights to different regions where necessary and possible, and year by year until all spacecraft elements in the model were delivered and serviced. All deliveries and visits scheduled within a given year were run in that year; none were postponed for a more favorable clustering opportunity in a subsequent year.

The impact of variations in the number of geosynchronous spacecraft was evaluated by application of this program evaluation methodology to the new traffic model. As with the baseline program, the new traffic model was the basis for development of "equivalent capability" platform delivery schedules. Then, using parameters determined during the development of the baseline programs, launch schedules were developed for the new traffic model.

The platform and servicing system concepts, plus the delivery schedules, provided the basis for the development of total program costs. These costs included the nonrecurring and recurring costs of the platforms, servicing systems, and spares for eight basic program alternatives. In addition, the operational costs of the transportation systems were established to define the total program costs.

The resultant program costs provided the basis for the definition of a preferred geosynchronous program alternative. In the context of this study, the preferred program alternative is defined as the preferred combination of platform concept (either single-function or multiple-function), servicing mode (either remote or manned), and servicing level and frequency. It must be pointed out, however, that the servicing levels and frequencies examined during this study were selected for the purpose of establishing the program sensitivity to these considerations and do not necessarily represent the values which will be required in an operational program.

The recommended program approach was developed considering the results of all major analyses conducted during the study. The principal considerations were program evaluations, the new traffic model analyses, contention analyses, and platform and servicing system configuration analyses.

4.0 PROGRAM OPERATIONAL REQUIREMENTS

The initial program evaluation task centered on the development of single-function and multiple-function platform delivery schedules which resulted in the same on-orbit operational capability as that defined by the baseline traffic model. These schedules defined when platform deliveries would be required and provided the basis for the subsequent development of shuttle/tug launch schedules. Geographic distribution also was considered in the development of these schedules to assure that the required world-wide operational capability would be provided.

Only the period from 1981 through 1990 was considered during the development of the platform delivery schedules. An examination of the baseline traffic model shows that the active satellite population builds up until 1982 and then remains relatively steady. This buildup, shown in Figure 4-1, is based on the data contained in Volume IV, Part 1. As shown in Figure 4-1, the active satellite population averages about 58 satellites from 1982 through 1990. The traffic analyses in Volume IV, Part 1, show that deliveries occur in all satellite categories during the 1981-83 period, which is after the space shuttle 1980 IOC defined for this study. It was assumed, therefore, that these deliveries would be representative of the initial placement of shuttle-compatible geosynchronous satellites. As a result, the programmatic analyses concentrated on the 1981-90 period.

The expendable satellite delivery schedule for the 1981-90 period is shown in Figure 4-2 for the baseline traffic model. For purposes of the program evaluation analyses, the science-and technology-type satellites were grouped separately from the applications type satellites. A total of 33 science and technology satellite deliveries is required during the 1981-90 period, resulting in an average launch rate of 3.3 satellites per year.

The communications type satellites and the operational earth observations satellites were grouped within the applications class. Of the 80 satellites within this class, there were eight international communications satellites (Comsats) and 42 domestic communications satellites (U.S. and foreign Domsats). Thus, 50 of the 80 (62.5 percent) applications satellites are concerned with either national or international data relay-type functions.

A total of 113 satellite deliveries is required over the ten-year period, resulting in an average delivery rate of 11.3 satellites per year. The maximum number of deliveries occurs in 1983, while the minimum occurs in 1986 (16 and 5 deliveries, respectively).

There is one slight difference between the delivery schedule shown in Figure 4-2 and the schedule shown in Figure 3.2-3 in Volume IV, Part 1. Figure 3.2-3 shows deliveries of "Synchronous Earth Observation Satellites" in 1980, 1982, 1985, 1987, and 1990. Rather than delay the initial shuttle delivery of this family of satellites until 1982 during the programmatic analyses, it was decided to delay all "Synchronous Earth Observation Satellite" deliveries by one year. Thus, the initial shuttle delivery of these satellites was scheduled in 1981 with subsequent deliveries in 1983, 1986, and 1988. This one year delay is reflected in the expendable satellite delivery schedule shown in Figure 4-2.

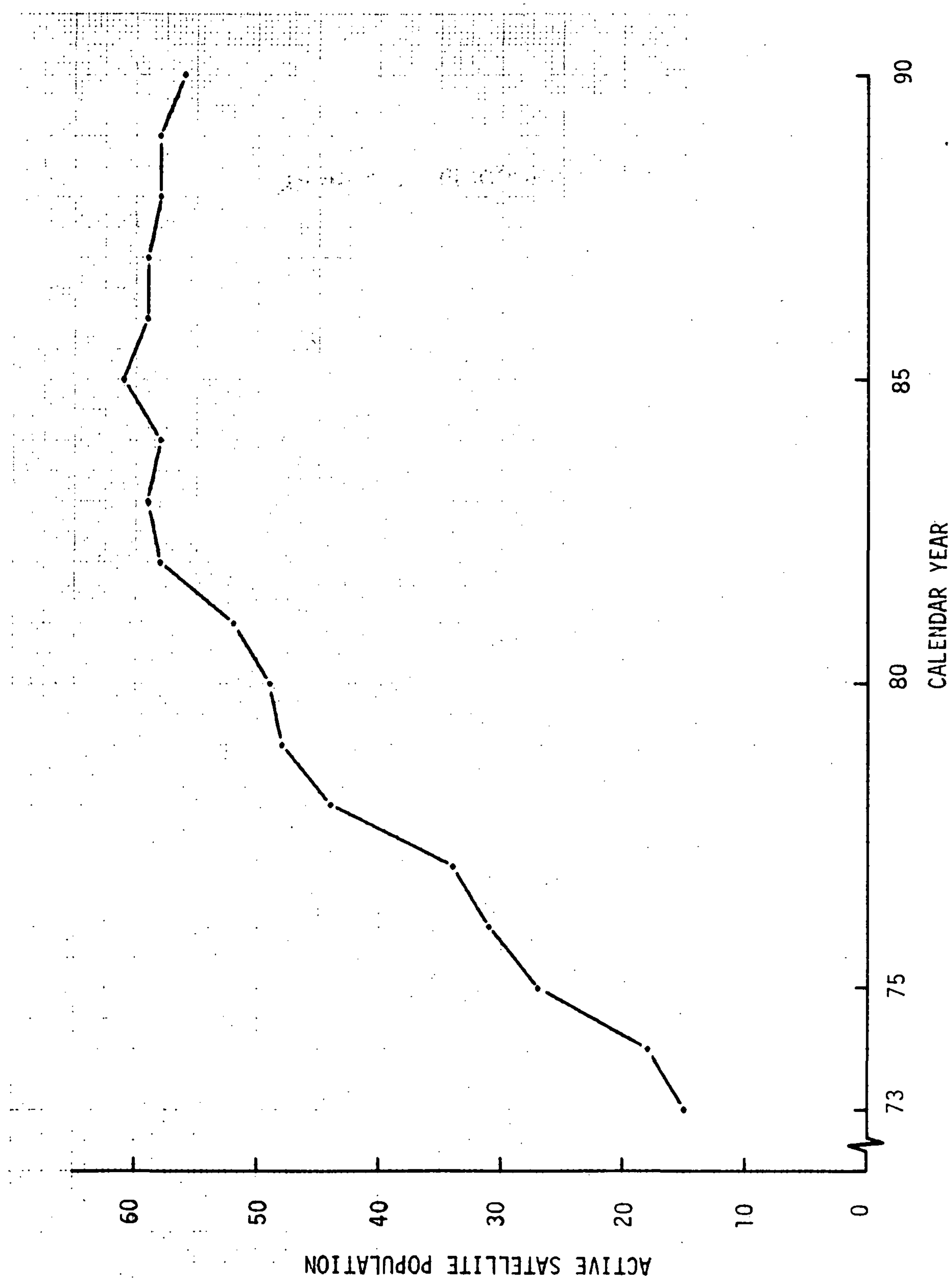

Figure 4-1. Baseline Traffic Model Active Satellite Population

		EXPENDABLE SATELLITE DELIVERIES											
	CALENDAR YEAR / SPACECRAFT	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	TOTAL	CUM TOTAL
SCIENCE & TECHNOLOGY	ASTRONOMY	▲ IV			▲ IV			▲ IV			▲ IV	4	4
	EARTH OBSERVATIONS--DEVELOPMENTAL*	▲ ▲ IV IV	▲ IV	▲ IV			▲ IV		▲ IV		▲ IV	7	11
	ATS		▲ IV	▲ IV		▲ IV		▲ IV		▲ IV		5	16
	SYSTEM TEST	▲ IV	▲ IV	▲ IV	▲ IV	▲ IV		▲ IV	▲ IV			7	23
	SATS	▲ IV	▲ IV	▲ IV	▲ IV	▲ IV	▲ IV	▲ IV	▲ IV	▲ IV	▲ IV	10	33
	DELIVERIES	5	4	4	3	3	2	4	3	2	3	33	33
APPLICATIONS	TDRS			▲ ▲ ▲ I III IV						▲ ▲ ▲ I III IV		6	6
	COMSAT		▲ ▲ III III	▲ III	▲ ▲ I III		▲ ▲ I II	▲ II				8	14
	U.S. DOMSAT	▲ ▲ IV IV	▲ ▲ ▲ ▲ IV IV IV IV	▲ ▲ ▲ IV IV IV	▲ IV				▲ ▲ IV IV	▲ ▲ ▲ ▲ IV IV IV IV	▲ ▲ ▲ IV IV IV	19	33
	FOREIGN DOMSAT	▲ ▲ ▲ II III III	▲ ▲ III IV	▲ ▲ III IV	▲ ▲ ▲ II II III	▲ ▲ ▲ I I III		▲ ▲ ▲ III IV IV	▲ ▲ ▲ II III III	▲ ▲ III IV	▲ ▲ III IV	23	56
	NAVIGATION AND TRAFFIC CONTROL		▲ III	▲ ▲ I II				▲ III	▲ ▲ I II			6	62
	EARTH OBSERVATIONS--OPERATIONAL	▲ I	▲ III	▲ II	▲ IV	▲ ▲ ▲ ▲ ▲ I I II III IV	▲ III	▲ II	▲ ▲ ▲ ▲ ▲ I II III IV IV	▲ I	▲ III	18	80
	DELIVERIES	6	10	12	7	8	3	6	12	10	6	80	80
TOTALS	DELIVERIES BY REGION IV III II I	7 2 1 1	9 5 - -	9 3 2 2	5 2 2 1	4 2 1 4	2 1 1 1	6 2 2 -	7 3 3 2	8 2 - 2	7 2 - -	64 24 12 13	
	DELIVERIES	11	14	16	10	11	5	10	15	12	9	113	
	FOOTNOTES	▲ DELIVER	*FOR THIS COMPARISON MODEL, THE SYNCHRONOUS EARTH OBSERVATION SATELLITE SCHEDULE HAS BEEN MODIFIED.										

Figure 4-2. Geosynchronous Delivery Schedule - Expendable Satellites

4.1 PLATFORM DELIVERY SCHEDULES

The transition from expendable satellite programs to single-function platform programs was made in the following manner. Serviceable platform deliveries began in 1981, the year they were assumed to be available. Deliveries in each instance substituted a serviceable platform for an expandable satellite that had become inactive, and the number of operational platforms on orbit was increased until the number of operational single-function platforms equalled the number of active expendable satellites in the traffic model. Servicing of these platforms began the year after placement and continued on a periodic schedule. Thus, while an expendable satellite would have to be replaced at the end of its useful life, the single-function platform would still be active and no increase in the on-orbit inventory would be required.

This systematic reduction in the number of spacecraft deliveries is shown for a typical satellite group in Figure 4-3. For this illustration, an on-orbit operational capability equivalent to 10 active satellites has been achieved prior to 1981 through the delivery of expendable satellites. Beginning in 1981, additional expendable satellite deliveries are required to maintain a constant active satellite population as the previously delivered expendable satellites reach the end of their operational life. A second series of deliveries, beginning in 1988, is required to replace the expendable satellites delivered during 1981, 1982, 1983, and 1984. In developing the equivalent, single-function platform program, the expendable satellite deliveries during 1981 through 1984 were replaced by single-function platform deliveries. The on-orbit operational capability was then maintained, though servicing of the platforms and deliveries during 1988, 1989, and 1990 is not required. Therefore, for this illustration, the number of spacecraft deliveries was reduced from 19 to 10 during the 1981-90 period.

The resultant single-function platform delivery schedule is shown in Figure 4-4. The traffic model presented in this figure shows that, for the single-function platform program, 50 fewer spacecraft (63 versus 113) are required to establish the same functional capability as the baseline expendable satellite program. However, if each single-function platform is serviced once a year, 426 servicings are required to maintain the platforms over the 10-year period under consideration. In addition, some platforms are updated (i.e., mission equipment is exchanged or added). Mission equipment updates were assumed to be required for the science-and technology-type spacecraft since these are developmental in nature. The scheduling of the mission equipment updates corresponds to the scheduling of new expendable satellite deliveries in the baseline traffic model. For example, the baseline traffic model called for the delivery of a small application technology satellite (SATS) once a year. These deliveries were replaced by one single-function platform delivery in 1981 and one mission equipment update in each of the subsequent years. A total of 18 mission equipment updates was required, and these updates are represented by the open triangles in Figure 4-3.

The multiple-function platform delivery schedules were developed in an analogous manner based on the multiple-function platform capabilities defined in Volume IV. The resultant delivery schedule, shown in Figure 4-5, ensures that an equivalent operational capability is achieved within each region at least as soon as that defined by the expendable satellite program. With the grouping of satellite functions on multiple-function platforms, 18 multiple-function platforms would be required in orbit, in contrast to 63 single-function platforms or 113 expendable satellites. As in the single-function platform program, updates of mission equipment are scheduled (a total of 17 in the 1981-90 period). A total of 19 multiple-function platforms was identified in Volume IV. The difference is due to elimination of three astronomy platforms and the addition of two development platforms. Instead of four astronomy platforms, only one is delivered, and mission equipment updates are used at the intervals specified for satellite deliveries in the expendable satellite schedule. The two developmental platforms consist of the basic platform structure and subsystems, with developmental equipment cycling at the update frequency shown in Figure 4-5.

The average delivery rate for the 10-year period is 11 deliveries per year for expendable satellites, 6 for single-function platforms, and 2 for multiple-function platforms. These delivery demands are overshadowed by the requirement for servicing of the platforms already in orbit, discussed in Sections 4.2 and 4.3.

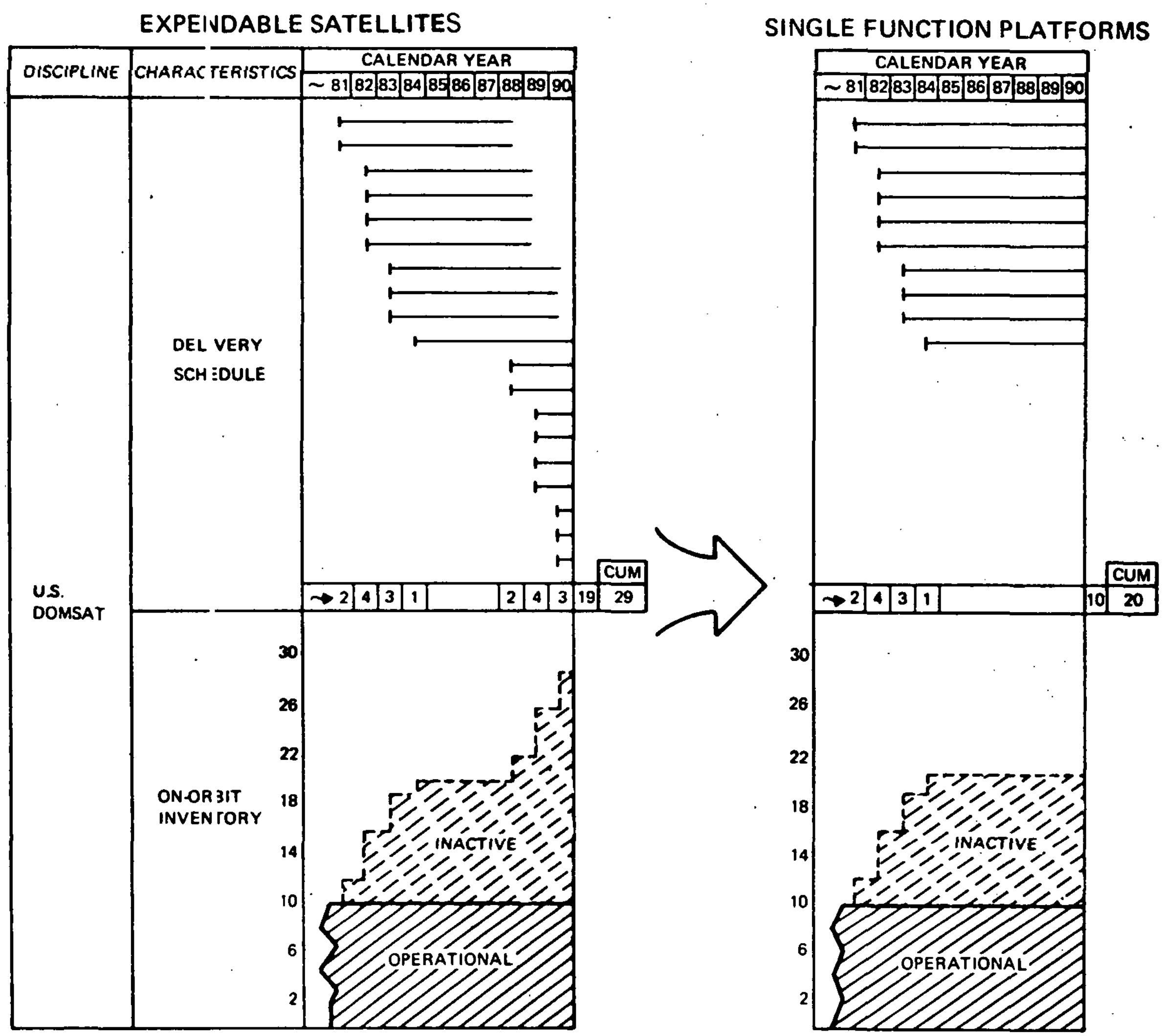

Figure 4-3. Equivalent Traffic Model Development Approach

SINGLE-FUNCTION PLATFORM DELIVERIES

	SPACECRAFT \ CALENDAR YEAR	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	TOTAL DEL.	TOTAL U/D	CUM TOTAL DEL.	CUM TOTAL U/D
SCIENCE & TECHNOLOGY	ASTRONOMY	▲ IV			Δ			Δ			Δ	1	3	1	3
	EARTH OBSERVATIONS--DEVELOPMENTAL*	▲ ▲ IV IV	▲ IV	▲ IV			Δ		Δ		▲ IV	5	2	6	5
	ATS		▲ IV	▲ IV		▲ IV		Δ		Δ		3	2	9	7
	SYSTEM TEST	▲ IV	▲ IV	▲ IV	▲ IV	▲ IV		Δ	Δ			5	2	14	9
	SATS	▲ IV	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	1	9	15	18
	DELIVERIES	5	3	3	1	2	-	-	-	-	1	15		15	
	UPDATES	-	1	1	2	1	2	4	3	2	2		18		18
	DELIVERIES + UPDATES	5	4	4	3	3	2	4	3	2	3	33		33	

	SPACECRAFT	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	TOTAL	CUM TOTAL
APPLICATIONS	TDRS			▲ ▲ ▲ I III IV								3	3
	COMSAT		▲ ▲ III III	▲ III	▲ ▲ I III		▲ ▲ I II	▲ II				8	11
	U.S. DOMSAT	▲ ▲ IV IV	▲ ▲ ▲ ▲ IV IV IV IV	▲ ▲ ▲ IV IV IV	▲ IV							10	21
	FOREIGN DOMSAT	▲ ▲ ▲ III III II	▲ ▲ III IV	▲ ▲ III IV	▲ ▲ ▲ II II III	▲ ▲ ▲ III I I		▲ ▲ ▲ III IV IV				16	37
	NAVIGATION AND TRAFFIC CONTROL		▲ III	▲ ▲ I II								3	40
	EARTH OBSERVATIONS--OPERATIONAL	▲ I	▲ III	▲ II	▲ IV	▲ ▲ ▲ ▲ I II III IV						8	48
	DELIVERIES	6	10	12	7	7	2	4	-	-	-	48	48

		1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	TOTAL DEL.	TOTAL U/D	CUM TOTAL DEL.	CUM TOTAL U/D
TOTALS	DELIVERIES BY REGION IV	7	8	8	3	3	-	2	-	-	1	32			
	III	2	5	3	2	2	-	1	-	-	-	15			
	II	1	-	2	2	1	1	1	-	-	-	8			
	I	1	-	2	1	3	1	-	-	-	-	8			
	DELIVERIES	11	13	15	8	9	2	4	-	-	1	63		63	
	UPDATES	-	1	1	2	1	2	4	3	2	2		18		18
	DELIVERIES + UPDATES	11	14	16	10	10	4	8	3	2	3	81		81	

▲ DELIVER
Δ UPDATE

*FOR THIS COMPARISON MODEL, THE SYNCHRONOUS EARTH OBSERVATION SATELLITE SCHEDULE HAS BEEN MODIFIED.

Figure 4-4. Geosynchronous Delivery Schedule - Single-Function Platforms

		MULTIPLE-FUNCTION PLATFORM DELIVERIES													
	CALENDAR YEAR / PLATFORM TYPE	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	TOTAL DEL.	TOTAL U/D	CUM TOTAL DEL.	CUM TOTAL U/D
SCIENCE & TECHNOLOGY	ASTRONOMY	▲ IV			△			△			△	1	3	1	3
	DEVELOPMENTAL	▲ ▲ IV IV	△ △	△ △	△	△	△ △	△	△ △	△	△ △	2	14	3	17
	DELIVERIES	3	-	-	-	-	-	-	-	-	-	3		3	
	UPDATES	-	2	2	2	1	2	2	2	1	3		17		17
	DELIVERIES + UPDATES	3	2	2	2	1	2	2	2	1	3	20		20	
APPLICATIONS	TDRS			▲ ▲ ▲ I III IV								3		3	
	DATA RELAY	▲ ▲ ▲ II III IV		▲ ▲ ▲ I III IV		▲ I	▲ II					8		11	
	EARTH OBSERVATIONS	▲ ▲ IV I	▲ III	▲ II								4		15	
	DELIVERIES	5	1	7	-	1	1	-	-	-	-	15		15	
TOTALS	DELIVERIES BY REGION IV	5	-	2	-	-	-	-	-	-	-	7			
	DELIVERIES BY REGION III	1	1	2	-	-	-	-	-	-	-	4			
	DELIVERIES BY REGION II	1	-	1	-	-	1	-	-	-	-	3			
	DELIVERIES BY REGION I	1	-	2	-	1	-	-	-	-	-	4			
	DELIVERIES	8	1	7	-	1	1					18		18	
	UPDATES	-	2	2	2	1	2	2	2	1	3		17		17
	DELIVERIES + UPDATES	8	3	9	2	2	3	2	2	1	3	35		35	

▲ DELIVER △ UPDATE

Figure 4-5. Geosynchronous Delivery Schedule - Multiple-Function Platforms

4.2 DEVELOPMENT OF SHUTTLE/TUG LAUNCH SCHEDULES

The previously defined delivery schedules identify when single-function and multiple-function platforms must be delivered in order to provide an operational capability at least equivalent to the baseline traffic model. In order to establish total program costs, it was necessary to define the required shuttle/tug launch schedule for platform delivery, mission equipment update, and on-orbit servicing. These schedules were developed for eight different platform program alternatives for both the baseline and new traffic models. In addition, shuttle/tug launch schedules were developed for the two expendable satellite programs, resulting in a total of 18 different launch schedules.

The eight basic program alternatives considered during this study are illustrated in Figure 4-6. The principal programs considered were the on-orbit serviced geosynchronous platform programs, including both single-function and multiple-function platforms. Both remote and manned servicing were considered for each platform concept. In order to parametrically assess the impact of servicing operations on total program costs, a limited set of alternate servicing levels and frequencies was examined. The values examined were selected for the purpose of establishing the impact and program sensitivity to the servicing level and frequency, and do not necessarily represent the values which will ultimately be required in an operational program. Relatively high servicing levels were selected to ensure that the impact of these considerations would be evident.

The required launch schedules were determined by combining platform deliveries, mission equipment updates, and servicing missions where possible. The constraints imposed were the physical volume within the shuttle cargo bay and the reusable tug performance capability. The manner in which the required shuttle/tug launches were determined is illustrated in Figure 4-7. For each year of the program, the required platform deliveries, mission equipment updates, and servicing missions were identified. In addition, the required delivery weights and, for the update and servicing missions, the required return weights were defined. The required payload lengths were also identified considering the number of servicing system tiers required for servicing missions. The logistics requirements for each year were then examined to determine the required number of shuttle/tug launched without exceeding the dimensional and performance capabilities of these systems. The capability to perform each candidate multiple mission was verified in light of the tug on-orbit maneuver requirements and the resultant impact on the tug payload capability.

Weight and sizing data for the platforms were developed to determine the transportation system requirement (i.e., the number of shuttle/tug flights required to deliver the platforms to geosynchronous orbit). The number of shuttle/tug flights required is a function of payload capability. Nominally, the round-trip payload capability of a single tug is taken to be 3225 pounds. However, the actual capability is a function of orbital maneuvers, which would be dictated by the mission profile (e.g., delivery only, delivery and servicing one platform, servicing two platforms, etc.). Rather than use generalized delivery/retrieval payload capability curves, it was decided to include this variability in orbital maneuvers. This was accomplished with the aid of a computerized routine which tracked the propellant consumed during ascent and descent as well as on-orbit for phasing between platforms. Input data included main propulsion system (MPS) ΔV, specific impulse (Isp), stage and payload gross weight, and usable MPS and auxiliary propulsion system (APS) propellant. Among these, the variables which characterized each flight were on-orbit MPS ΔV, payload gross weight, and usage MPS propellant.

Proposed shuttle flights were loaded with tug and spacecraft or servicing units up to the usable cargo bay envelope of 60 by 15 feet. With a 35-foot tug, 25 feet were available for the payload. Opportunities for combining delivery and servicing functions were limited by the dimensions of the servicing unit and the number of spares (and therefore tiers) to be delivered.

For a single tug, 56,585 pounds are available for payload, MPS propellant, and APS propellant. The weight of selected payload combinations was calculated and subtracted from the tug capacity; the remainder was allocated to propellant. The sum of MPS propellant required for the mission through rendezvous and docking with the shuttle was then calculated on the basis of the ΔV requirements identified in Section 3.3 of Volume III. If this sum was greater than the allocated propellant, the flight was disallowed. One of the payload elements was then removed, the propellant increased by that amount, and the flight rerun. This process was repeated until the weight of the excess propellant was greater than zero. This was done region by region, combining flights to different regions where necessary and possible, and year by year, until all spacecraft elements in the model were delivered and serviced. All deliveries and visits scheduled within a given year were run in that year;none were postponed for a more favorable clustering opportunity in a subsequent year.

As many single tug missions were scheduled as were feasible within weight and ΔV constraints. Where the alternatives were one dual or two single tug missions, the latter was selected. If the alternatives were one dual or three single tug missions, one dual tug mission was selected.

The effects of increased traffic levels were evaluated by applying this methodology to the new traffic model. As with the baseline program, the new traffic model was the basis for development of "equivalent capability" platform delivery schedules from which the launch schedules were developed.

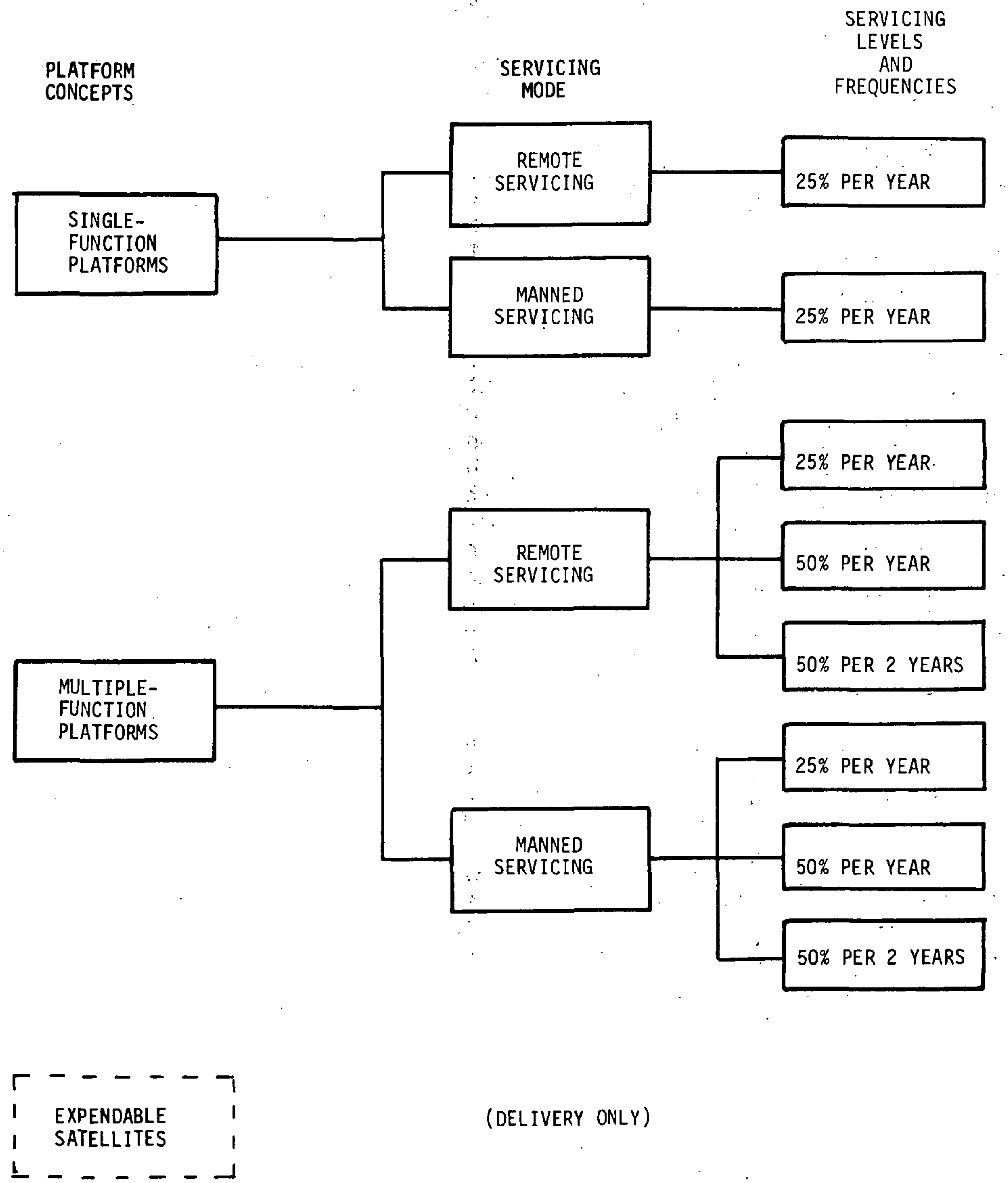

Figure 4-6. Program Alternatives

REGION	PLATFORM TYPE	81	82	83	84	85	86	87	88	89	90	TOTAL
IV	ASTRONOMY	18 ▲ 4600	(8) 610	(8) 610	△ 5-377↑ 12-958↓ (4) 300	(8) 610	(8) 610	△ 9-518↑ 5-377↓ (4) 300	(8) 610	(8) 610	△	
	DEVELOPMENTAL	20 ▲ 4500 20 ▲ 4200	△ 5-190↑ (3) 300 △ 10-1000↑ 2-150↓ (3) 300	△ 1-110↑ (3) 300 △ 10-1000↑ 2-150↓ (3) 300	(4) 327 △ 5-500↑ 2-150↓ (4) 420	(4) 327 △ 10-1000↑ 2-150↓ (3) 300	△ 8-430↑ 10-878↓ (3) 300 △ 2-150↑ 2-150↓ (6) 512	(5) 410 △ 10-…	△ 8-430↑ 1-…			
	TDRS			14 ▲ 2100	(4) 320	(4) 320						
	DATA RELAY	17 ▲ 2650	(7) 650	17 ▲ 3350 (7) 650	(7) 650							
	EARTH OBSERVATIONS	25 ▲ 2650	(11) 765	(11) …								
	SHUTTLE FLTS/YR - R	5										
	- M	5										
III	TDRS								(4) 320	(4) 320	(4) 320	
	DATA RELAY						(5) 500	(5) 500	(5) 500	(5) 500	(5) 500	
	EARTH OBSERVATIONS		25 ▲ 5700	(11) 765	(11) 765	(11) 765	(11) 765	(11) 765	(11) 765	(11) 765	(11) 765	
I	SHUTTLE FLTS/YR - R	1	1	2	2	2	1 ↑↓	1 ↑ +	1 +	1 +	1 +	
	- M	1	↑	3 (2)	2 (1)	3 (2)	2 (1)	2 (1)	2 (1)	2 (1)	2 (1)	
TOTAL FLIGHTS/YEAR	- R	8	6	11	9	9	9	10	9	9	9	89
	- M	8	9 (5)	14 (9)	12 (6)	13 (7)	13 (7)	12 (6)	12 (6)	12 (6)	12 (6)	117
PAYLOAD WEIGHT (UP)		32,950	11,140	26,365	8,964	11,527	11,652	10,288	10,020	9,730	9,460	142,096
(DOWN)		0	4,400	5,165	9,195	8,427	9,800	10,147	9,635	9,730	9,328	75,827
TOTAL PAYLOAD (UP + DOWN)		32,950	15,540	31,530	18,159	19,954	21,327	20,435	19,655	19,460	18,788	217,923

LEGEND:

- L ▲ W : Deliver
  - L = length, feet
  - W = weight, pounds
- △ : Update
  - ↑, ↓ = weight up, down
- (n) m : Service
  - n = number of modules
  - m = weight, pounds
- R : Remote Servicing
- M : Manned Servicing

Figure 4-7. Sample Delivery/Servicing Summary Chart

4.3 DEVELOPMENT OF SHUTTLE/TUG LAUNCH REQUIREMENTS

This section details the shuttle/tug launch requirements for the 16 basic program alternatives and the two conventional expendable satellite programs discussed in the previous section. Launch schedules were established by combining platform delivery, mission equipment update, and platform servicing missions where possible.

Baseline Traffic Model Requirements

A comparison of the number of spacecraft deliveries for the single-and multiple-function platform program alternatives, as well as the expendable satellite program, is shown in Figure 4-8. Also, the cumulative spacecraft populations in geosynchronous orbit for the three programs are shown. In 1990, the cumulative difference in the number of spacecraft deliveries (measured from an expendable satellite base in 1980 when the satellites on orbit number 68) is 50 for the single-function platform program and 95 for the multiple-function platform program. Based on the total cumulative spacecraft population in 1990, the single-function and multiple-function platforms represent 72 percent and 48 percent of the baseline expendable satellite population.

Tables 4-1 through 4-5 contain the program summaries for:

1. Expendable satellites
2. Single-function platforms, 25 percent spares per year
3. Multiple-function platforms, 25 percent spares per year
4. Multiple-function platforms, 50 percent spares per year
5. Multiple-function platforms, 50 percent spares every two years

Table 4-6 is a synopsis of the principal program characteristics for each of these alternative programs. The annual demand for servicing and update visits, superimposed on the delivery schedule, is the first entry in these program summaries for the serviceable platforms. In addition, the numbers of shuttle/tug flights, payload weight (W_{PL}), and payload capability ($W_{PL\ CAP}$) were compiled to describe the program characteristics. The number of shuttle/tug flights had been determined previously. From the last two data elements, a measure of tug utilization efficiency was computed. Efficiency is defined as the ratio of actual payload carried to the payload capability:

$$E = \frac{W_{PL}\ (\text{Actual})}{W_{PL}\ (\text{Cap})}$$

where $W_{PL}\ (\text{Actual}) = W_{PL}\ (\text{Up}) + W_{PL}\ (\text{Down})$

Only usable payload weight is included in this sum; weight of the remote servicing unit or the crew module in manned flight is not included. The payload capability is the sum of the usable payloads actually carried up and down, plus twice the sum of the excess MPS propellant carried through the mission; i.e.,

$$W_{PL}\ (CAP) = W_{PL}\ (Up) + W_{PL}\ (Down) + 2\ W_{PROP}\ Excess$$

This excess propellant term arises from the fact that, if additional on-orbit maneuvers are not required, payload might have been exchanged on a pound-for-pound basis up to the amount of excess propellant carried throughout the mission.

It is possible to obtain a flight-by-flight measure of tug utilization efficiency. However, it was decided to compute efficiency on a yearly basis, summing the payload capability and payload carried on all flights during a given year. (This displays the variability in efficiency year by year.) Then the total efficiency for the 10-year program is computed. In the expendable satellite program, notwithstanding the advantages to be gained by clustering satellites, the efficiency attained is just below 50 percent. This can be attributed to the fact that the largest satellite, a 20-foot earth observation satellite, weighs only 3500 pounds, 5000 pounds below the one-way delivery capability of the tug. A typical clustered combination (e.g., three 8-foot, 1100-pound Domsats) is 5200 pounds less than that capability. (The payload weights used in these analyses were those available at the time of the Second Progress Review.)

In terms of spacecraft deliveries only, the following clustering densities (defined as the average number of spacecraft delivered per flight) were achieved:

Program	Clustering Density (Delivery Only)	Program Average Weight (lb)
Expendable satellite	2.6 (avg)	1226
Single-function platform	1.8 (1981)	2241
Multipurpose platform	1.0 (1981)	3522

For expendable satellites, the program comprise delivery flights only so that the clustering density figure represents the average across the total program (113 satellites ÷ 44 flights). In the single-function and multiple-function platform programs, the clustering density was calculated in the first year of the program, 1981, when only delivery flights were scheduled.

In the serviceable satellite/platform programs, clustering density represents the average number of deliveries and visits accommodated per flight (deliveries + visits ÷ shuttle flights). This measure is specified for each of serviceable programs in the summary comparison chart, Table 4-6. Regardless of the program concept, the clustering density is higher for the remote servicing mode than for manned servicing; consequently, the number of shuttle/

tug flights required to implement the program is higher for man-attended servicing. This result is obvious, since a dual tug launch is required for each manned servicing mission regardless of the payload weight involved; in contrast, the remote servicing program contains a number of single tug missions for a combined spares and remote servicing unit weight (plus payload deliveries where feasible) below the nominal 3225 pounds round-trip capability of the single tug. With a single tier of spares and subtracting the 1100-pound remote servicing unit, the round-trip spares capability (to a single platform) is 2125 pounds. At a 25-percent or even a 50-percent replacement level, this spares weight is never achieved so that in fact, spares for two or more platforms are carried on a single flight. Taking into account the on-orbit maneuvering between spacecraft, actual spares capability for a three-platform mission was calculated at 1853 pounds, carrying a single tier weighing 1100 pounds, or 1453 pounds carrying two tiers weighing 1500 pounds. For a two-platform servicing-only mission, with one tier of spares, the spares payload capability was found to be 1912 pounds.

Summarizing these results for remote, servicing-only, single-tug missions, the round-trip spares capability is:

Spares Capability (lb)	Number of Tiers	Number of Platforms Visited
1912	1	2
1853	1	3
1453	2	3

This spares capability is one-half of the up-down capability (i.e., for the three-platform case, 1853 pounds of spares were delivered to orbit and 1853 pounds of expended spares were returned for refurbishing). In line with the definition of capability used in these analyses, this represents a payload capability ($W_{PL\ CAP}$) of 2 x 1853 = 3706 pounds. When this number is compared with the average payload capability measured across the program (summarized for each program alternative in Table 4-7), the average payloads obscure the data because of the high capability measures afforded by delivery-only missions and by combined delivery-servicing missions. These flights represent 20 to 40 percent of the remote servicing and 10 to 30 percent of the manned servicing flight programs. Specific percentages are shown in Table 4-8 for each of the programs. Tables 4-9 through 4-17 present the shuttle flight profile or characteristics for each program.

In Table 4-7, the normalized index provides the discrimination necessary to evaluate the impact of spares level. With the expendable satellite program used as a basis for comparison, only the remote platform programs at 50 percent per year and 50 percent every two years could approximate the payload capability achieved on the delivery-only expendable satellite program. Combining deliveries with servicing missions whenever possible, the actual (average) payload carried was higher for the servicing programs, by a factor of 1.2, so that the shuttle/tug system efficiency achieved was 60 percent and 58 percent versus 49 percent for the expendable satellite program. Note that in the remote servicing platform program, the payload capability and actual payload carried increases significantly as the spares level increases. This results from carrying a larger (and heavier) spares complement through the same ΔV profile with the increase in W_{PL} up and down, replacing propellant which otherwise could have been carried in excess of requirements.

The shuttle flight schedules for the program alternatives are shown in Figures 4-9 through 4-16. Finally, the comparison of shuttle flights for the platform programs at the variable servicing level and frequency is displayed in Figures 4-17 through 4-20 for remote and manned servicing alternatives.

New Traffic Model Scheduling Analyses

The impact of demand variations on the geosynchronous program was evaluated by extending the foregoing scheduling analyses to the new traffic model. That model with deliveries and active satellite population is summarized for the 1981-90 period in Table 4-18. A single-function platform program equivalent in functional capability to the expendable satellite program is outlined in Table 4-19. The number of satellites is reduced from 316 to 239. If each platform is serviced once annually, the number of deliveries plus visits totals 1100 over the 10-year period.

An equivalent multiple-function platform program for both baseline and new traffic models is summarized in Table 4-20. The schedule for delivery of these platforms is shown in Table 4-21. Table 4-22 compares the number of spacecraft in each of these programs. This data are shown graphically with cumulative totals in Figures 4-21 and 4-22.

The detailed flight scheduling routine was not repeated during analysis of the new traffic model; rather, the measures of "clustering density" achieved in the baseline program were used to calculate the number of shuttle/tug flights required to implement these delivery/servicing programs.

Looking at the expendable satellite program in Table 4-18, at an average of 2.6 satellites per flight, a total of 122 flights would be required to deliver the 316 expendable satellites in this model during the period 1981-90.

The single-function and multiple-function platform programs also use the clustering densities determined for the baseline models. Shuttle flight requirements, calculated for both remote and manned servicing concepts, are detailed in Tables 4-19 and 4-21 and summarized in Table 4-23.

Figures 4-23 through 4-30 display the shuttle flights required to implement the following programs for the new traffic model:

1. Single-function and multiple-function platforms, remote, 25 percent spares per year

2. Single-function and multiple-function platforms, manned, 25 percent spares per year

3. Multiple-function platform, remote and manned, 50 percent spares per year

4. Multiple-function platform, remote and manned, 50 percent spares per two years

In each case, the expendable satellite program is included as a point of reference.

The comparisons of shuttle flights for the platform programs at the variable servicing levels and frequencies are displayed in Figures 4-31 through 4-34 for the remote and manned servicing alternatives.

Table 4-1. Expendable Satellite Delivery Summary

	81	82	83	84	85	86	87	88	89	90	Total
No. of satellites	11	14	16	10	11	5	10	15	12	9	113
W_{PL} UP (lb)	15,050	15,200	16,950	10,300	14,150	7,050	10,950	21,050	14,850	13,050	138,600
No. of shuttle flights	5	5	5	4	4	2	4	6	4	5	44
W_{PL} CAPABILITY (lb)	34,006	33,098	30,564	26,856	24,128	10,892	27,100	39,062	24,318	35,188	285,212
Efficiency (percent)	44	46	55	38	59	65	40	54	61	37	49

Table 4-2. Single-Function Platform Delivery/Servicing Summary (25-Percent Spares per Year)

		81	82	83	84	85	86	87	88	89	90	TOTAL
SATELLITES DELIVERED		11	13	15	8	9	2	4	-	-	1	63
VISITS												
UPDATE AND/OR SERVICE		-	1	1	2	1	2	4	3	2	2	18
SERVICE		-	10	23	37	46	54	54	59	60	60	403
Σ (DELIVERIES + VISITS)		11	24	39	47	56	58	62	62	62	63	484
W_{PL} UP (LB)		26,704	31,105	37,600	27,258	38,250	19,990	25,224	17,486	17,376	18,821	259,814
W_{PL} DOWN (LB)		0	3,155	6,425	10,929	12,000	16,388	17,083	17,486	17,376	17,389	118,231
Σ W_{PL} (UP + DOWN) (LB)		26,704	34,260	44,025	38,187	50,250	36,378	42,307	34,972	34,752	36,210	378,045
REMOTE	NO. OF SHUTTLE FLIGHTS	6	11	15	15	21	20	21	22	22	22	175
	W_{PL} CAPABILITY (LB)	42,056	59,252	74,231	61,377	87,834	73,552	78,701	82,398	82,398	83,436	725,235
	EFFICIENCY (PERCENT)	64	58	59	62	57	49	54	42	42	43	52
MANNED	NO. OF SHUTTLE FLIGHTS	6	14	19	21	25	22	24	24	24	24	203
	W_{PL} CAPABILITY (LB)	42,056	69,192	85,377	83,823	109,560	70,676	80,501	77,256	77,256	78,520	774,217
	EFFICIENCY (PERCENT)	64	50	52	46	46	51	52	45	45	46	49

Table 4-3. Multiple-Function Platform Delivery/Servicing Summary (25-Percent Spares per Year)

		81	82	83	84	85	86	87	88	89	90	TOTAL
	PLATFORMS DELIVERED	8	1	7	-	1	1	-	-	-	-	18
	VISITS											
	UPDATE/SERVICE	-	2	2	2	1	2	2	2	1	3	17
	SERVICE	-	6	7	14	15	15	16	16	17	15	121
	Σ (DELIVERIES + VISITS)	8	9	16	16	17	18	18	18	18	18	156
	$W_{PL\ UP}$ (LB)	32,950	11,140	26,365	8,964	11,527	11,652	10,288	10,020	9,730	9,460	142,096
	$W_{PL\ DOWN}$ (LB)	0	4,400	5,165	9,195	8,427	9,800	10,147	9,635	9,730	9,328	75,827
	ΣW_{PL} (UP + DOWN)	32,950	15,540	31,530	18,159	19,954	21,327	20,435	19,655	19,460	18,788	217,923
REMOTE	NUMBER OF SHUTTLE FLIGHTS	8	6	11	9	9	9	10	9	9	9	89
	W_{PL} CAPABILITY (LB)	60,402	27,246	57,152	32,959	32,182	34,339	38,227	33,325	34,038	31,282	381,152
	EFFICIENCY (PERCENT)	55	57	55	55	62	62	53	59	57	60	57
MANNED	NUMBER OF SHUTTLE FLIGHTS	8	9	14	12	13	13	12	12	12	12	117
	W_{PL} CAPABILITY (LB)	60,402	36,578	66,388	45,301	52,252	51,501	43,791	43,859	43,770	44,620	488,462
	EFFICIENCY (PERCENT)	54	42	47	40	38	41	47	45	44	42	45

Table 4-4. Multiple-Function Platform Delivery/Servicing Summary (50-Percent Spares per Year)

		81	82	83	84	85	86	87	88	89	90	TOTAL
PLATFORMS DELIVERED		8	1	7	-	1	1	-	-	-	-	18
VISITS												
UPDATE AND/OR SERVICE		-	2	2	2	1	2	2	2	1	3	17
SERVICE		-	6	7	14	15	15	16	16	17	15	121
Σ(DELIVERIES + VISITS		8	9	16	16	17	18	18	18	18	18	156
$W_{PL\ UP}$ (LB)		32,950	15,390	31,390	17,051	19,804	20,474	19,058	19,110	18,810	18,120	212,157
$W_{PL\ DOWN}$ (LB)		0	8,650	10,180	17,982	16,704	17,794	18,917	18,725	18,810	17,988	145,750
ΣW_{PL} (UP + DOWN)		32,950	24,040	41,570	35,033	36,508	38,268	37,975	37,835	37,620	36,108	357,907
REMOTE	NUMBER OF SHUTTLE FLIGHTS	8	7	11	10	9	10	10	10	10	10	95
	W_{PL} CAPABILITY (LB)	60,402	43,426	69,598	58,737	51,898	55,596	64,763	64,787	64,700	65,482	599,389
	EFFICIENCY (PERCENT)	54	55	60	60	70	69	59	58	58	55	60
MANNED	NUMBER OF SHUTTLE FLIGHTS	8	11	16	18	19	21	20	20	20	20	173
	W_{PL} CAPABILITY (LB)	60,402	43,898	73,646	61,053	65,704	70,056	66,207	72,571	72,484	73,234	659,255
	EFFICIENCY (PERCENT)	54	55	56	57	56	55	57	52	52	49	54

Table 4-5. Multiple-Function Platform Delivery/Servicing Summary (50-Percent Spares per Two Years)

		81	82	83	84	85	86	87	88	89	89	TOTAL
	PLATFORMS DELIVERED	8	1	7	-	1	1	-	-	-	-	18
	VISITS											
	UPDATE AND/OR SERVICE	-	2	2	2	1	2	2	2	1	3	17
	SERVICE	-	-	6	1	14	1	14	2	15	2	55
	Σ(DELIVERIES + VISITS)	8	3	15	3	16	4	16	4	16	5	90
	W_{PL} UP (LB)	32,950	6,890	29,860	2,407	18,274	4,360	17,428	3,180	16,560	3,050	134,959
	W_{PL} DOWN (LB)	0	150	8,650	2,638	15,174	2,508	17,287	2,795	16,560	2,918	68,680
	ΣW_{PL} (UP + DOWN)	32,950	7,040	38,510	5,045	33,448	6,868	34,715	5,975	33,120	5,968	203,639
REMOTE	NUMBER OF SHUTTLE FLIGHTS	8	2	10	2	8	3	9	2	9	3	56
	W_{PL} CAPABILITY (LB)	60,402	11,568	67,224	7,955	46,304	13,790	56,917	10,291	56,898	17,782	349,131
	EFFICIENCY (PERCENT)	54	61	57	63	72	50	61	58	58	33	58
MANNED	NUMBER OF SHUTTLE FLIGHTS	8	3	15	4	17	5	14	4	16	6	92
	W_{PL} CAPABILITY (LB)	60,402	14,920	72,106	17,513	64,982	22,084	57,515	10,091	57,666	20,354	397,633
	EFFICIENCY (PERCENT)	54	47	53	29	51	31	60	59	57	29	51

Table 4-6. Geosynchronous Program Summary

	CHARACTERISTIC	EXPENDABLE SATELLITE PROGRAM	PLATFORM PROGRAMS			
			SINGLE FUNCTION PLATFORMS	MULTIPLE FUNCTION PLATFORMS		
			25% PER YEAR	25% PER YEAR	50% PER YEAR	50% PER 2 YEARS
	DELIVERIES + VISITS (TOTAL)	113 (DELIVERIES ONLY)	484	156	156	90
	PAYLOAD: W_{PL} (UP + DOWN) LB	138,600	378,045	217,923	357,907	203,639
	SPACECRAFT WEIGHT (LB)	138,600	141,179	63,400	63,400	63,400
REMOTE	NUMBER OF SHUTTLE FLIGHTS	44	175	89	95	56
	NUMBER OF MISSIONS	44	175	89	58	39
	CLUSTERING DENSITY UNITS*/FLIGHT	2.6	2.8	1.8	1.6	1.6
	W_{PL} CAPABILITY (LB)	285,212	725,235	381,152	599,389	349,131
	EFFICIENCY (PERCENT)	49	52	57	60	58
MANNED	NUMBER OF SHUTTLE FLIGHTS	N/A	203	117	173	92
	NUMBER OF MISSIONS	N/A	112	66	94	54
	CLUSTERING DENSITY UNITS/FLIGHT		2.4	1.3	0.9	1.0
	W_{PL} CAPABILITY (LB)		774,217	488,462	659,255	397,633
	EFFICIENCY (PERCENT)		49	45	54	51

*UNIT $\triangleq$ DELIVERY OR VISIT

Table 4-7. Payload Comparison of Alternative Programs

PROGRAM			AVG $W_{PL(CAP)}$/FLIGHT	NORMALIZED		AVG $W_{PL(ACTUAL)}$/FLIGHT	NORMALIZED		EFFICIENCY (PERCENT)
EXPENDABLE SATELLITES			6482	1.0*	-	3150	1.0*	-	49
REMOTE	SINGLE FUNCTION PLATFORMS		4144	0.6	1.0*	2160	0.7	1.0*	52
REMOTE	MULTIPLE FUNCTION PLATFORMS	SPARES 25 PERCENT PER YEAR	4283	0.7	1.0	2448	0.8	1.1	57
REMOTE	MULTIPLE FUNCTION PLATFORMS	50 PERCENT PER YEAR	6309	1.0	1.5	3767	1.2	1.7	60
REMOTE	MULTIPLE FUNCTION PLATFORMS	50 PERCENT PER 2 YEARS	6234	1.0	1.5	3636	1.2	1.7	58
MANNED	SINGLE FUNCTION PLATFORMS		3814	0.6	1.0	1862	0.6	1.0	49
MANNED	MULTIPLE FUNCTION PLATFORMS	SPARES 25 PERCENT PER YEAR	4175	0.6	1.1	1863	0.6	1.0	45
MANNED	MULTIPLE FUNCTION PLATFORMS	50 PERCENT PER YEAR	3811	0.6	1.0	2069	0.7	1.1	54
MANNED	MULTIPLE FUNCTION PLATFORMS	50 PERCENT PER 2 YEARS	4322	0.7	1.1	2213	0.7	1.2	51

*BASE

Table 4-8. Flight Characteristics Summary

Program	Percent of Total Flights by Flight Characteristics					
	Remote Servicing			Manned Servicing		
	Delivery Only	Mixed Delivery/Servicing	Servicing Only	Delivery Only	Mixed Delivery/Servicing	Servicing Only
Single Function Platforms	10	19	71	10	23	67
Multiple Function Platforms 25% per year	12	8	80	13	5	82
Multiple Function Platforms 50% per year	12	8	80	9	3	88
Multiple Function Platforms 50% per 2 years	25	11	64	18	4	78

Table 4-9. Shuttle Flight Characteristics (Expendable Satellite)

Type	81	82	83	84	85	86	87	88	89	90	Total
Deliver 1	1	-	-	1	-	-	1	-	-	3	6
Deliver 2	2	1	-	-	1	1	1	3	1	-	10
Deliver 3	2	4	4	3	3	1	1	3	2	2	25
Deliver 4	-	-	1	-	-	-	1	-	1	-	3
Total	5	5	5	4	4	2	4	6	4	5	44

Table 4-10. Shuttle Flight Characteristics (Single-Function Platforms, Remote Servicing)

Type	81	82	83	84	85	86	87	88	89	90	Total
Delivery only	6	5	4	-	1	-	-	-	-	-	16
Delivery and 1 service	-	-	2	1	4	-	-	-	-	-	7
Delivery and 2 services	-	4	-	2	2	-	3	-	-	-	11
Delivery and 3 services	-	-	5	5	2	2	1	-	-	1	16
Service 1	-	1	2	1	1	1	1	1	1	1	10
Service 2	-	1	1	-	1	2	-	2	2	2	11
Service 3	-	-	1	6	10	15	16	19	19	18	104
Subtotal (service only)	(-)	(2)	(4)	(7)	(12)	(18)	(17)	(22)	(22)	(21)	(125)
Total	6	11	15	15	21	20	21	22	22	22	175

Table 4-11. Shuttle Flight Characteristics
(Multiple-Function Platforms, Remote Servicing, 25-Percent Spares per Year)

Type	81	82	83	84	85	86	87	88	89	90	Total
Delivery only	8	1	3	-	-	-	-	-	-	-	11
Delivery and 1 service	-	-	4	-	-	1	-	-	-	-	6
Delivery and 2 services	-	-	-	-	1	-	-	-	-	-	1
Service 1	-	2	3	2	2	1	3	1	1	1	16
Service 2	-	3	1	7	6	6	6	7	7	6	49
Service 3	-	-	-	-	-	1	1	1	1	2	6
Subtotal (service only)	(-)	(5)	(4)	(9)	(8)	(8)	(10)	(9)	(9)	(9)	(71)
Total	8	6	11	9	9	9	10	9	9	9	89

Table 4-12. Shuttle Flight Characteristics
(Multiple-Function Platforms, Remote Servicing, 50-Percent Spares per Year)

Type	81	82	83	84	85	86	87	88	89	90	Total
SINGLE TUG MISSIONS											
Delivery only	8	1	2	-	-	-	-	-	-	-	11
Delivery + 1 service	-	-	-	-	1	1	-	-	-	-	2
Service 1	-	2	3	2	-	1	-	-	-	-	8
Subtotal: Flights/Missions	8	3	5	2	1	2	-	-	-	-	21
DUAL TUG MISSIONS											
Delivery and 1 service	-	-	2	-	-	-	-	-	-	-	2
Delivery and 4 service	-	-	1	-	-	-	-	-	-	-	1
Service 3	-	2	-	2	1	1	2	2	2	2	14
Service 4	-	-	-	2	3	3	3	3	3	3	20
Subtotal	-	2	3	4	4	4	5	5	5	5	37
Equivalent Shuttle Flights	-	4	6	8	8	8	10	10	10	10	74
Total Shuttle Flights	8	7	11	10	9	10	10	10	10	10	95

Table 4-13. Shuttle Flight Characteristics
(Multiple-Function Platforms, Remote Servicing, 50-Percent Spares per Two Years)

Type	81	82	83	84	85	86	87	88	89	90	Total
SINGLE TUG MISSIONS											
Delivery only	8	1	3	-	1	1	-	-	-	-	14
Service 1	-	-	1	-	1	1	1	-	1	1	6
Service 2	-	1	-	-	-	1	-	-	-	-	2
Subtotal: Flights/Missions	8	2	4	-	2	3	1	-	1	1	22
DUAL TUG MISSIONS											
Delivery and 2 service	-	-	1	-	-	-	-	-	-	-	1
Delivery and 3 service	-	-	2	-	-	-	-	-	-	-	2
Service 3	-	-	-	1	-	-	1	-	1	-	3
Service 4	-	-	-	-	2	-	3	1	3	1	10
Service 5	-	-	-	-	1	-	-	-	-	-	1
Subtotal	-	-	3	1	3	-	4	1	4	1	17
Equivalent Shuttle Flights	-	-	6	2	6	-	8	2	8	2	34
Total Shuttle Flights	8	2	10	2	8	3	9	2	9	3	56

Table 4-14. Shuttle Flight Characteristics
(Single-Function Platforms, Manned Servicing, 25-Percent Spares per Year)

Type	81	82	83	84	85	86	87	88	89	90	Total
SINGLE TUG MISSIONS											
Delivery only	6	4	5	1	5	-	-	-	-	-	21
DUAL TUG MISSIONS											
Delivery and 2 service	-	3	-	-	-	-	-	-	-	-	3
Delivery and 3 service	-	-	2	2	-	-	-	-	-	-	4
Delivery and 4 service	-	1	1	2	2	-	1	-	-	-	7
Delivery and 5 service	-	-	1	2	-	1	3	-	-	-	7
Delivery and 6 service	-	-	-	-	1	1	-	-	-	-	2
Service 1	-	1	1	1	1	1	1	1	1	1	9
Service 4	-	-	2	1	-	1	1	2	2	2	11
Service 5	-	-	-	2	4	2	2	1	1	1	13
Service 6	-	-	-	-	2	5	4	8	8	8	35
Subtotal	-	5	7	10	10	11	12	12	12	12	91
Equivalent Shuttle Flights	-	10	14	20	20	22	24	24	24	24	182
Total Shuttle Flights	6	14	19	21	25	22	24	24	24	24	203

Table 4-15. Shuttle Flight Characteristics
(Multiple-Function Platforms, Manned Servicing, 25-Percent Spares per Year)

Type	81	82	83	84	85	86	87	88	89	90	Total
SINGLE TUG MISSIONS											
Delivery only	8	1	4	-	1	1	-	-	-	-	15
DUAL TUG MISSIONS											
Delivery and 1 service	-	-	1	-	-	-	-	-	-	-	1
Delivery and 2 service	-	-	2	-	-	-	-	-	-	-	2
Service 1	-	1	1	1	1	1	1	1	1	1	9
Service 2	-	2	-	1	1	1	-	-	-	-	5
Service 3	-	1	1	3	3	2	3	3	3	3	22
Service 4	-	-	-	1	1	2	2	2	2	2	12
Subtotal	-	4	5	6	6	6	6	6	6	6	51
Equivalent Shuttle Flights	-	8	10	12	12	12	12	12	12	12	102
Total Shuttle Flights	8	9	14	12	13	13	12	12	12	12	117

Table 4-16. Shuttle Flight Characteristics
(Multiple-Function Platforms, Manned Servicing, 50-Percent Spares per Year)

Type	81	82	83	84	85	86	87	88	89	90	Total
SINGLE TUG MISSIONS											
Delivery only	8	1	4	-	1	1	-	-	-	-	15
DUAL TUG MISSIONS											
Delivery and 1 service	-	-	2	-	-	-	-	-	-	-	2
Delivery and 2 service	-	-	1	-	-	-	-	-	-	-	1
Service 1	-	2	1	3	3	3	2	2	2	2	20
Service 2	-	3	2	5	5	7	8	8	8	8	54
Service 3	-	-	-	1	1	-	-	-	-	-	2
Subtotal	-	5	6	9	9	10	10	10	10	10	79
Equivalent Shuttle Flights	-	10	12	18	18	20	20	20	20	20	158
Total Shuttle Flights	8	11	16	18	19	21	20	20	20	20	173

Table 4-17. Shuttle Flight Characteristics
(Multiple-Function Platforms, Manned Servicing, 50-Percent Spares per Two Years)

Type	81	82	83	84	85	86	87	88	89	90	Total
SINGLE TUG MISSIONS											
Delivery only	8	1	5	-	1	1	-	-	-	-	16
DUAL TUG MISSIONS											
Delivery and 1 service	-	-	1	-	-	-	-	-	-	-	1
Delivery and 2 service	-	-	1	-	-	-	-	-	-	-	1
Service 1	-	-	1	1	2	1	1	-	1	1	8
Service 2	-	1	2	1	5	1	5	2	6	2	25
Service 3	-	-	-	-	1	-	1	-	1	-	3
Subtotal	-	1	5	2	8	2	7	2	8	3	38
Equivalent Shuttle Flights	-	2	10	4	16	4	14	4	16	6	76
Total Shuttle Flights	8	3	15	4	17	5	14	4	16	6	92

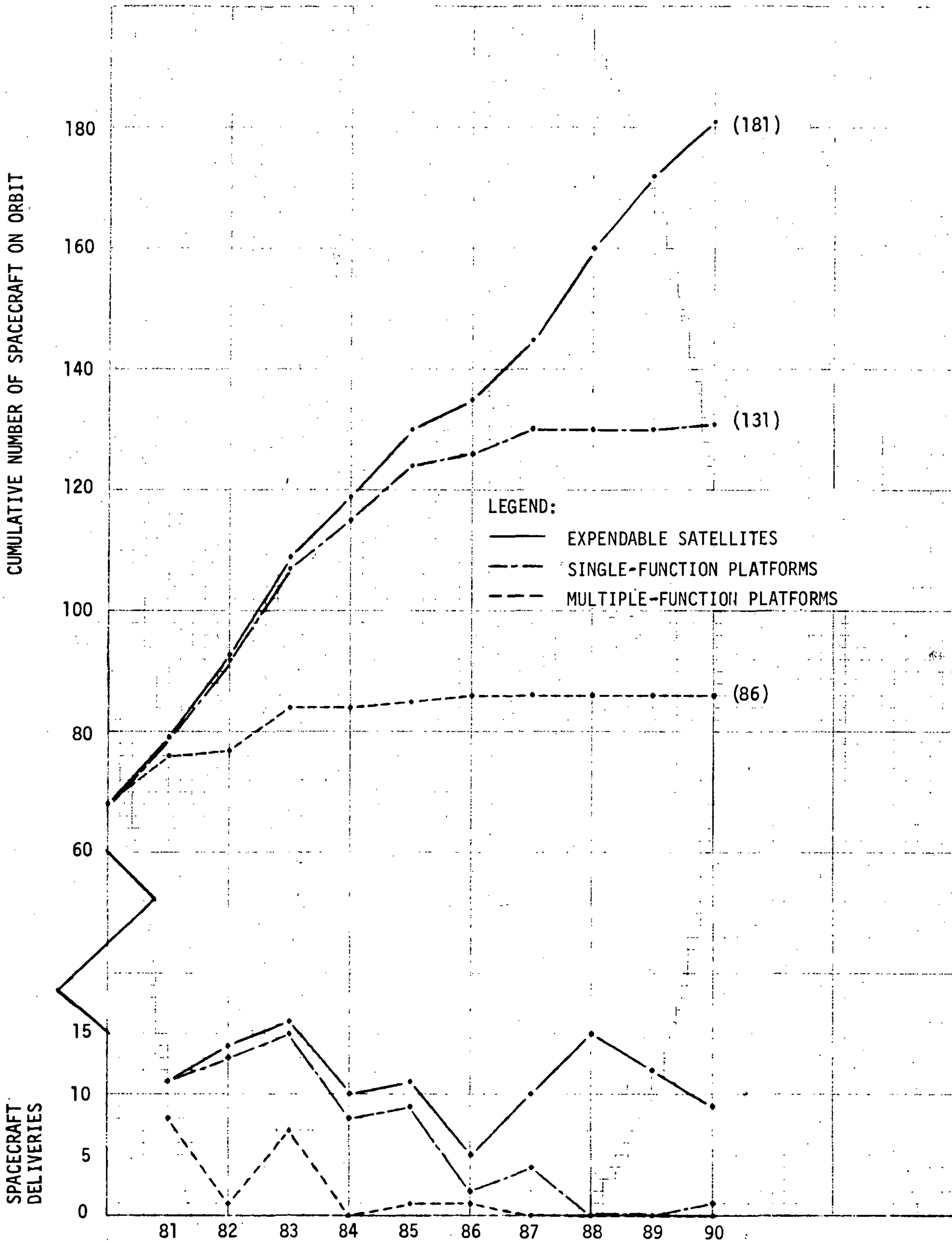

Figure 4-8. Traffic Model Comparison (Baseline Traffic Model)

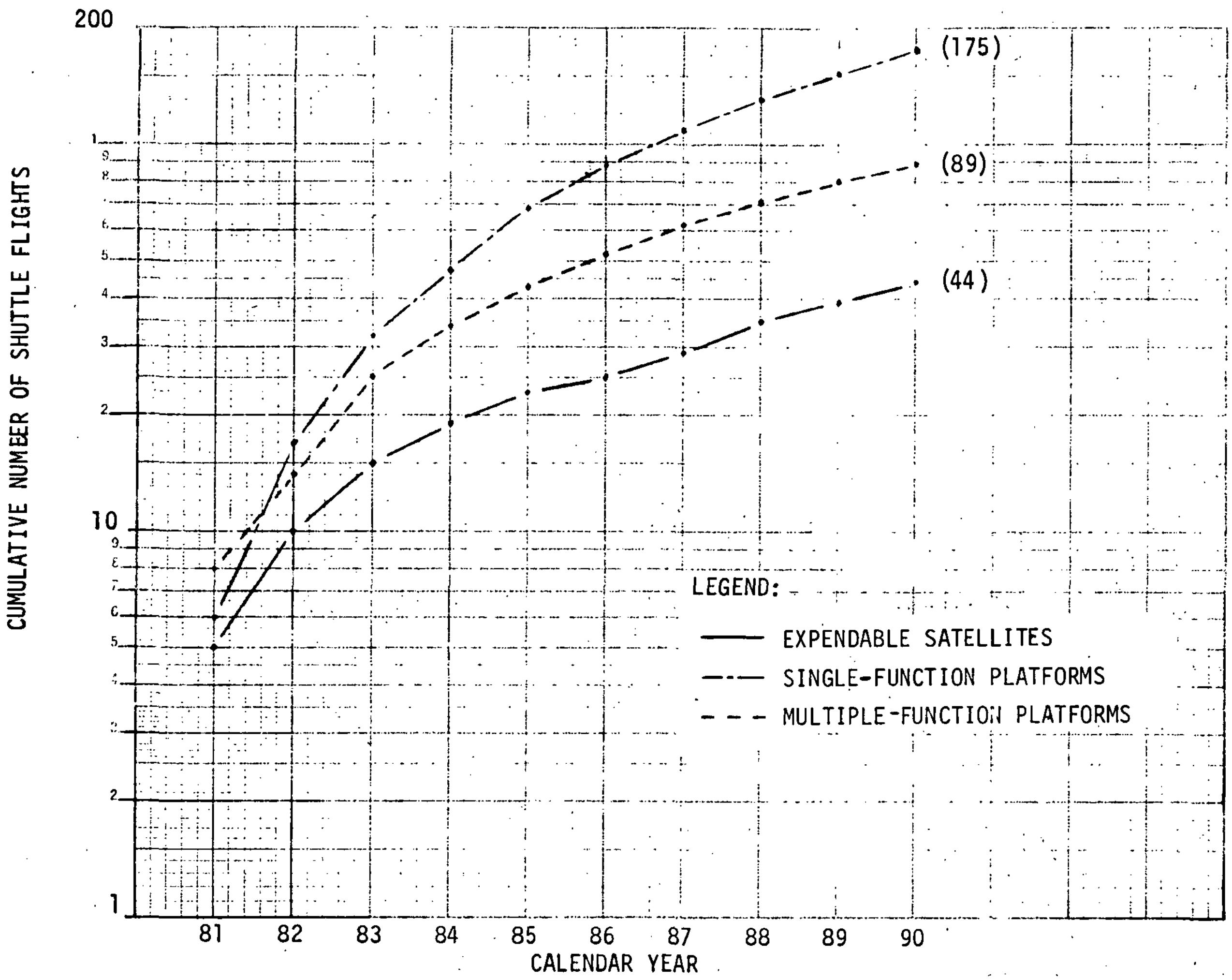

Figure 4-9. Cumulative Shuttle Flights (Remote - 25% Spares per Year)

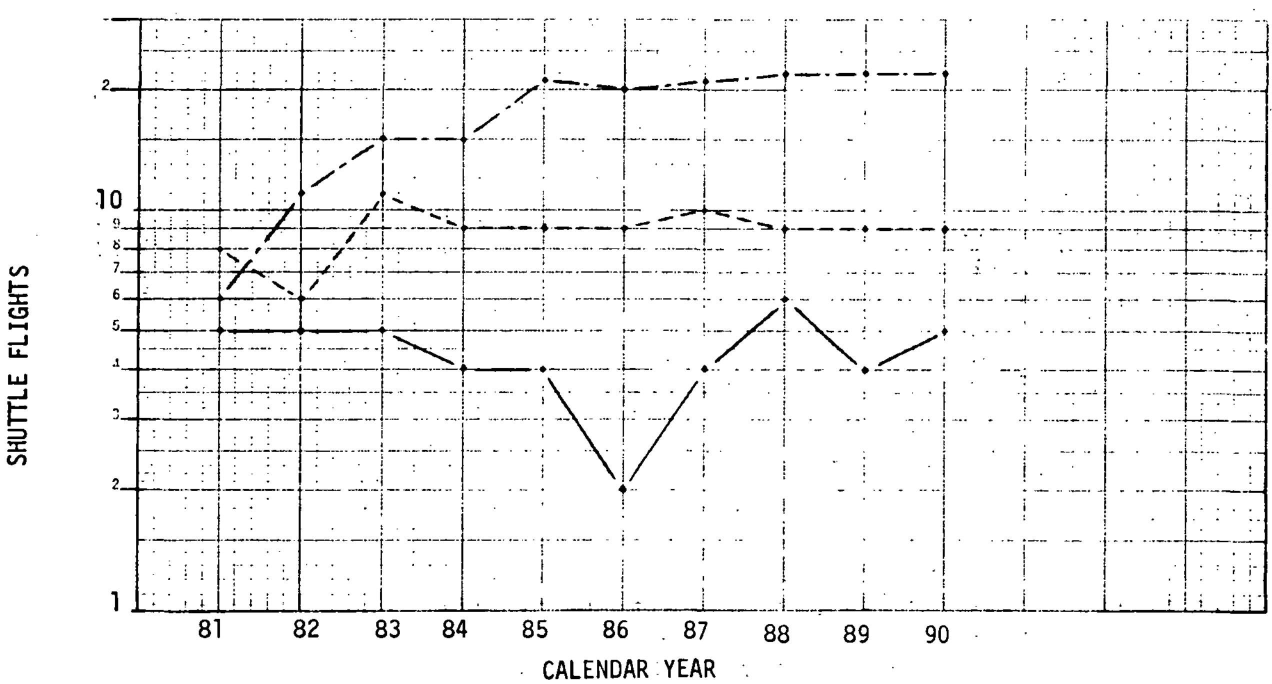

Figure 4-10. Shuttle Flight Schedule (Remote - 25% Spares per Year)

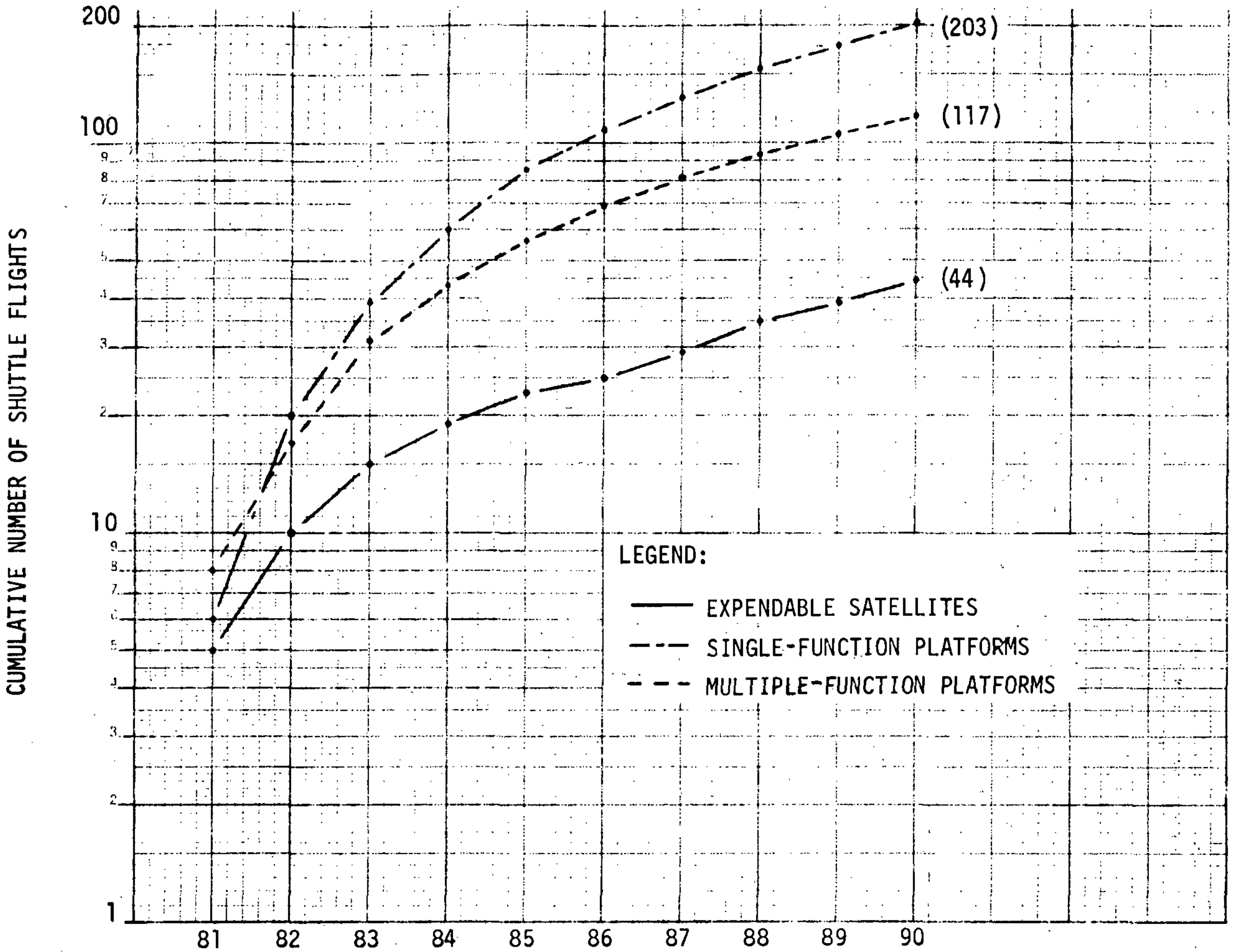

Figure 4-11. Cumulative Shuttle Flights (Manned - 25% Spares per Year)

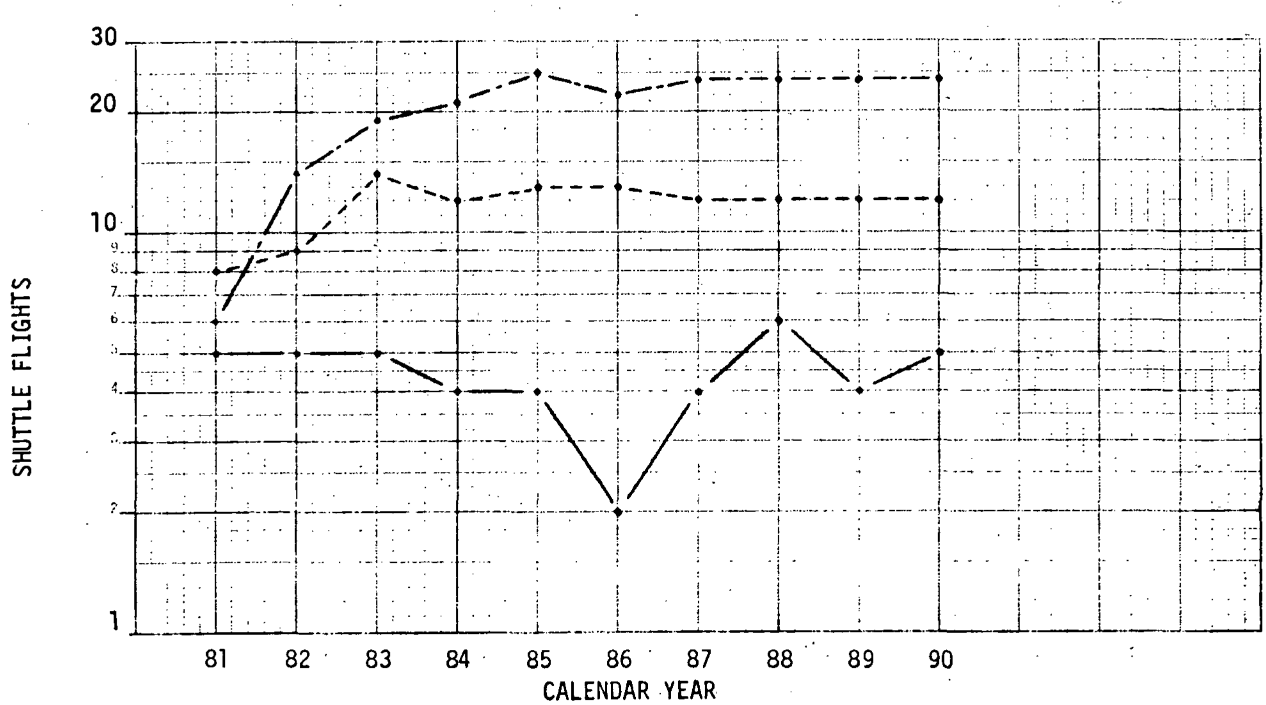

Figure 4-12. Shuttle Flight Schedule (Manned - 25% Spares per Year)

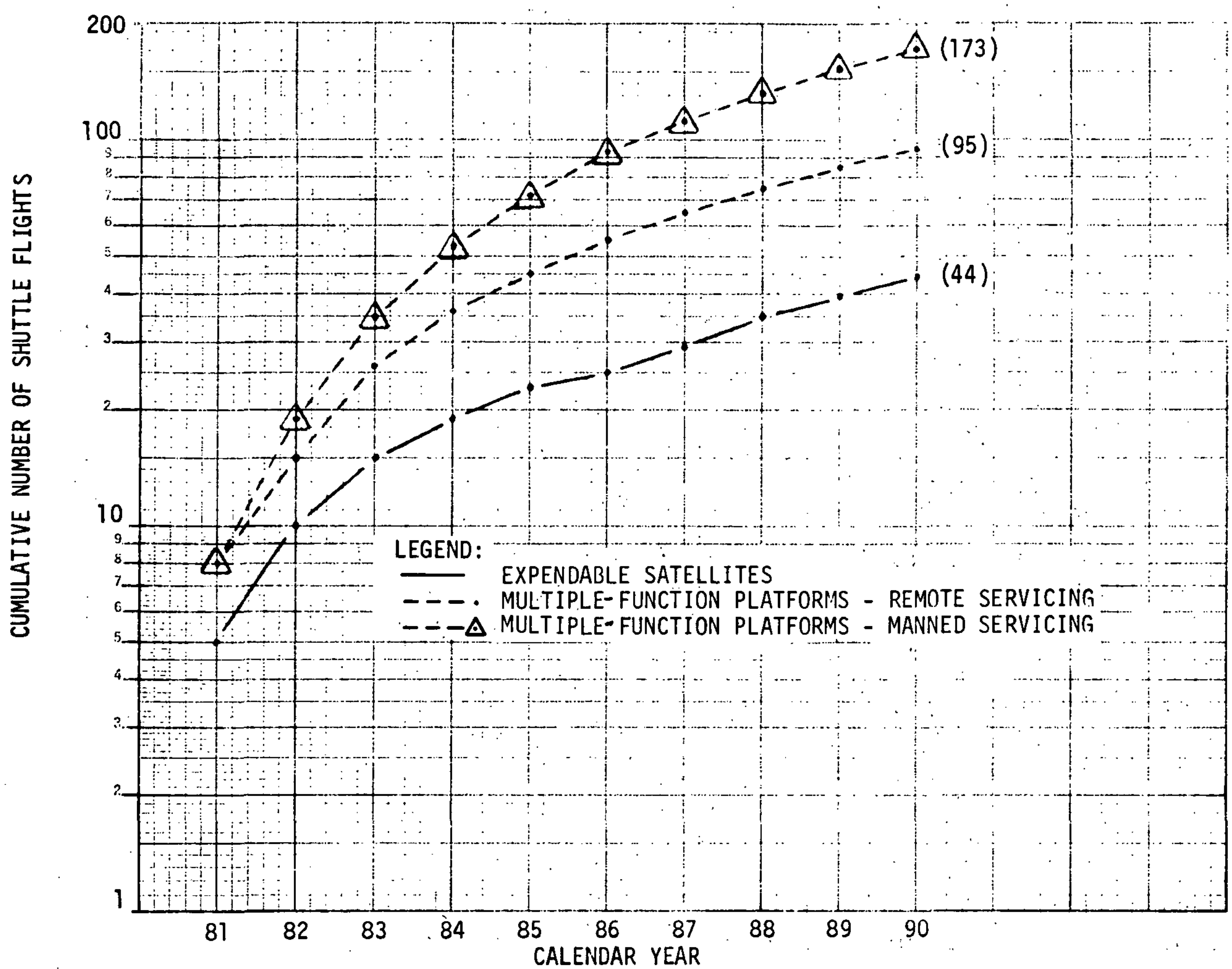

Figure 4-13. Cumulative Shuttle Flights (50% Spares per Year)

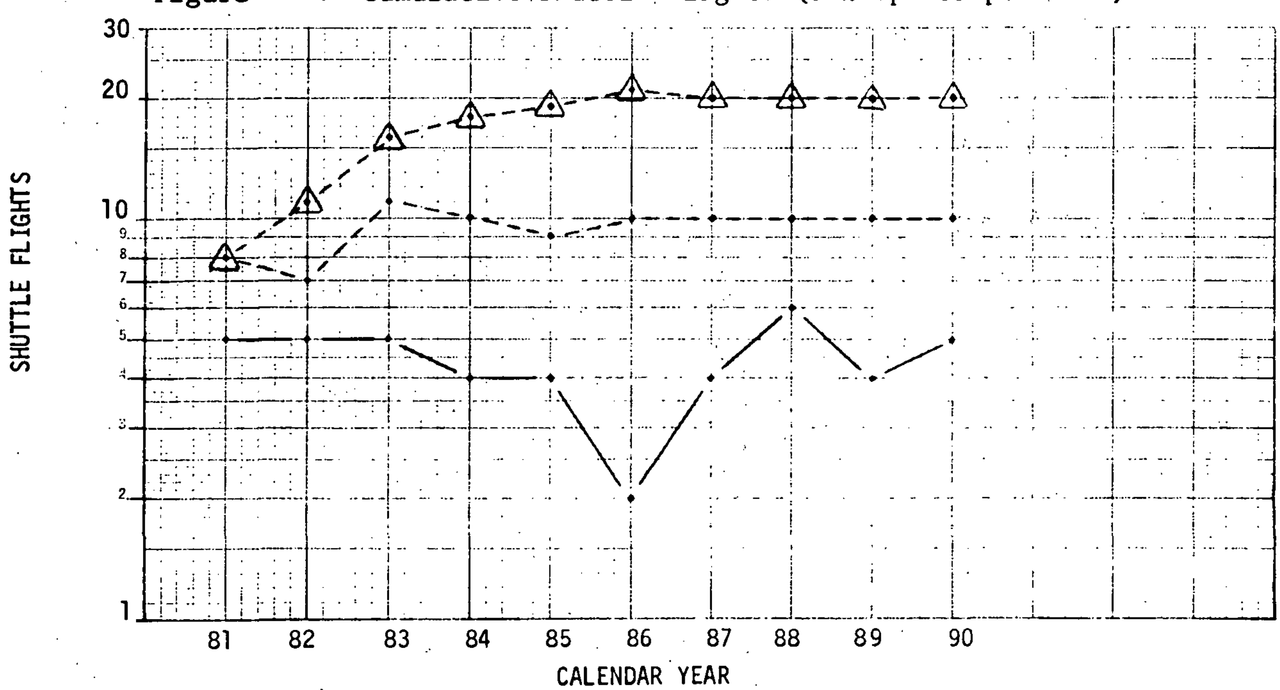

Figure 4-14. Shuttle Flight Schedule (50% Spares per Year)

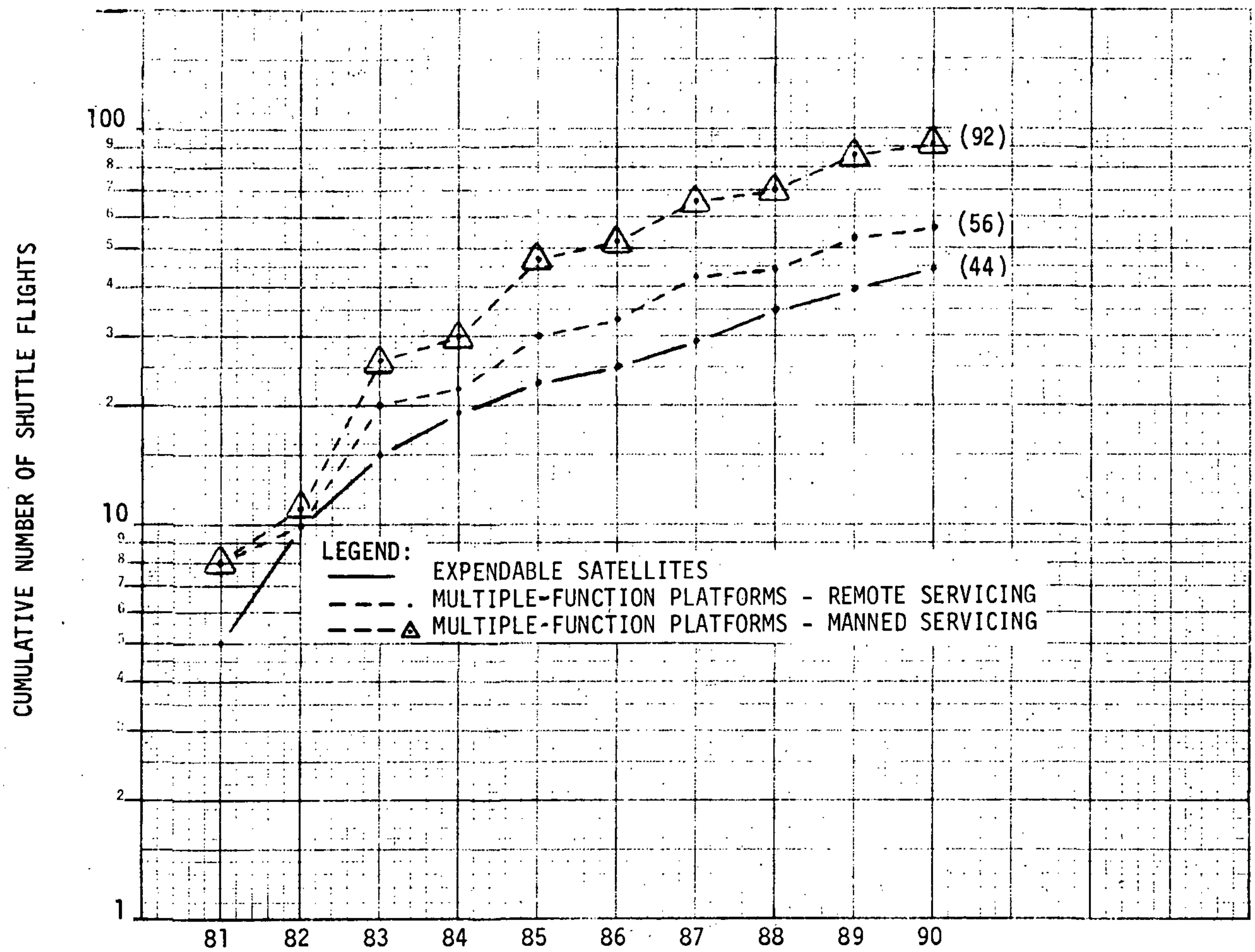

Figure 4-15. Cumulative Shuttle Flights (50% Spares per 2 Years)

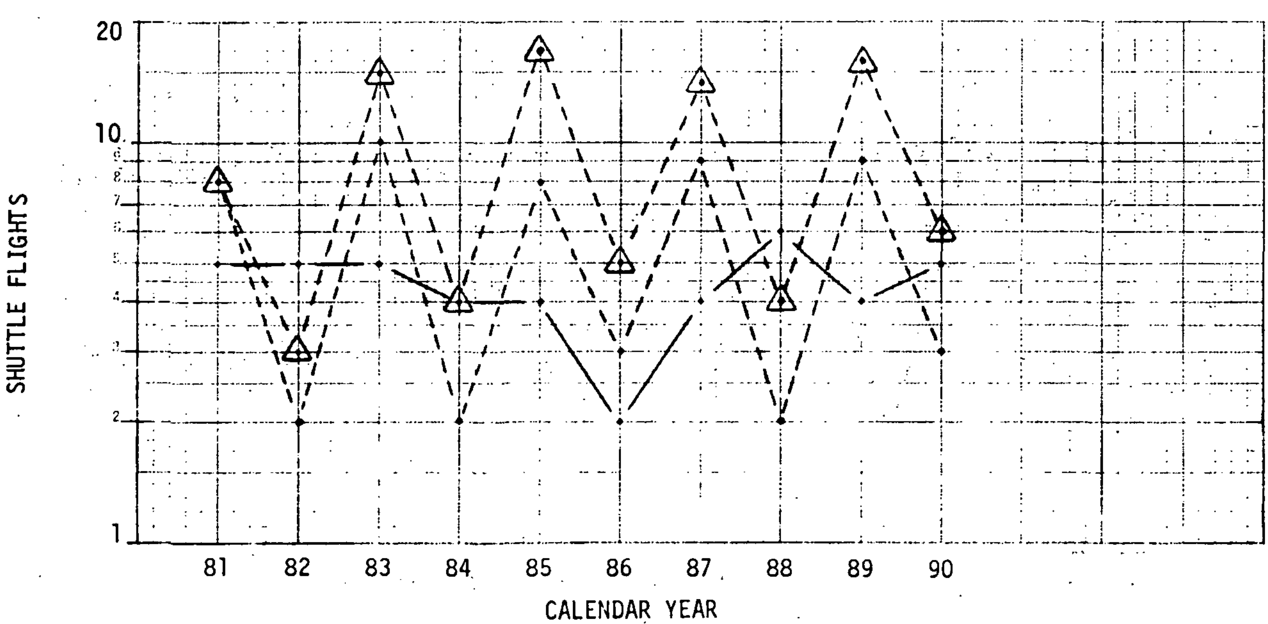

Figure 4-16. Shuttle Flight Schedule (50% Spares per 2 Years)

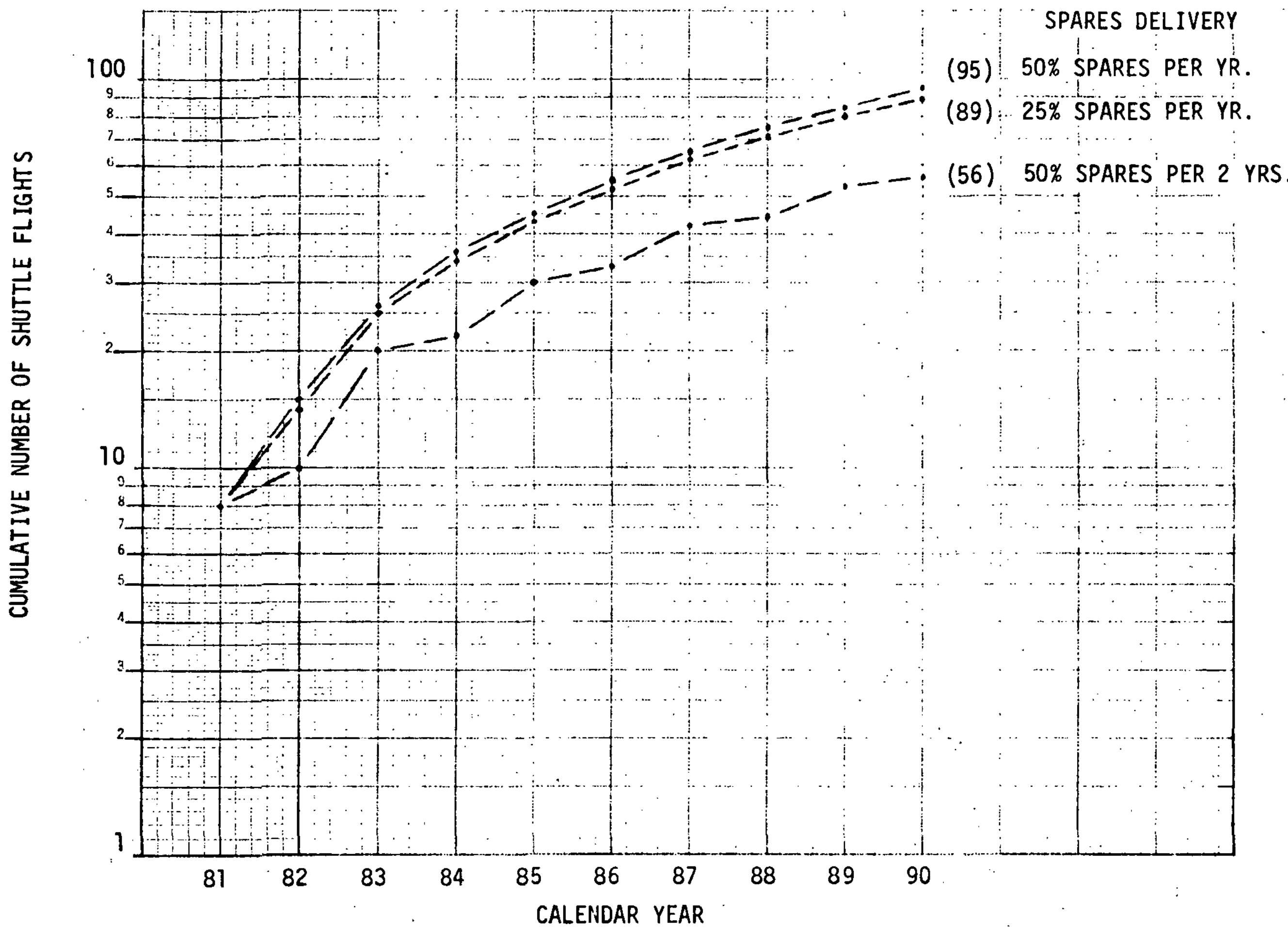

Figure 4-17. Cumulative Shuttle Flight Comparison - Platform Programs - Remote Servicing

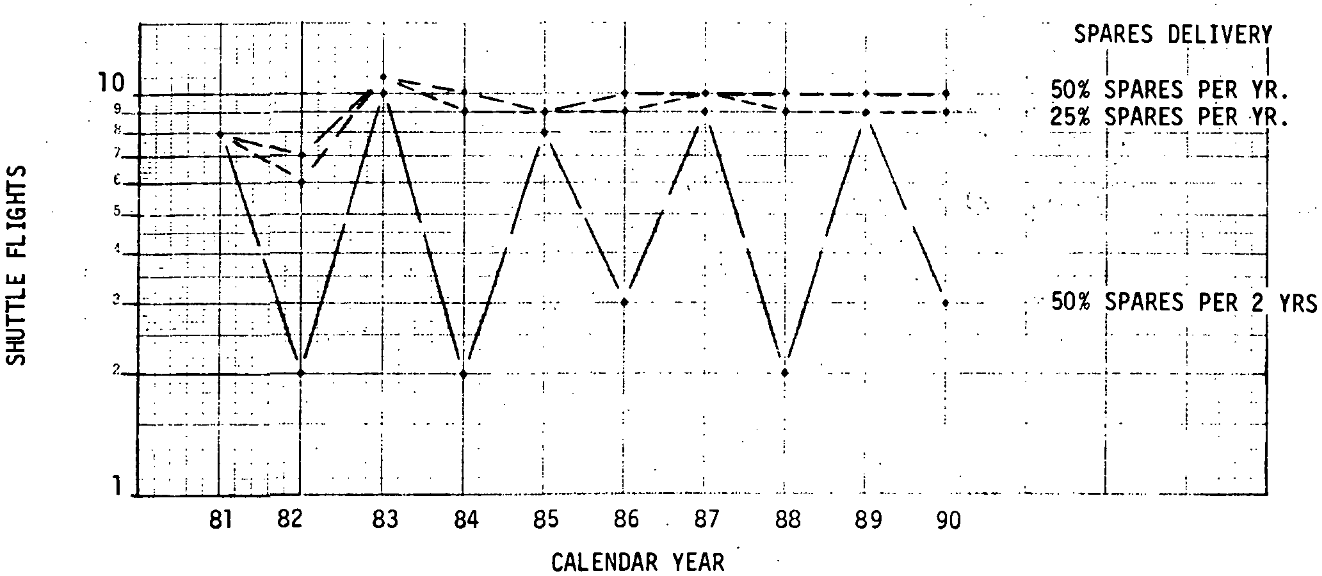

Figure 4-18. Shuttle Flight Comparison - Platform Programs - Remote Servicing

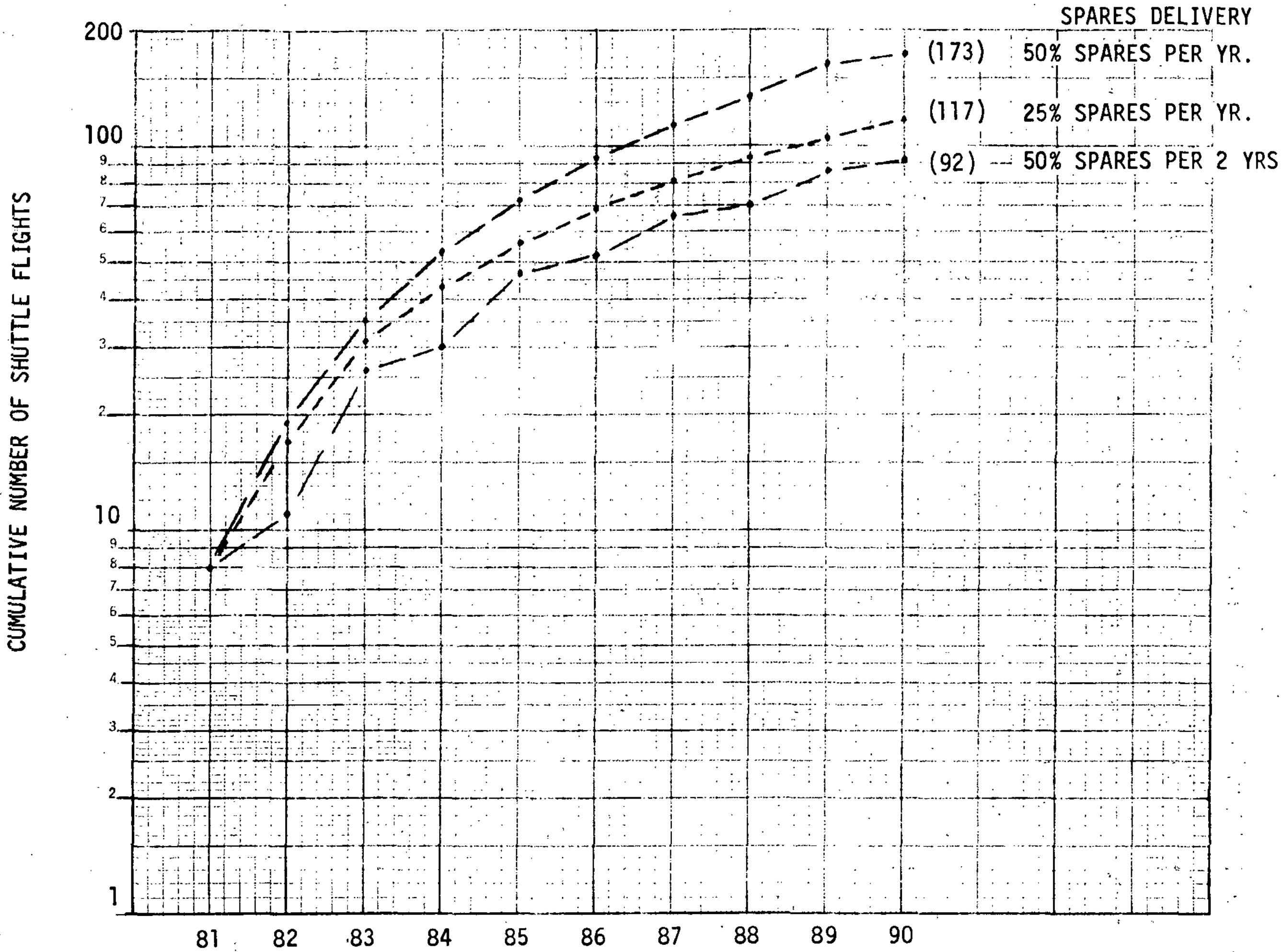

Figure 4-19. Cumulative Shuttle Flight Comparison - Platform Programs - Manned Servicing

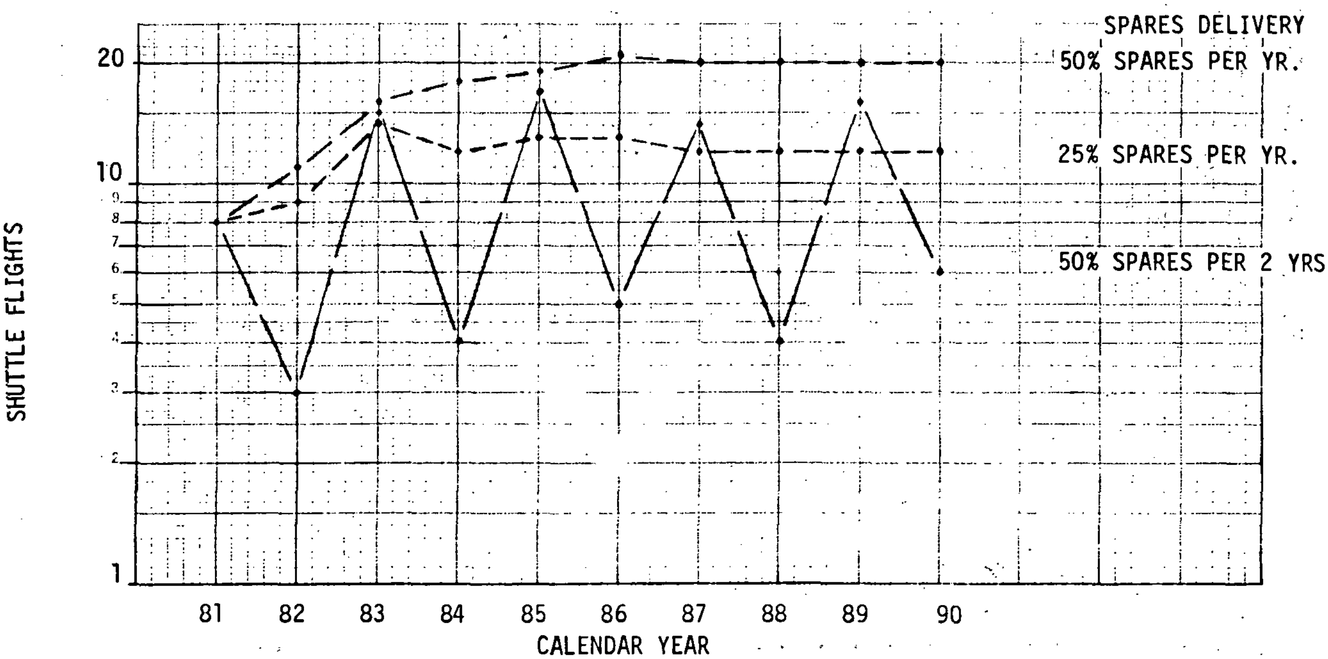

Figure 4-20. Shuttle Flight Comparison - Platform Programs - Manned Servicing

Table 4-18. New Traffic Model, Expendable Satellite Delivery Schedule

	81	82	83	84	85	86	87	88	89	90	Total
Astronomy	-	2	-	3	-	2	-	3	-	3	13
(Active)	(4)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(6)	
Mersat	-	2	2	-	2	2	-	-	-	-	8
(Active)	(5)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	
ATS	2	2	-	3	3	-	2	2	3	2	19
(Active)	(6)	(5)	(4)	(4)	(4)	(4)	(4)	(3)	(5)	(5)	
TDRS	1	1	6	5	1	1	1	6	5	1	28
(Active)	(6)	(7)	(9)	(14)	(14)	(14)	(14)	(14)	(14)	(14)	
Nacsat	4	4	4	4	4	4	4	4	4	-	36
(Active)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	
Intelsat	1	2	5	4	4	6	6	6	7	11	52
(Active)	(10)	(12)	(15)	(17)	(20)	(24)	(28)	(33)	(38)	(44)	
Domsat	1	6	7	7	9	13	17	22	35	43	160
(Active)	(20)	(23)	(28)	(30)	(35)	(44)	(60)	(81)	(110)	(146)	
Total Deliveries	9	19	24	26	23	28	30	43	54	60	316
(Total Active)	(71)	(76)	(85)	(94)	(102)	(115)	(135)	(160)	(196)	(239)	
Shuttle Flights at 2.6 satellites/flight	3	7	9	10	9	11	12	17	21	23	122

Table 4-19. New Traffic Model, Single-Function Platform Delivery Schedule

	81	82	83	84	85	86	87	88	89	89	Total
Astronomy	-	2	-	3	-	-	-	-	-	1	6
Mersat	-	2	2	-	-	-	-	-	-	-	4
ATS	2	2	-	-	-	-	-	-	1	-	5
TDRS	1	1	6	5	1	-	-	-	-	-	14
Nacsat	4	4	4	4	4	-	-	-	-	-	20
Intelsat	1	2	5	4	4	6	6	5	5	6	44
Domsat	1	6	7	7	9	13	17	21	29	36	146
Total Deliveries	9	19	24	23	18	19	23	26	35	43	239
Deliveries + Visits	9	28	52	75	93	112	135	161	196	239	1100
Shuttle Flights											
@ 2.8 Remote	4	10	19	27	33	40	48	57	70	85	393
@ 2.4 Manned	4	12	21	31	39	47	56	67	82	99	458

Table 4-20. Multiple-Function Platform Requirements Comparison, Baseline and New Traffic Model

Class	Baseline Traffic Model			New Traffic Model		
	Satellites		Platforms Delivered	Satellites		Platforms Delivered
	Delivered	Active		Delivered	Active	
Astronomy	4		1 + updates	13	(6)	3
Mersat (E-O)	25		4	8		4
ATS (+ system test and SATS)	22		2 + updates	19		2
TDRS	6	(3)	3	28	(14)	14
Nacsat	6	(3)		36	(20)	20
Intelsat	8	(8) (37)	8	52	(44) (210)	23
Domsat	42	(26)		160	(146)	
Total	113		18	316		66

Table 4-21. New Traffic Model - Multiple-Function Platform Delivery Schedule

			81	82	83	84	85	86	87	88	89	90	Total
		ASTRONOMY	-	2	-	1	-	-	-	-	-	-	3
		DEVELOPMENTAL	2	-	-	-	-	-	-	-	-	-	2
		TDRS	1	1	6	5	1	-	-	-	-	-	14
		NACSAT	4	4	4	4	4	-	-	-	-	-	20
		DATA RELAY	1	1	1	1	2	2	3	3	4	5	23
		EARTH OBSERVATIONS	-	2	2	-	-	-	-	-	-	-	4
		TOTAL DELIVERIES	8	10	13	11	7	2	3	3	4	5	66
		DELIVERIES + VISITS	8	18	31	42	49	51	54	57	61	66	437
SHUTTLE FLIGHTS	25% SPARES PER YEAR	@ 1.8 REMOTE	8	10	17	23	27	28	30	31	33	36	243
		@ 1.3 MANNED	8	14	24	32	37	39	41	44	47	50	336
	50% SPARES PER YEAR	@ 1.6 REMOTE	8	11	19	26	30	32	33	35	38	41	273
		@ 0.9 MANNED	8	20	35	47	55	57	60	63	68	73	486
	50% SPARES PER 2 YEARS	DELIVERIES + VISITS	(8)	(10)	(21)	(21)	(28)	(23)	(31)	(26)	(35)	(31)	(234)
		@ 1.6 REMOTE	8	10	12	12	17	13	19	16	20	19	146
		@ 1.0 MANNED	8	10	21	21	28	23	31	26	35	31	234

Table 4-22. New Traffic Model, Spacecraft Requirements

Spacecraft Type	Deliveries by Spacecraft Concept (1981-1990)		
	Expendable Satellites	Single Function Platforms	Multiple Function Platforms
Astronomy	13	6	3
Mersat	8	4	4
ATS	19	5	2
TDRS	28	14	14
Nacsat	36	20	20
Intelsat	52	44	23
Domsat	160	146	
Total Deliveries	319	239	66

Table 4-23. New Traffic Model - Geosynchronous Program Summary

Characteristic		Expendable Satellite Program	Platform Programs			
			Single-Function Platforms	Multiple-Function Platforms		
			25% Per Year	25% Per Year	50% Per Year	50% Per 2 Years
Deliveries + visits Total		(Deliveries only) 316	1100	437	437	234
REMOTE	Number of shuttle flights	122	393	243	273	146
MANNED	Number of shuttle flights	N/A	458	336	486	234

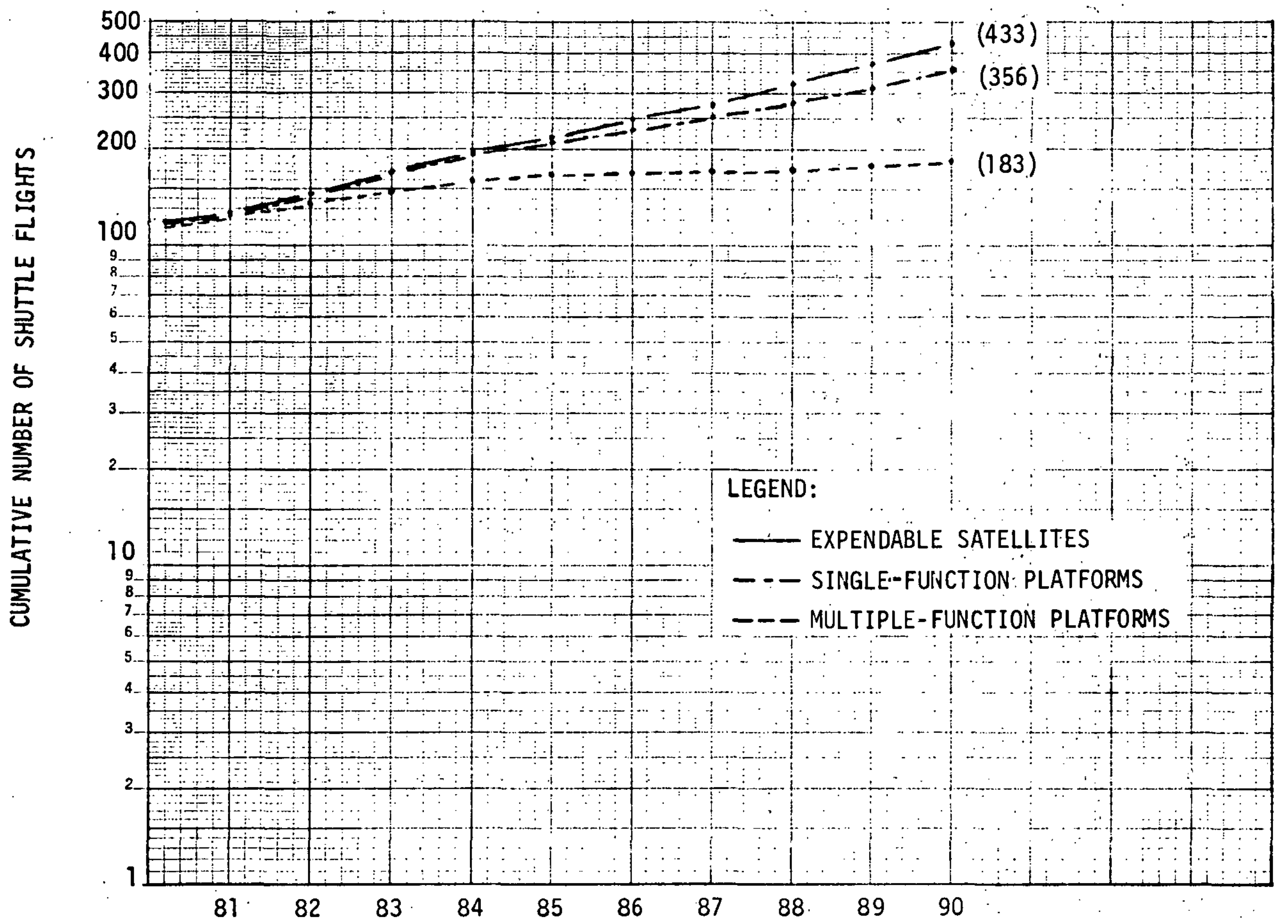

Figure 4-21. Cumulative Spacecraft (New Traffic Model)

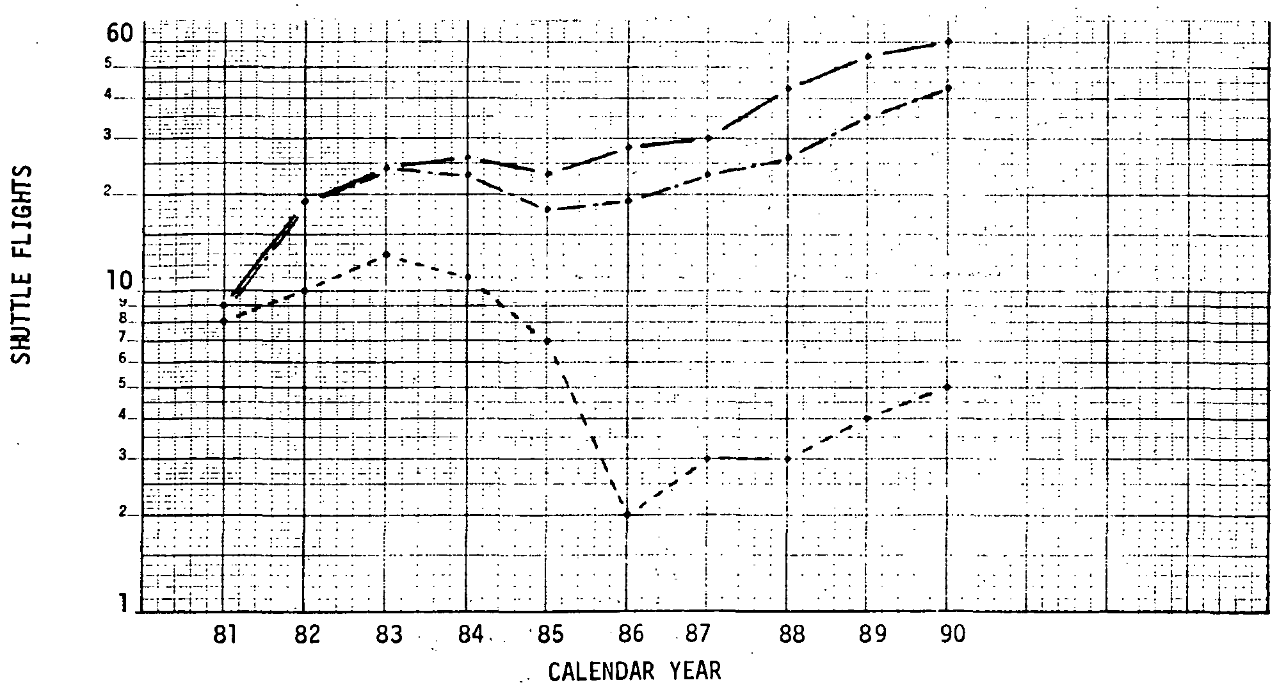

Figure 4-22. Traffic Model Comparison (New Traffic Model)

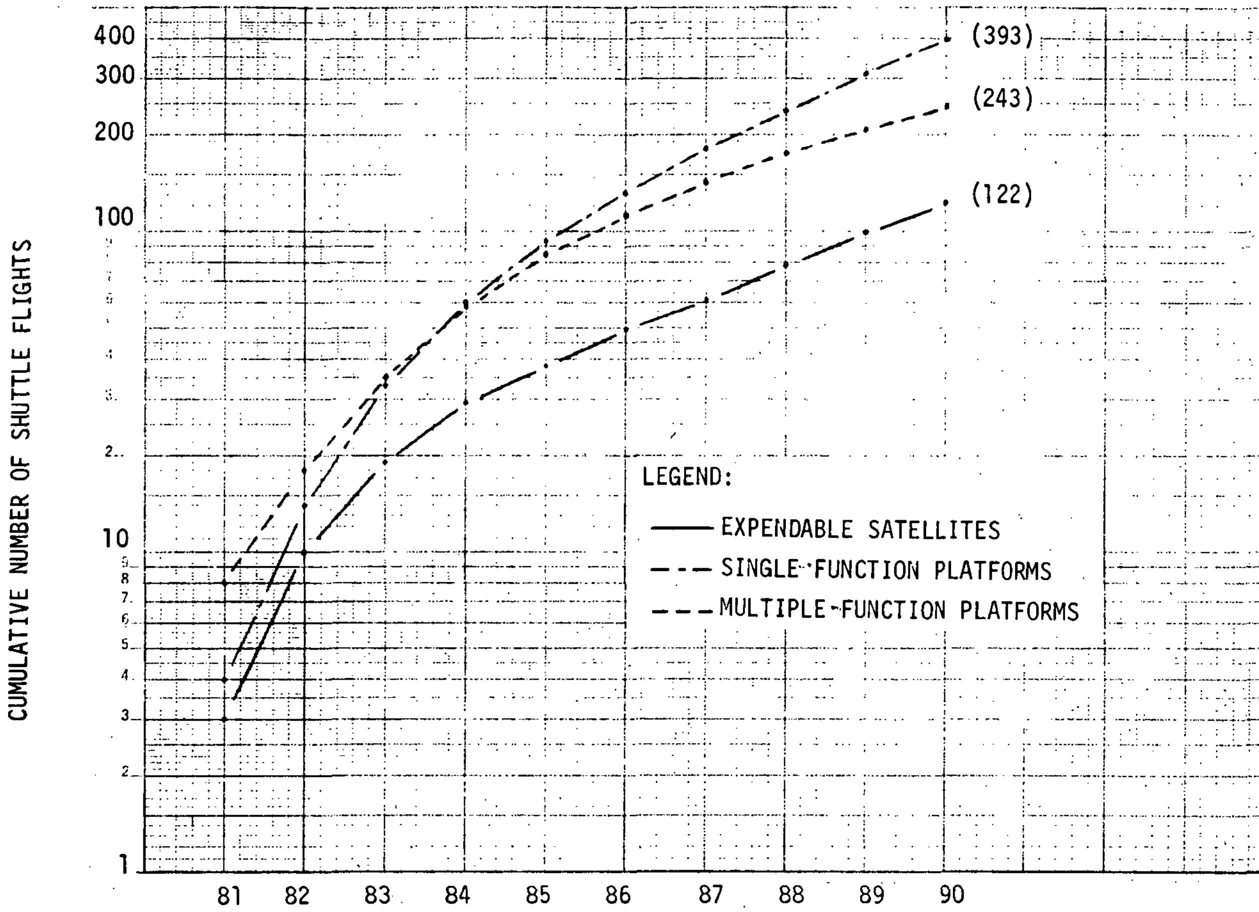

Figure 4-23. Cumulative Shuttle Flights (Remote - 25% Spares per Year, New Traffic Model)

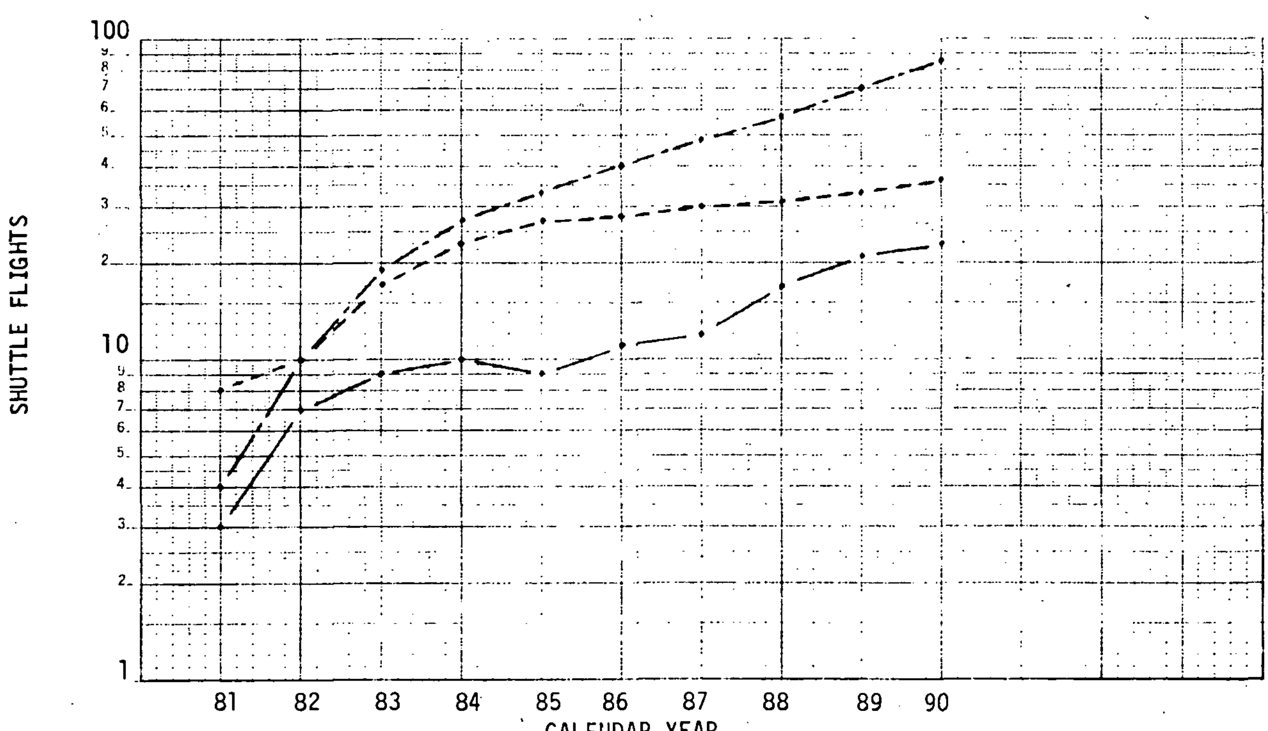

Figure 4-24. Shuttle Flight Schedule (Remote - 25% Spares per Year, New Traffic Model)

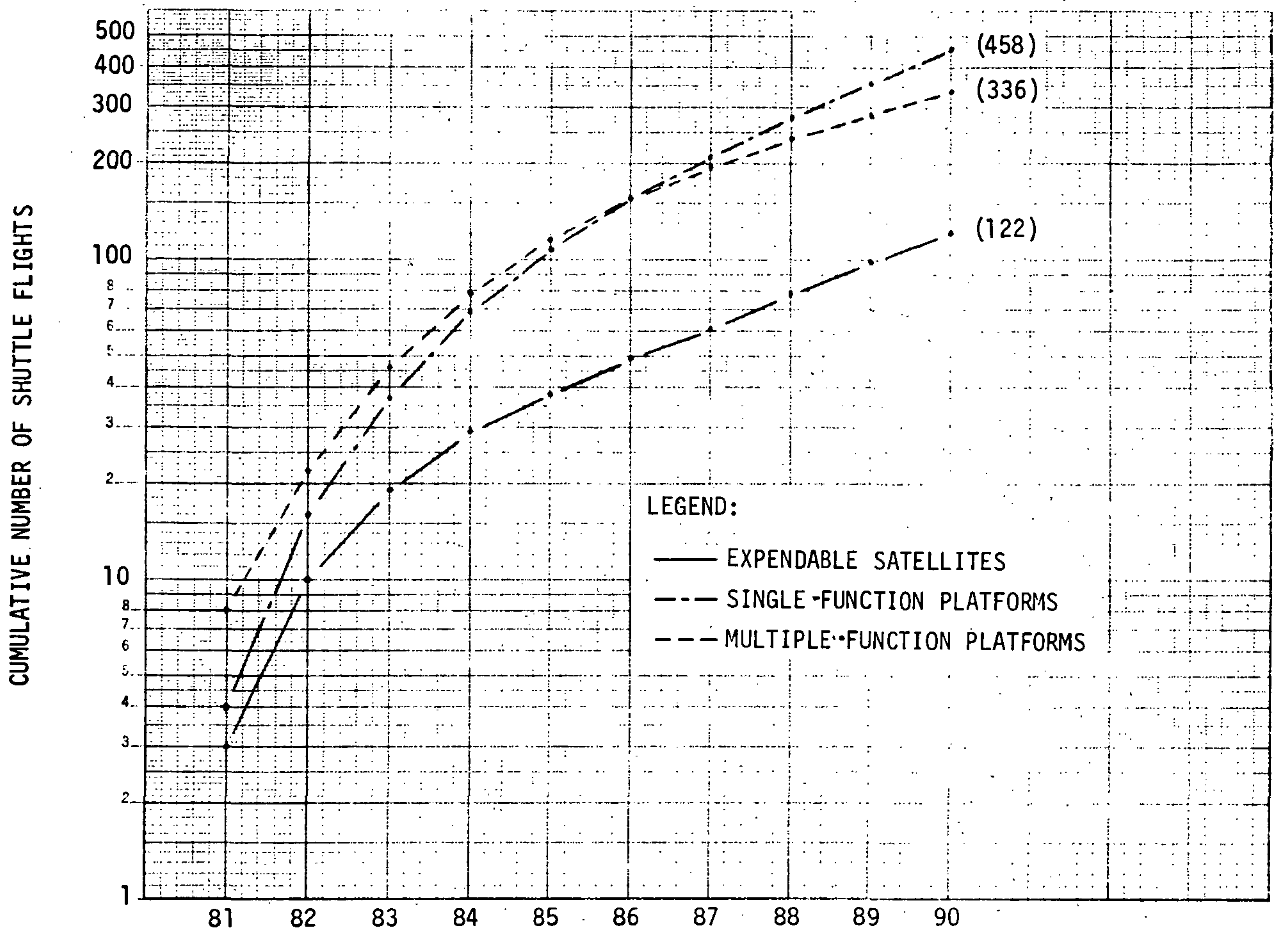

Figure 4-25. Cumulative Shuttle Flights (Manned - 25% Spares per Year, New Traffic Model)

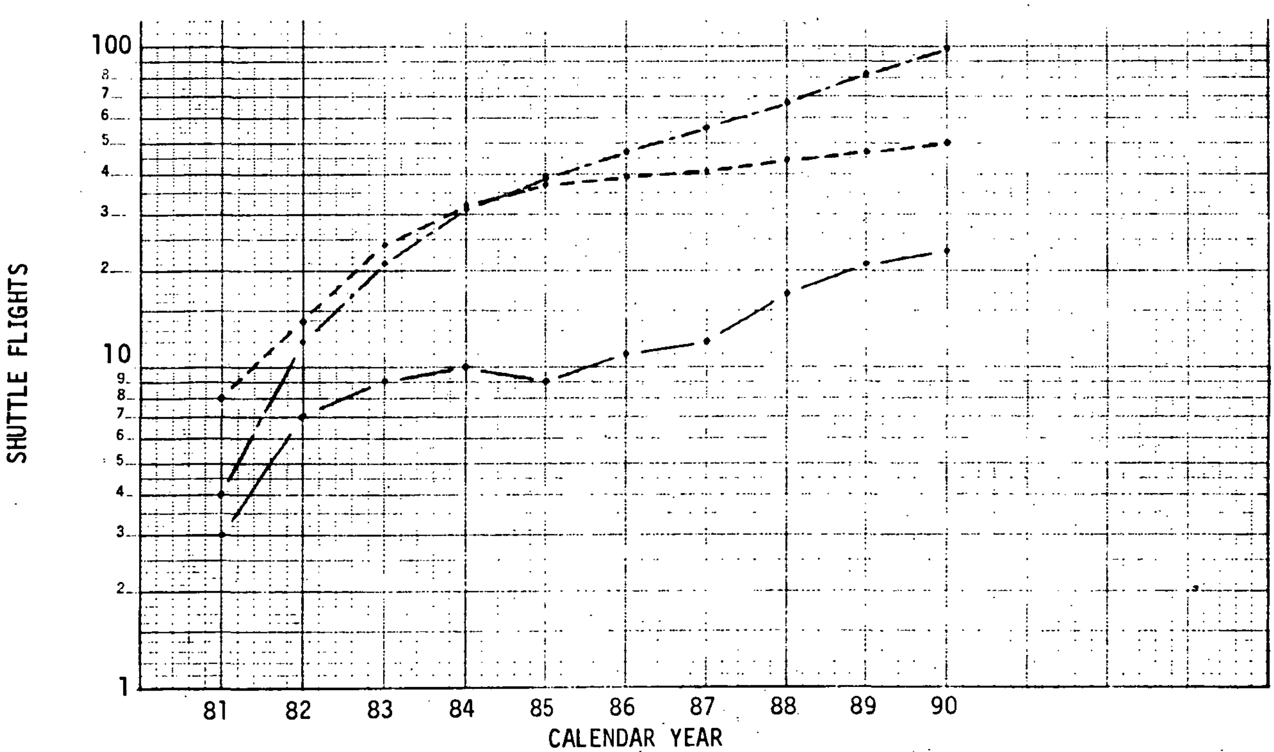

Figure 4-26. Shuttle Flight Schedule (Manned - 25% Spares per Year, New Traffic Model)

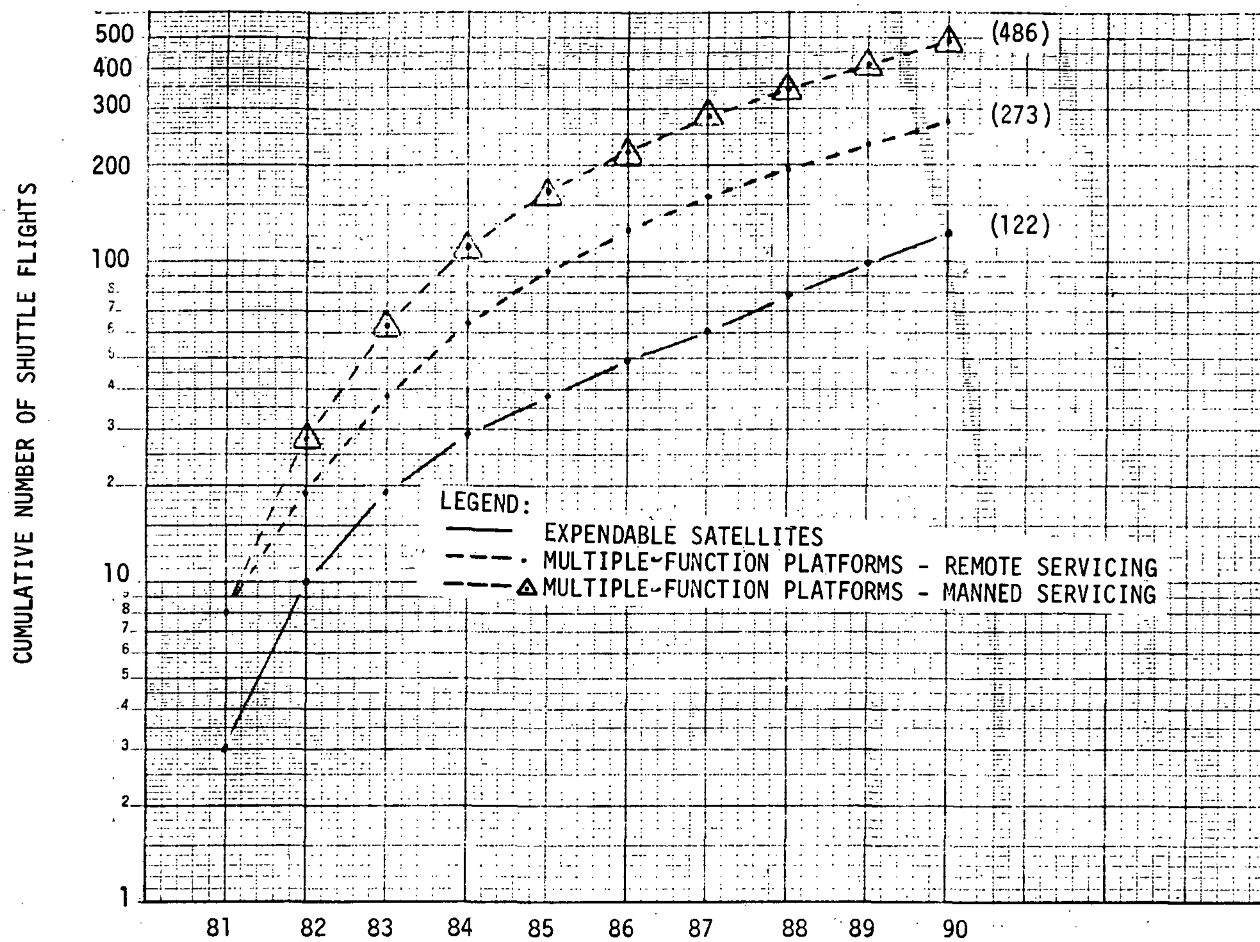

Figure 4-27. Cumulative Shuttle Flights (50% Spares per Year, New Traffic Model)

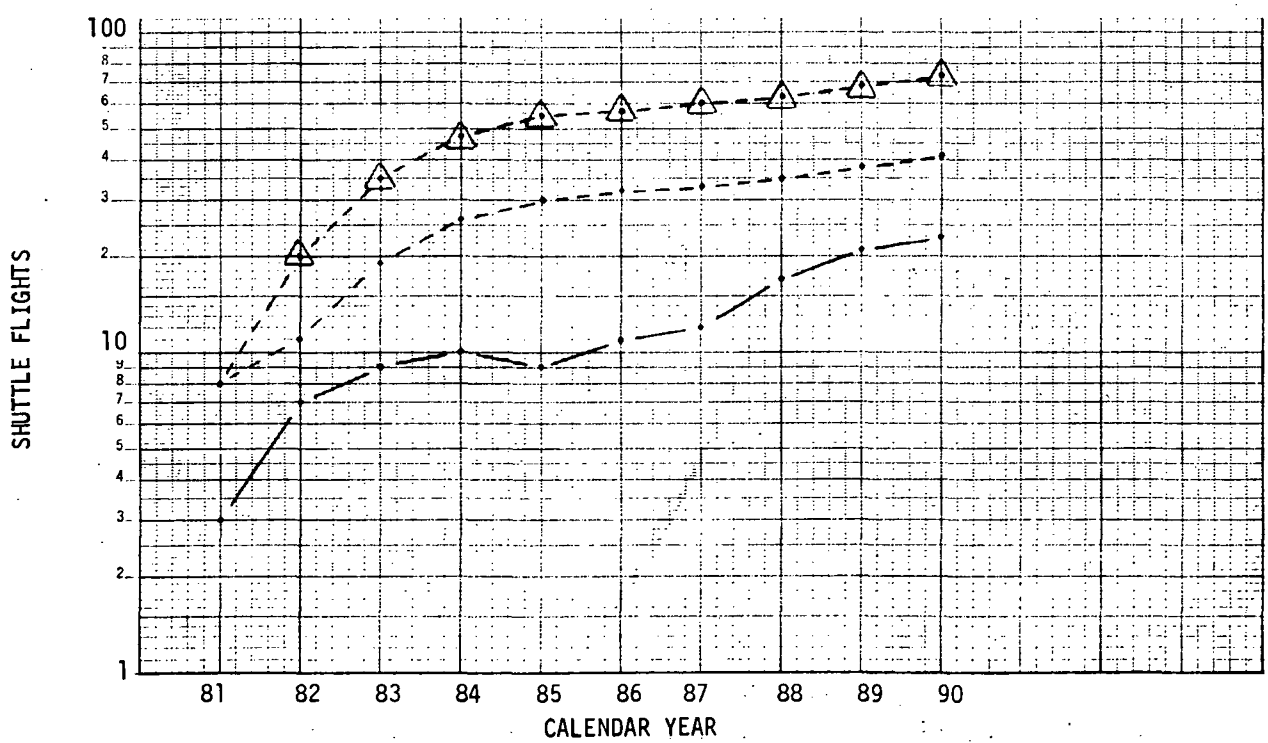

Figure 4-28. Shuttle Flight Schedule (50% Spares per Year, New Traffic Model)

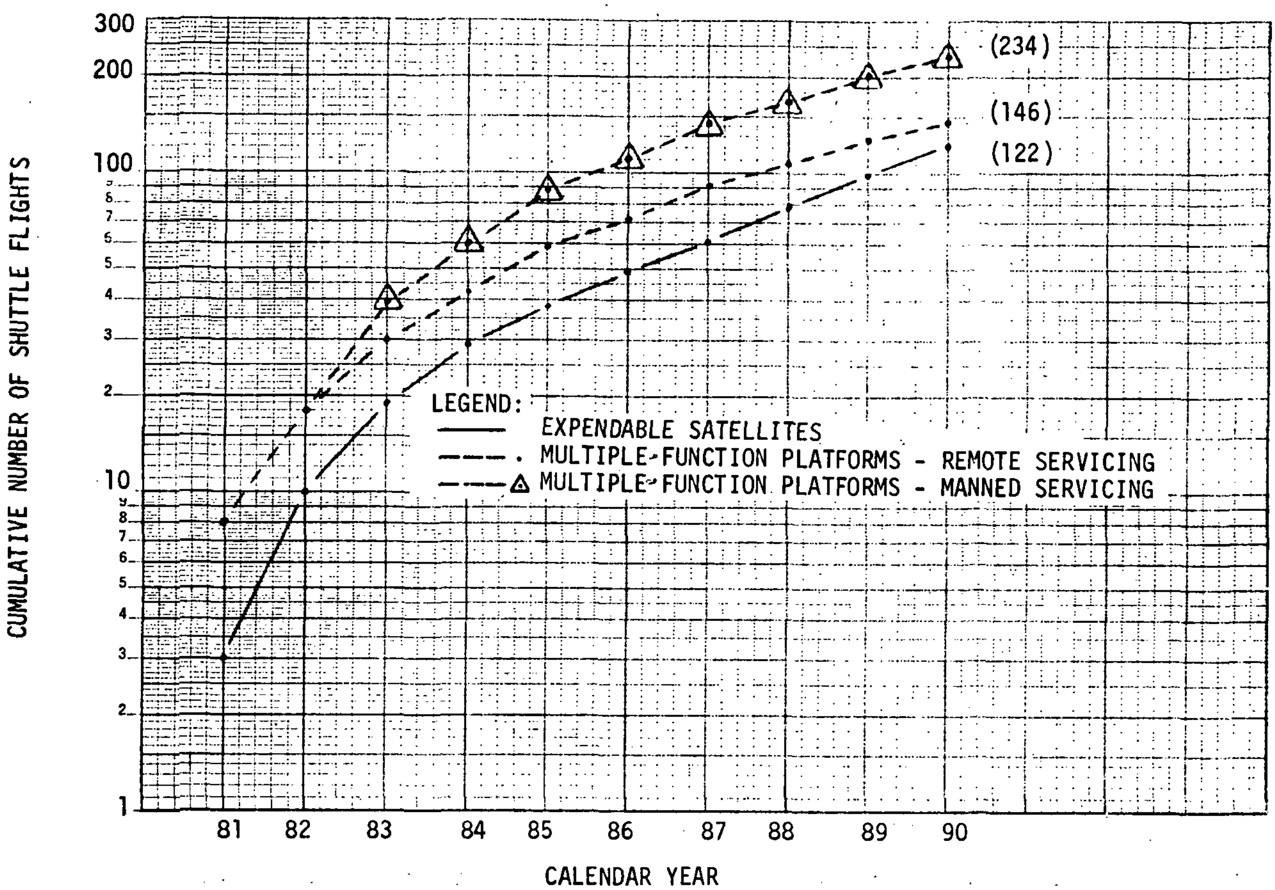

Figure 4-29. Cumulative Shuttle Flights (50% Spares per 2 Years, New Traffic Model)

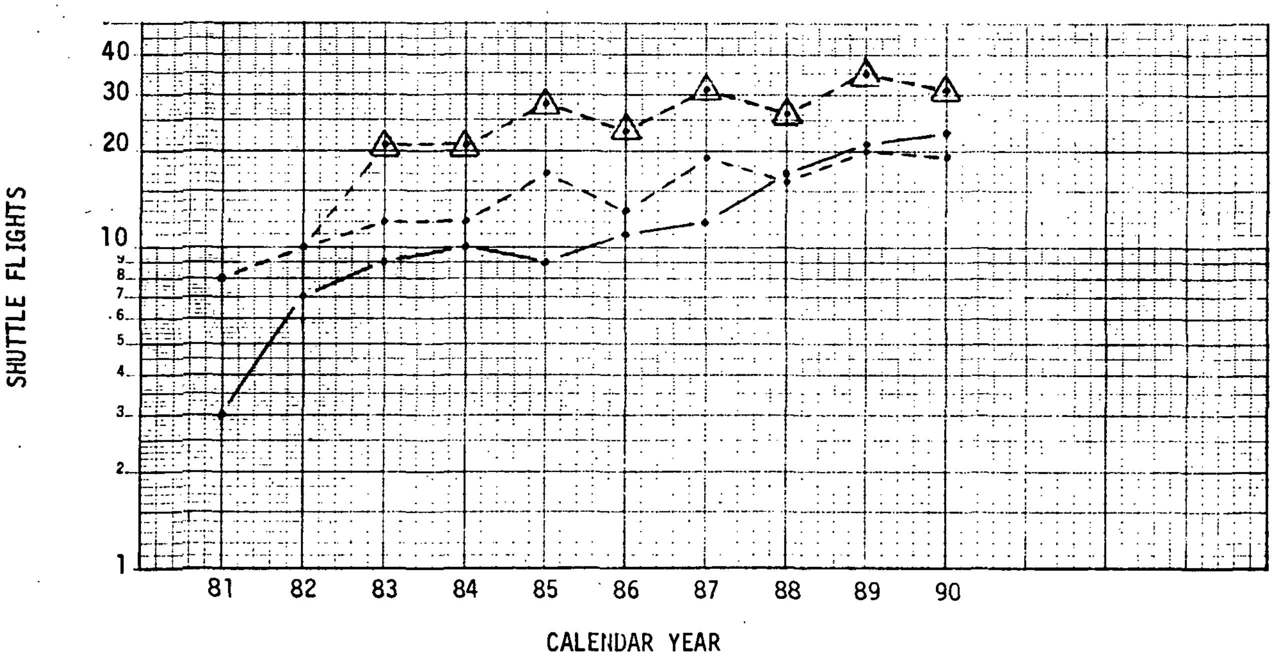

Figure 4-30. Shuttle Flight Schedule (50% Spares per 2 Years, New Traffic Model)

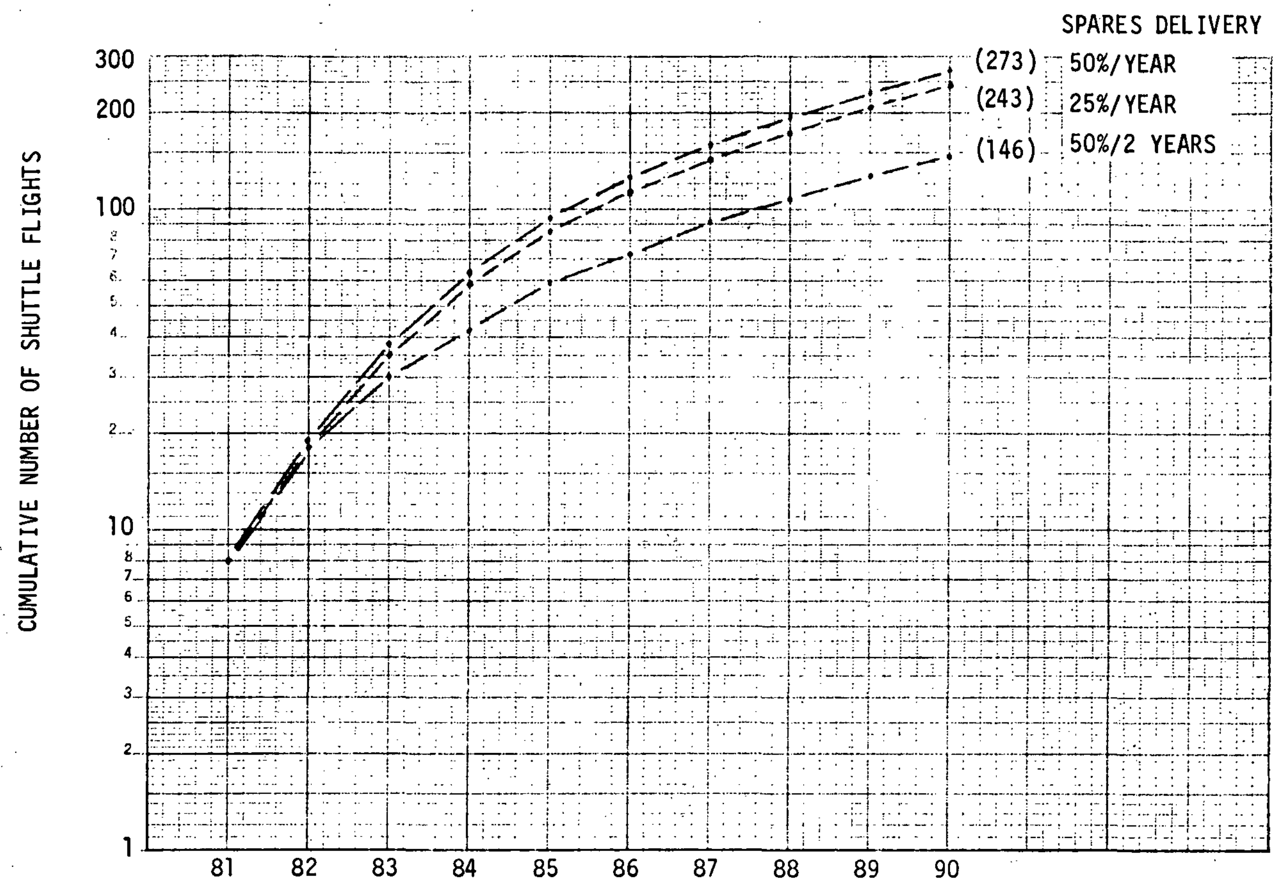

Figure 4-31. Cumulative Shuttle Flight Comparison (New Traffic Model Platform Programs - Remote Servicing)

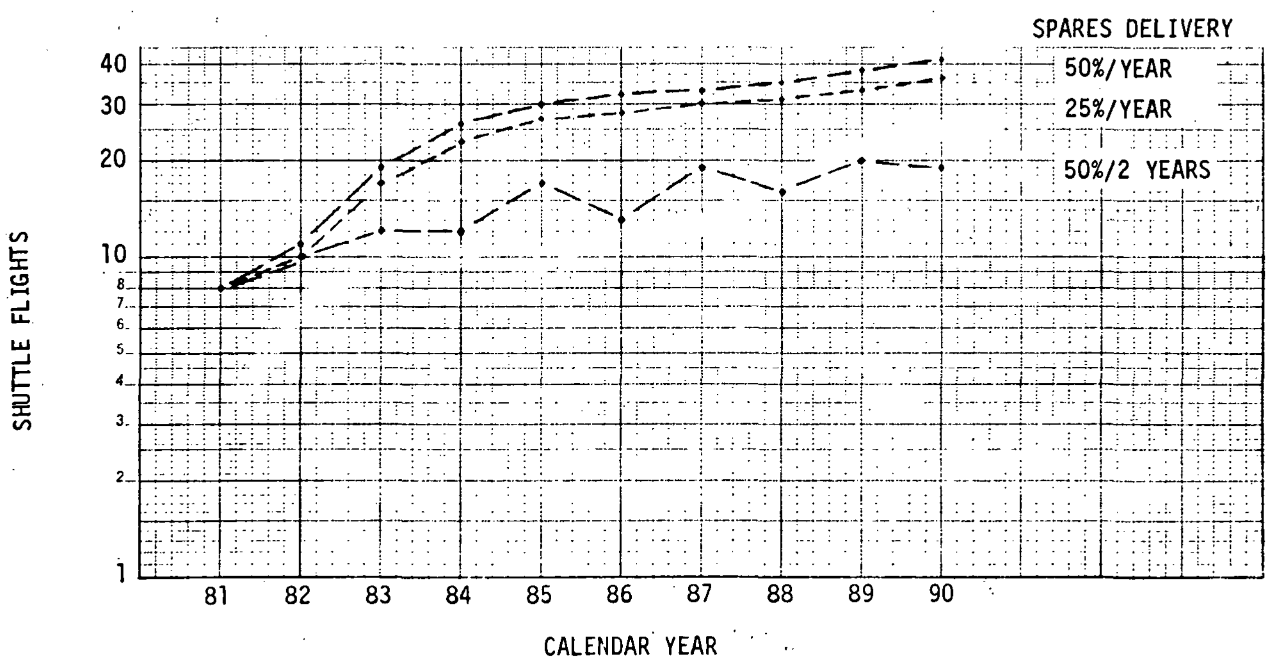

Figure 4-32. Shuttle Flight Comparison (New Traffic Model Platform Programs - Remote Servicing)

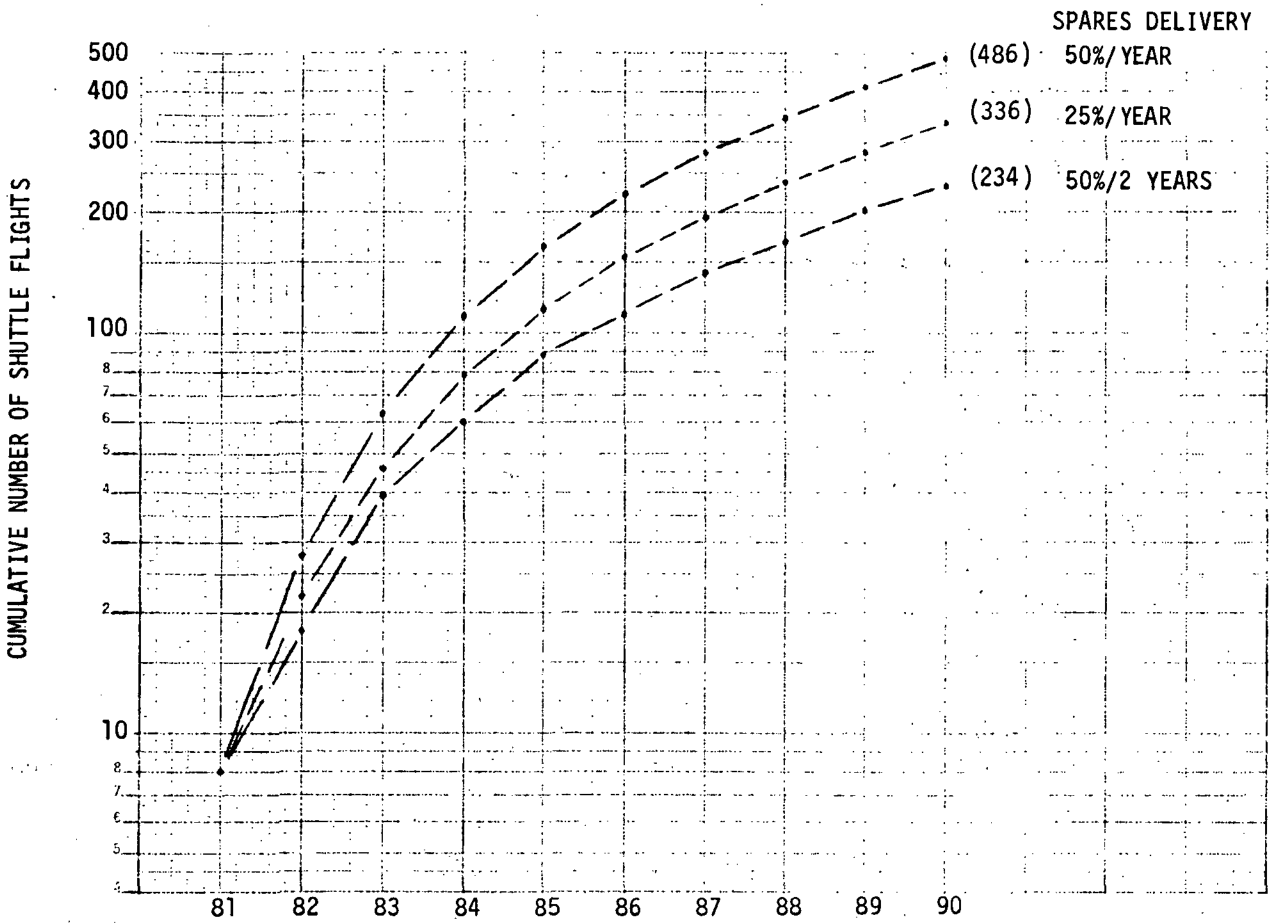

Figure 4-33. Cumulative Shuttle Flight Comparison (New Traffic Model Platform Programs - Manned Servicing)

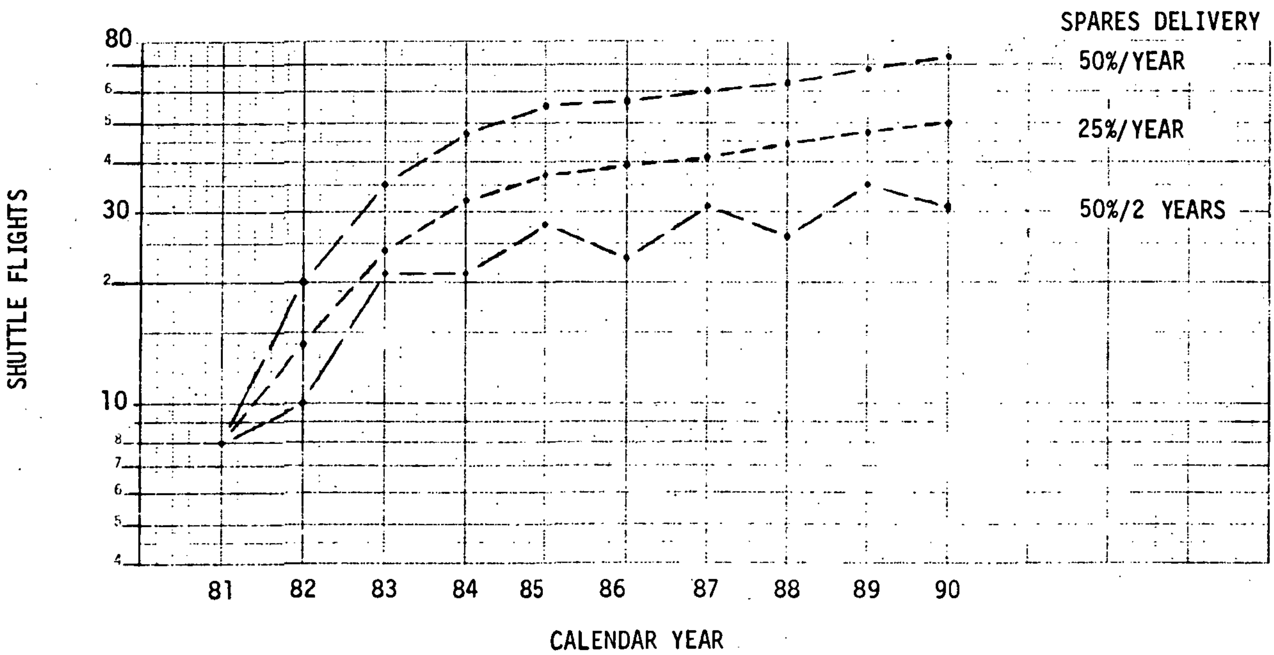

Figure 4-34. Shuttle Flight Comparison (New Traffic Model Platform Programs - Manned Servicing)

5.0 PROGRAM COSTS

The basic data used to develop the costs of the program alternatives identified in the previous section are discussed in this section. The data base consists of the costs of the following program elements which are necessary to support the programs:

1. Common support modules
2. Remote servicing units
3. Crew modules
4. Spares storage modules
5. Mission equipment
6. Spares
7. Shuttle/tug flights

These elements were included in the construction of total costs for all programs except the expendable satellite programs for the baseline and new traffic models. The levels and quantities of the elements varied according to the changing program descriptions and requirements. All of the program costs are stated in 1973 dollars.

The cost of the common support module (Table 5-1) is defined as the nonrecurring and recurring costs of the module subsystems exclusive of the recurring structure costs, which are contained in the spares storage module estimates. Thus, each common support module (CSM) type spacecraft contains one CSM equipment set plus at least one spares storage module. This approach was used in the cost analyses because of the similarity of the structure (for costing purposes) between the common support module and the spares storage module. The sources for the cost of platform subsystems also are shown in Table 5-1. The space station data were applied with appropriate scaling for the reduced sizes of these subsystems and for the changes in the technology base. The only exception was the attitude stabilization and control subsystem, which employed a different technology than that defined for the space station. A complexity factor was used to account for the technology increase.

The remote servicing unit was costed as an unmanned system capable of performing up to 50 missions. In the development of program costs, if more than 50 remote servicing missions were required in a given program, additional buys were required. The subsystem cost estimates were developed from three sources; these are noted in Table 5-2. The design concept selected for the servicing unit utilized a basic structure similar to that of the common support module and spares storage module. The most significant element of the remote servicing unit, in terms of cost, is the manipulator. The nonrecurring and recurring costs of the manipulator were estimated to be $15.4 and $3.85 million, respectively.

The crew module was costed as a manned system which also was capable of up to 50 servicing missions; additional buys were required each time the number of missions exceeded 50. Additional buys also were required if the traffic density exceeded 12 flights per year. It was assumed that an annual traffic density in excess of 12 would not permit adequate time between flights for servicing and refurbishment of the crew modules. The crew module costs (Table 5-3) also were based on the space station study costs, with the exception of the environmental control and life support subsystem, which was scaled from Apollo costs with allowances for changes in mission requirements and change in the technology base from the 60's to the 80's. The Apollo subsystem costs were considered applicable to the crew module because of the similarities in system requirements, crew size, and pressurized volume.

Since the structure of the crew module was identical to that of the spares storage module, only recurring costs were included in the cost estimates. The recurring costs of the structural elements of the crew module are included in the cost estimates for each crew module.

The spares storage module, for costing purposes, is basically a structural element used with the common support module, remote servicing units, and crew modules. Therefore, this program element was assumed to be developed by a separate contractor. It was estimated that the programmatic benefits of a common development exceeded any integration problems that might be incurred. For costing purposes, each common support module consisted of one subsystem set plus at least one, and generally two, spares storage modules; each remote servicing unit included one or more spares storage modules; and each crew module included one or more spares storage modules. The cost estimates for the spares storage modules (Table 5-4) were developed from the SAMSO/Rockwell unmanned spacecraft costing model.

The mission equipment costs were based on cost data contained in the Aerospace Fleet Analysis Report (Reference 5-1) and Rockwell estimates. Where direct correlation with mission equipment could be identified, the Fleet Analysis costs were used. Where direct correlations could not be obtained, the costs were estimated on the basis of equipment similarity to satellite systems described in the Fleet Analysis Report or by direct estimates based on past Rockwell studies.

Different philosophies were adopted for establishing the cost of spares for platform subsystems and for mission equipment. The platform spares cost were based on the recurring costs of replaceable items. The spares costs per servicing missions were then taken as being equal to the total recurring costs of all replaceable elements, adjusted by the sparing level being examined. For example, the spares costs per servicing mission at a spares level of 25 percent were one-fourth of the total recurring cost of all replaceable equipment.

In establishing the total program costs, no spares costs were assumed for mission equipment. The basic mission equipment costs were based on equivalent expendable mission equipment, and it was felt that the costs of spares or refurbishment would offset any potential reduction in nonrecurring and recurring costs that could be achieved from utilizing refurbishable mission equipment.

Each mission to geosynchronous orbit requires the use of both the shuttle and tug. Therefore, for the purposes of this study, only a single cost of $12.5 million was assumed for each shuttle/tug flight. This appears to be consistent with values used in past studies.

The RDT&E and investment costs for each of the program cost elements utilized are summarized as follows:

Element	RDT&E ($\overline{M}$)	Investment* ($\overline{M}$)
Common support module	47.6	10.8
Remote servicing unit	48.4	10.1
Crew module	101.3	23.6
Spares storage module	0**	0.47

*95-percent Crawford cost-reduction curves utilized

**The RDT&E costs for the spares module are included in the platform cost estimate.

The costs of the program alternatives are presented in Tables 5-5 through 5-7 for the baseline traffic model and in Tables 5-8 through 5-10 for the new traffic model. For the expendable satellite programs (Tables 5-5 and 5-8), the nonrecurring and recurring satellite, mission equipment, and operations costs are identified by program element. The total cost of the baseline traffic model expendable satellite program is approximately $4.9 billion, compared to $7.5 billion dollars for the expendable satellite program based on the new traffic model. Approximately $1.0 billion of the cost difference is due to the 78 additional shuttle/tug flights required for the delivery of 203 more spacecraft in the new traffic model. The remaining $1.6 billion difference is in the RDT&E and investment costs for the satellites and mission equipment.

The costs of the single-function platform programs are given in Tables 5-6 and 5-9 for the baseline and new traffic models. The tables show the costs of the basic program hardware plus that associated with both manned and remote servicing. The costs for the programs based on the new traffic model are approximately twice those of the baseline traffic model. It can also be seen that most of the difference in cost between the remote and manned servicing modes is due to the increased number of shuttle/tug flights for the manned mode. For the baseline traffic model programs (Table 5-6), $350 million of the $512.3-million difference is due to the requirement for 28 additional shuttle/tug flights for the manned servicing approach.

The costs of the multiple-function platform program alternatives are shown in Tables 5-7 and 5-10. As can be seen, both the servicing mode and the servicing level and frequency have a significant impact on total cost. In both traffic models, the remote servicing approach with a servicing level and frequency of 50 percent every two years results in the lowest total program cost. These programs also require the least number of shuttle/tug flights for both the baseline and new traffic model programs.

Table 5-1. Common Support Module Costs

Cost Element	Costs ($M) Nonrecurring	Costs ($M) Recurring	Cost Data Source
Structure Primary structure Secondary structure Docking assembly Thermal control	4.65	0.78	SAMSO Unmanned Spacecraft Cost Model*
Electrical Power	7.74	3.80	Space Station**
Data Handling	2.85	0.40	Space Station
Attitude Stability and Control	11.20	2.58	Space Station with adjustment of complexity factor for change to hydrazine
Subtotal	26.44	7.56	
GSE	5.29	0.76	
Program Management and Support	15.87	2.50	
Total	47.60	10.82	

* Report No. SAMSO TR-69-335, SAMSO (SMCC), November 1969.

**Modular Space Station Phase B Definition, DRL No. MSC T-575, Line Item 77, SD 71-226-1, dated January 1972.

Table 5-2. Remote Servicing Unit Costs

Cost Element	Costs ($M) Nonrecurring	Costs ($M) Recurring	Cost Data Source
Structure	3.52	0.44	SAMSO Unmanned Spacecraft Cost Model*
Manipulator	15.40	3.85	Shuttle costs (scaled from shuttle contractor estimates)
Docking Mechanism and Tug Adapter	3.30	0.20	Space Station**
Other Subsystems (TV, Comm., Thermal, etc.)	2.0	0.55	Space Station
Subtotal	24.22	5.04	
GSE	8.06	1.69	
Program Management and Support	16.12	3.37	
Total	48.40	10.10	

* Report No. SAMSO TR-69-335, SAMSO (SMCC), November 1969.

**Modular Space Station Phase B Definition, DRL No. MSC T-575, Line Item 77, SD 71-226-1, dated January 1972.

Table 5-3. Crew Module Costs

Cost Element	Costs ($M) Nonrecurring	Costs ($M) Recurring	Cost Data Source
Structure	18.1	1.0	Space Station*
Docking Mechanism and Adapter	1.7	0.1	Space Station
Electrical Power	10.0	5.5	Space Station
Crew and Habitability	6.7	3.6	Space Station
Environmental Control and Life Support	7.7	2.7	Apollo**
Information Management	7.1	1.9	Space Station
Reaction Control	4.7	1.7	Space Station
Subtotal	56.0	16.5	
GSE	11.6	1.7	
Program Management and Support	33.7	5.4	
Total	101.3	23.6	

* Modular Space Station Phase B Definition, DRL No. MSCT-575, Line Item 77, SD 71-226-1, dated January 1972.

**Contractor cost records.

Table 5-4. Spares Storage Module Costs

Cost Element	Costs ($M)		Cost Data Source
	Nonrecurring*	Recurring	
Structure		0.37	SAMSO Unmanned Spacecraft Cost Model**
Thermal Control (Passive)		0.05	SAMSO Unmanned Spacecraft Cost Model
Electrical Power (Wiring and Lighting)		0.05	SAMSO Unmanned Spacecraft Cost Model
Total		0.47	

* No nonrecurring costs were included in this estimate. The RDT&E costs for the spares storage module are included in the common support module estimates.

**Report No. SAMSO TR-69-335, SAMSO (SMCC), November 1969.

Table 5-5. Expendable Satellite Program (Baseline Traffic Model)

Program Element	Satellite ($M)		Mission Equip ($M)		Operations Costs ($M)		
	RDTE	Investment	RDTE	Investment	$M/Launch	No. of Units	Total
Astronomy							
Opt. Interfer/Stellar	107	28.0	26	10.0	7.0	1	7.0
Radio Astro. Explorer	59	6.1	42	5.1	2.8	1	2.8
Solar Orbit Pair	57	9.4	26	9.9	4.5	1	4.5
X-Ray Astronomy	56	19.0	80	21.0	5.0	1	5.0
Subtotal	279	62.5	174	46.0		4	19.3
Earth Obs. - Development							
Payload 1	40	9.0	28	21.4	-	1	1.0
Payload 2	79	9.4	52	4.6	1.0	1	1.0
Payload 3	39	8.5	14	5.7	3.7	1	3.7
Payload 4	65	6.6	33	5.7	0.8	1	0.8
Payload 5	54	10.0	17	5.0	3.6	1	3.6
Payload 6	54	10.0	17	5.0	3.6	1	3.6
Payload 7	79	9.4	52	4.6	1.1	1	1.1
Subtotal	410	62.9	213	52.0		7	14.8
ATS	312	225.0	136	60.0	3.6	5	18.0
Systems Test	64	113.0	45	29.0	1.6	7	11.2
Small ATS	78	52.0	151	32.0	2.3	9	20.7
Disaster Warning	52	12.0	17	8.0	1.5	1	1.5
Subtotal	506	402.0	349	129.0		22	51.4
TDRS	0	24.6	32	34.8	0.9	6	5.4
Comsat	0	40.0	0	33.0	0.8	8	6.4
U.S. Domsat	1	147.0	17	149.0	1.3	19	24.7
Foreign Domsat	3	122.0	58	88.0	0.8	23	18.4
Navigation & Traffic Control	0	37.0	0	14.0	0.7	6	4.2
Subtotal	4	370.6	107	318.8		62	59.1
Earth Obs. Operation							
Type 1	63.0	40.0	20	20.0	3.6	4	14.4
Type 2	78.5	26.4	40	22.8	0.8	4	3.2
Type 3	85.0	18.8	55	9.2	1.0	2	2.0
Type 4	46.8	34.0	17	22.8	3.7	4	14.8
Type 5	34.0	9.0	34	8.0	5.0	4	20.0
Subtotal	307.3	128.2	166	82.8	14.1	18	54.4
Total	1506.3	1026.2	1009	628.6		113	199.0

	Year										Cumulative
	81	82	83	84	85	86	87	88	89	90	
Satellites	11	14	16	10	11	5	10	15	12	9	113
Shuttle Flights	5	5	5	4	4	2	4	6	4	5	44

EXPENDABLE SATELLITE PROGRAM COSTS ($M)

	RDTE	Investment	Operations	Remarks
Satellite	1506.3	1026.2	0	
Mission Equipment	1009.0	628.6	0	
Launch Operations	0	0	199	
Shuttle Flights	0	0	550	44 flights @ $12.5M each
Total	2515.3	1654.8	749	

CUMULATIVE
$4919.1 M

Table 5-6. Single-Function Platform Program Costs (Baseline Traffic Model)

	Program Element	Quantity Required	Cost x 10^6 Nonrecurring	Cost x 10^6 Recurring	
BASIC PROGRAM	Common Support Modules	63	47.6	539.5	
	Spares Storage Modules	128	-	45.3	
	Mission Equipment	-	1009.0	629.0	
	Spares	426	-	489.9	
			1056.6	1703.7	
MANNED SERVICING	Basic Program	-	1056.6	1703.7	
	Crew Module	9	101.3	191.2	
	Spares Storage Modules	6	-	2.8	
	Shuttle Flights	203	-	2537.5	
			1157.9	4435.2	$5593.1
REMOTE SERVICING	Basic Program	-	1056.6	1703.7	
	Remote Servicing Unit	9	48.4	81.8	
	Spares Storage Modules	6	-	2.8	
	Shuttle Flights	175	-	2187.5	
			1105.0	3975.8	$5080.8

Table 5-7. Multiple-Function Platform Program Costs (Baseline Traffic Model)

	Program Element	Qty Req'd	Nonrecurring (Costs x 10^6)	Recurring (Costs x 10^6)
BASIC PROGRAM	Platforms	18	47.6	167.7
	Spare Storage Modules	53	--	20.0
	Mission Equipment	--	1009.0	629.0
	Subtotal	--	1056.6	816.7

SERVICING OPTIONS

	MANNED				REMOTE			
	Program Element	Qty Req'd	Nonrecurring (Costs x 10^6)	Recurring (Costs x 10^6)	Program Element	Qty Req'd	Nonrecurring (Costs x 10^6)	Recurring (Costs x 10^6)
	Basic Program	--	1056.6	816.7	Basic Program	--	1056.6	816.7
	Crew Module	3	101.3	70.8	Remote Servicing Unit	3	48.4	30.3
	SSM's	9	--	4.5	SSM's	6	--	3.0
			1157.9	892.0			1105.0	850.0
25% PER YR	Spares	138	--	158.7	Spares	138	--	158.7
	Shuttle Flights	117	--	1462.5	Shuttle Flights	89	--	1112.5
			1157.9	2513.2			1105.0	2121.2
50% PER YR	Spares	138	--	317.4	Spares	138	--	317.4
	Shuttle Flights	173	--	2162.5	Shuttle Flights	95	--	1187.5
			1157.9	3371.9			1105.0	2354.9
50% PER 2 YR	Basic Program	--	1056.6	816.7	Basic Program	--	1056.6	816.7
	Crew Module	2	101.3	47.2	Remote Servicing Unit	2	48.4	20.2
	SSM's	6	--	3.0	SSM's	4	--	2.0
	Spares	61	--	140.3	Spares	61	--	140.3
	Shuttle Flights	92	--	1150.0	Shuttle Flights	56	--	700.0
			1157.9	2157.2			1105.0	1679.2

COST COMPARISON	SPARES LEVEL / OPTION	25 PERCENT PER YEAR	50 PERCENT PER YEAR	50 PERCENT PER 2 YR
	MANNED	3,671.1	4,529.8	3,315.1
	REMOTE	3,226.2	3,459.9	2,784.2

Table 5-8. Expendable Satellite Program (New Traffic Model)

Program Element	Satellite ($M)		Mission Equip ($M)		Operations Costs ($M)		
	RDTE	Investment	RDTE	Investment	$M/Launch	Number of Units	Total
Astronomy							
Radio Explorer	85	19	49	15	2.8	3	8.4
Magnetosphere, Upper	59	13	45	7	2.5	2	5.0
Orbit Solar Observatory	1	68	25	32	5.0	4	20.0
Solar Orbit A	50	21	26	20	4.5	2	9.0
Optical Interferometer A	107	56	26	20	7.0	2	14.0
Subtotal	302	177	171	94		13	56.4
Synch Meteorology Satellite	142	80	73	58	2.3	8	18.4
ATS	430	853	242	211	3.6	19	68.4
TDRS	20	120	50	282	0.9	28	25.2
Navigation and Traffic Control	-	181	-	71	0.7	36	25.2
Intelsat	-	209	-	175	0.8	52	41.6
Domsat	20	809	100	716	1.1	160	176.0
Total	914	2,429	636	1,607		316	411.2
Shuttle Flights					12.5	122	1,525.0

	Year										Cumulative
	81	82	83	84	85	86	87	88	89	90	
Satellites	9	19	24	26	23	28	30	43	54	60	316
Shuttle Flights	3	7	9	10	9	11	12	17	21	23	122

EXPENDABLE SATELLITE PROGRAM COSTS ($M)

	RDTE	INVESTMENT	OPERATIONS
SATELLITES	914	2,429	-
MISSION EQUIPMENT	636	1,607	-
LAUNCH OPERATIONS	-	-	411.2
SHUTTLE FLIGHTS	-	-	1,525.0
TOTAL	1,550	4,036	1,936.2

CUMULATIVE ($M)
7,522.2

Table 5-9. Single-Function Platform Program Costs (New Traffic Model)

	Program Element	Quantity Required	Costs x 10^6 Nonrecurring	Recurring	
BASIC PROGRAM	Common Support Modules	239	47.6	1,735.8	
	Spares Storage Modules	478	-	155.3	
	Mission Equipment	-	636.0	1,607.0	
	Spares	861	-	990.1	
			683.6	4,488.2	
MANNED SERVICING	Basic Program	-	683.6	4,488.2	
	Crew Module	17	101.3	346.9	
	Spares Storage Modules	15	-	7.5	
	Shuttle Flights	458	-	5,725.0	
			784.9	10,567.6	$11,352.5
REMOTE SERVICING	Basic Program	-	683.6	4,488.2	
	Remote Servicing Unit	17	48.4	148.5	
	Spares Storage Modules	16	-	8.0	
	Shuttle Flights	393	-	4,912.5	
			732.0	9,557.2	$10,289.2

Table 5-10. Multiple-Function Platform Program Costs (New Traffic Model)

BASIC PROGRAM	Program Element	Qty Req'd	Costs x 10^6 Nonrecurring	Costs x 10^6 Recurring
	Platforms	66	47.6	562.7
	Spare Storage Modules	159	--	55.4
	Mission Equipment	--	729.0	1632.0
	Subtotal	--	776.6	2250.1

SERVICING OPTIONS								
	MANNED				REMOTE			
	Program Element	Qty Req'd	Costs x 10^6 Nonrecurring	Costs x 10^6 Recurring	Program Element	Qty Req'd	Costs x 10^6 Nonrecurring	Costs x 10^6 Recurring
	Basic Program	--	776.6	2250.1	Basic Program	--	776.6	2250.1
	Crew Module	7	101.3	165.2	Remote Servicing Unit	7	48.4	70.7
	SSM's	21	--	9.9	SSM's	14	--	6.6
			877.9	2425.2			825.0	2327.4
25% PER YR	Spares	369	--	424.4	Spares	369	--	424.4
	Shuttle Flights	336	--	4200.0	Shuttle Flights	243	--	3037.5
			877.9	7049.6			825.0	5789.3
50% PER YR	Spares	369	--	848.7	Spares	369	--	848.7
	Shuttle Flights	486	--	6075.0	Shuttle Flights	273	--	3412.5
			877.9	9348.9			825.0	6588.6
50% PER 2 YEARS	Basic Program	--	776.6	2250.1	Basic Program	--	776.6	2250.1
	Crew Module	3	101.3	70.8	Remote Servicing Unit	3	48.4	30.3
	SSM's	9	--	4.5	SSM's	6	--	3.0
	Spares	168	--	386.4	Spares	168	--	386.4
	Shuttle Flights	234	--	2925.0	Shuttle Flights	146	--	1825.0
			877.9	5636.8			825.0	4494.8

COST COMPARISON	OPTION \ SPARES LEVEL	25 PERCENT PER YEAR	50 PERCENT PER YEAR	50 PERCENT PER 2 YR
	MANNED	7,927.5	10,226.8	6,514.7
	REMOTE	6,614.3	7,413.6	5,319.8

6.0 RECOMMENDED PROGRAM APPROACH

The program alternatives shown in Figure 4-6 provided the basis for defining the basic characteristics of single-function and multiple-function platform programs. An examination of the results of these analyses provided the basis for the identification of the recommended program alternative. The preferred geosynchronous on-orbit platform program approach was then developed in light of the results of all major analyses conducted during the study. The principal considerations were the new traffic model analyses, contention analyses, and platform and servicing system configuration analyses reported in Volumes III through V. This section summarizes the results of the analyses of the platform program alternatives, identifies the preferred alternative, and discusses the recommended geosynchronous platform program approach.

6.1 LOGISTICS COMPARISON

The number of shuttle/tug flights per year to support the alternative program approaches is summarized in Tables 6-1 and 6-2 for the baseline and new traffic models, respectively. As shown in Table 6-1, the total number of shuttle/tug flights for the platform programs based on the baseline traffic model varies from a minimum of 56 to a maximum of 203. The corresponding variation for the new traffic model (Table 6-2) is 146 to 486 total flights. For both traffic models, the manned servicing alternatives impose the highest shuttle/tug flight requirements for a given servicing level and frequency due to the requirement for dual shuttle/tug flights on each servicing mission. For a given servicing mode, the servicing level and frequency has a significant effect on the shuttle/tug flight requirements. This impact is particularly significant for the manned servicing mode. In addition, the servicing frequency alone has a significant impact on the shuttle/tug flight requirements. The multiple-function platform programs with servicing every two years require the least number of flights for both the baseline and new traffic models. This characteristic is due to the decrease in the number of servicing visits, while the number of spacecraft deliveries remains constant. Since the servicing levels and frequencies used during these analyses were selected for examining the program sensitivity to servicing level and frequency, the values selected do not necessarily represent the values which will ultimately be required by an operational program.

For comparison, the required number of shuttle/tug flights for expendable satellite programs also are shown in Tables 6-1 and 6-2. For both traffic models, the expendable satellite programs require the least number of shuttle/tug flights since only satellite deliveries are required. During the development of the shuttle/tug flight requirements for these programs, the delivery schedules were based on the traffic models and did not include additional deliveries for replacement of failed satellites. Since the operational capability of the platforms was considered to be maintained by servicing, the on-orbit operational capability of the platform programs will be greater than, or at least equal to, the operational capability provided by the expendable satellite programs. A more rigorous comparison would require considerations of failed expendable satellites, as well as considerations of unsuccessful platform servicing missions.

6.2 TRANSPORTATION UTILIZATION EFFICIENCY

The shuttle/tug utilization efficiency is summarized in Table 6-3 for the baseline traffic model. As noted earlier, efficiency is defined in terms of the tug payload weight capability versus the actual weight which could be accommodated by the shuttle/tug system with dimensional constraints being considered. The weight efficiencies are seen to vary from 45 to 60 percent, with an average of slightly more than 50 percent. It can be seen that the remote servicing programs are more efficient in shuttle/tug system utilization than the manned servicing programs. In the remote servicing programs, there are many opportunities for single tug servicing missions, even at the 50-percent spares level. In the manned servicing programs, these missions must be dual tug in order to carry the crew module to orbit. Each dual tug mission does have more payload capability; hence, additional platforms might be visited. However, because of the concurrent ΔV's imposed by the additional visits, the extra payload capability is usually not available.

Efficiency increases as the servicing level increases from 25 to 50 percent per year. The on-orbit ΔV profile between spacecraft is identical, and the higher spares weight to each platform allows more use of the payload capability. The decrease in efficiency as the spares frequency is reduced to two-year intervals is not significant in the remote servicing mode. It follows the 50-percent-per-year pattern rather consistently. The exceptions are 1986 and 1990, where there are few actual servicing demands and thus less flexibility for combining visits. In the manned servicing mode, at 50-percent spares every two years and after deliveries in the first year of the program, the next five years show considerably lower efficiencies than the annual servicing program because of fewer opportunities to combine servicing visits. This trend reverses again in 1987, when the number of platforms on-orbit has reached its peak and continues until 1990 when only five visits are required.

6.3 PROGRAM COSTS

The annual costs for shuttle/tug flights are shown in Tables 6-4 and 6-5 for the baseline and new traffic models. Since the shuttle/tug costs are directly proportional to the number of flights, the expendable satellite programs have the lowest shuttle/tug costs when all program approaches are considered. Of the platform programs, the multiple-function platform programs with remote servicing at a spares level/frequency of 50 percent every two years result in the lowest total transportation system costs.

In addition to the launch rate, total flights, and total costs associated with the shuttle/tug delivery systems, the number of hardware end items and the costs of these end items must be considered in a total program evaluation. The total hardware end item requirements and the associated non-recurring and recurring costs are summarized in Table 6-6. The expendable satellite programs result in the highest satellite hardware costs. Of the platform programs, the remote-serviced multiple-function platform programs have the lowest costs when comparing programs at comparable spares levels/frequencies. Of the remote serviced programs, a servicing level/frequency of 50 percent every two years results in the lowest costs due to the reduced number of remote servicing units and associated spares storage modules.

Program evaluation data are summarized in Tables 6-7 and 6-8 for the baseline and new traffic models. In addition to the data presented in the previous tables, the worst-case spacecraft population densities and total program costs are presented. The spacecraft population density is defined as the total number of spacecraft delivered to each of the four regions described in Volume IV. The total program costs include the costs for shuttle/tug operations, spacecraft hardware, servicing hardware, spares, and mission equipment.

Tables 6-7 and 6-8 show that the multiple-function platform programs with a servicing level/frequency of 50 percent every two years result in the lowest total program costs. Although these programs have more shuttle/tug flights, operational costs are more than offset by the decrease in the number of platforms and platform-servicing hardware costs because of the high degree of equipment commonality and the resultant reduction in the nonrecurring costs. This general characteristic is true for both the baseline and new traffic models.

On the basis of the considerations presented, the preferred platform program approach would be the multiple-function platform with remote servicing. Although the program alternative based on 50 percent spares every two years results in the lowest total program costs, other combinations of servicing levels and frequencies which produce a more optimum utilization of the shuttle/tug system could potentially reduce the total program costs even further. For example, future studies may indicate that redundancy or high reliability could reduce the 50 percent per two years servicing level/frequency to some other value which would be more economical from a total program standpoint. It should be noted that the servicing levels/frequencies examined were selected to establish program trends. The established trend, commensurate with the depth of hardware definition attained in this study, is that total program costs are reduced by lowering the servicing frequency. A subsequent study will be required to establish the crossover point between spares level/frequency costs and platform complexity costs.

6.4 USE OF KICK STAGES

There are additional considerations which further substantiate the selection of the multiple-function platform/remote servicing program approach, as well as considerations which must be taken into account before the final program approach selection. These considerations include the potential use of expendable delivery systems (kick stages) for the initial delivery of platforms and the retention of the programmatic flexibility to introduce manned servicing. They are discussed briefly in the following paragraphs.

It may be desirable, from a total program point of view, to perform initial deliveries of platforms with expendable delivery systems. This approach could possibly defer the initial development costs for the reusable space tug. It should be pointed out, however, that some development costs will be incurred to make expendable kick stages shuttle-compatible. Therefore, this alternative must be examined in the context of the total earth-orbital space program during the shuttle era, including the possible use of kick stages for delivery of payloads to non-geosynchronous orbits. As noted in Volumes IV and V, the platforms defined during this study are within the payload delivery capability of some of the kick stages. The platform program approach developed during this study, however, depends on the ability to perform on-orbit servicing. Any deferral in provision of this ability could result in a decline of on-orbit capability through lack of servicing and an increase in total program costs even though initial costs are reduced.

6.5 PLATFORM CONFIGURATION ADAPTIBILITY

The remote-serviced platform should be compatible with the programmatic option to introduce manned servicing if it should prove to be either desired or required. No significant drivers were identified in the study which would require the introduction of manned servicing during the program period (i.e., up through 1990). Future studies may indicate, however, that man's presence may be required for change-out of mission equipment on science and technology type payloads or for the on-orbit assembly of large, advanced, complex space systems such as the space power relay systems or Lunettas discussed in Volume IV. If such a requirement eventually evolves, it may be desirable to introduce manned servicing during the late 1980's or early 1990's to develop servicing techniques and, potentially, enhance the on-orbit capability of early platforms through the introduction of more complex on-orbit systems. The platform design approach discussed in Volume V would permit such an evolutionary program approach. Through the use of an adapter, a properly designed remote serviced platform could be made compatible with manned servicing.

With respect to both remote and manned servicing, no significant new supporting research and technology (SRT) requirements were identified which would impact the recommended program approach. Both servicing approaches will require the development of techniques for on-orbit change-out of equipment; the required characteristics of such systems are being examined in both NASA and industry studies.

6.6 CONCLUSIONS

Based on the data developed during this study and the evaluations presented in this volume, the following overall conclusions were reached:

1. Selected groupings of geosynchronous payloads are feasible and desirable.

2. A common subsystem module which can support a variety of mission payloads (either singularly or in multiples) is feasible and desirable.

3. Of the program alternatives examined, remote servicing results in the lowest total program costs through the development of standardized replaceable modules.

4. A single platform configuration concept capable of operating with all servicing modes is feasible and holds open the option for future selection of a preferred servicing mode.

5. Grouping of payloads reduces the total inventory requirements and related transportation costs, and commonality of subsystems further reduces the developmental and hardware unit costs. Also, compatibility with all servicing modes eliminates the need for developing separate platform concepts for each servicing mode.

The traffic analyses resulted in several important conclusions. First, the new traffic model was judged to be more representative of the full potential for geosynchronous traffic than the baseline model. It reflects growing global demands of world user population. Second, orbit saturation analyses determined that satellite physical contention is not likely to be critical through 1990, even without satellite retrieval; however, electromagnetic interference (EMI) would be widespread in the new traffic model if communications relay services were restricted to the use of C-band frequencies. Wider RF spectrum usage (K-bands) would be required such as those utilized in the platform synthesized in the study to preclude EMI among geosynchronous satellites. S-band EMI problems already exist between geosynchronous satellites and users in other orbits as a result of geometric interrelationships. This problem would be reduced with multifunction platforms because of the reduced inventory of traffic elements.

It was concluded that cooperation in mission planning and control is required on both national and international levels to preclude satellite physical and EMI contention. This cooperation will be required for the traffic levels depicted in both models, but is more acute with the higher traffic levels predicted in the new traffic model.

6.7 RECOMMENDED GEOSYNCHRONOUS PROGRAM APPROACH

Evaluation of the principal study results leads to a recommended geosynchronous program approach offering improved traffic definitions, feasible groupings of mission functions, and a configuration concept adaptable to various servicing modes. Specifically, the following recommendations are made:

1. <u>That efforts be continued toward identification and refinement of geosynchronous traffic characteristics.</u>

   Significant progress was made during this study. Many new functions were identified, along with several very advanced concepts offering vast benefits to mankind. A model framework, including rationale and construction techniques, also was produced. However, new sensors, new technologies, and new user populations require continual updating of traffic characteristics.

2. <u>That feasible payload grouping options be applied with multi-function platforms in future program/system definition activities.</u>

   Additional or different groupings may be possible as new and better definitions of geosynchronous traffic become available. Further efforts are required on mission equipment integration issues, particularly as better definitions of equipment configuration and accommodation requirements become known. New functions in the updated and refined traffic models also will require integration analysis.

3. <u>That the "tri-mode" platform configuration approach be applied to hold open the option for manned servicing.</u>

   Much effort is required to determine a preferred servicing mode. Analysis results, design trades, and operational experience must be accumulated on both the spacecraft to be serviced and the systems performing the servicing operations before preferred servicing modes can be selected. The multi-mode approach offers the desired flexibility at almost no design penalty. Safety considerations would introduce variations in qualification programs, but applying this basic configuration approach to further studies of hardware standardization and subsystem commonality could focus their results to useful products somewhat independent of future decisions on servicing operations.

Table 6-1. Baseline Traffic Model, Shuttle/Tug Flights Per Year

Program	Servicing Mode	Spares Level/ Frequency	Shuttle/Tug Flights — Calendar Year 81	82	83	84	85	86	87	88	89	90	Total
Single-Function Platforms	Remote	25% Per Year	6	11	15	15	21	20	21	22	22	22	175
	Manned	25% Per Year	6	14	19	21	25	22	24	24	24	24	203
Multiple-Function Platforms	Remote	25% Per Year	8	6	11	9	9	9	10	9	9	9	89
		50% Per Year	8	7	11	10	9	10	10	10	10	10	95
		50% Per 2 Yr.	8	2	10	2	8	3	9	2	9	3	56
	Manned	25% Per Year	8	9	14	12	13	13	12	12	12	12	117
		50% Per Year	8	11	16	18	19	21	20	20	20	20	173
		50% Per 2 Yr.	8	3	15	4	17	5	14	4	16	6	92
Expendable Satellite	N/A	N/A	5	5	5	4	4	2	4	6	4	5	44

Table 6-2. New Traffic Model, Shuttle/Tug Flights Per Year

Program	Servicing Mode	Spares Level/ Frequency	Shuttle/Tug Flights — Calendar Year 81	82	83	84	85	86	87	88	89	90	Total
Single Function Platforms	Remote	25% Per Year	4	10	19	27	33	40	48	57	70	85	393
	Manned	25% Per Year	4	12	21	31	39	47	56	67	82	99	458
Multiple Function Platforms	Remote	25% Per Year	8	10	17	23	27	28	30	31	33	36	243
		50% Per Year	8	11	19	26	30	32	33	35	38	41	273
		50% Per 2 Yr.	8	10	12	12	17	13	19	16	20	19	146
	Manned	25% Per Year	8	14	24	32	37	39	41	44	47	50	336
		50% Per Year	8	20	35	47	55	57	60	63	68	73	486
		50% Per 2 Yr.	8	10	21	21	28	23	31	26	35	31	234
Expendable Satellite	N/A	N/A	3	7	9	10	9	11	12	17	21	23	122

Table 6-3. Baseline Traffic Model, Shuttle Utilization Efficiency

Program	Servicing Mode	Spares Level/ Frequency	Shuttle Utilization Efficiency, Percent										
			Calendar Year										Program Average
			81	82	83	84	85	86	87	88	89	90	
Single Function Platforms	Remote	25% Per Year	64	58	59	62	57	49	54	42	42	43	52
	Manned	25% Per Year	64	50	52	46	46	51	52	45	45	46	49
Multiple Function Platforms	Remote	25% Per Year	55	57	55	55	62	62	53	59	57	60	57
		50% Per Year	54	55	60	60	70	69	59	58	58	55	60
		50% Per 2 Yr.	54	61	57	63	72	50	61	58	58	33	58
	Manned	25% Per Year	54	42	47	40	38	41	47	45	44	42	45
		50% Per Year	54	55	56	57	56	55	57	52	52	49	54
		50% Per 2 Yr.	54	47	53	29	51	31	60	59	57	29	51
Expendable Satellite	N/A	N/A	44	46	55	38	59	65	40	54	61	37	49

Table 6-4. Baseline Traffic Model, Shuttle/Tug Flight Cost Per Year

Program	Servicing Mode	Spares Level/ Frequency	Shuttle/Tug Cost/Year, $Million										
			Calendar Year										
			81	82	83	84	85	86	87	88	89	90	Total
Single Function Platforms	Remote	25% Per Year	75.0	137.5	187.5	187.5	262.5	250.0	262.5	275.0	275.0	275.0	2187.5
	Manned	25% Per Year	75.0	175.0	237.5	262.5	312.5	275.0	300.0	300.0	300.0	300.0	2537.5
Multiple Function Platforms	Remote	25% Per Year	100.0	75.0	137.5	112.5	112.5	112.5	125.0	112.5	112.5	112.5	1112.5
		50% Per Year	100.0	87.5	137.5	125.0	112.5	125.0	125.0	125.0	125.0	125.0	1187.5
		50% Per 2 Yr.	100.0	25.0	125.0	25.0	100.0	37.5	112.5	25.0	112.5	37.5	700.0
	Manned	25% Per Year	100.0	112.5	175.0	150.0	162.5	162.5	150.0	150.0	150.0	150.0	1462.5
		50% Per Year	100.0	137.5	200.0	225.0	237.5	262.5	250.0	250.0	250.0	250.0	2162.5
		50% Per 2 Yr.	100.0	37.5	187.5	50.0	212.5	62.5	175.0	50.0	200.0	75.0	1150.0
Expendable Satellite	N/A	N/A	62.5	62.5	62.5	50.0	50.0	25.0	50.0	75.0	50.0	62.5	550.0

Table 6-5. New Traffic Model, Shuttle/Tug Flight Cost Per Year

Program	Servicing Mode	Spares Level/ Frequency	Shuttle/Tug Cost/Year, $Million										
			Calendar Year										Total
			81	82	83	84	85	86	87	88	89	90	
Single Function Platforms	Remote	25% Per Year	50.0	125.0	237.5	337.5	412.5	500.0	600.0	712.5	875.0	1062.5	4912.5
	Manned	25% Per Year	50.0	150.0	262.5	387.5	487.5	587.5	700.0	837.5	1025.0	1237.5	5725.0
Multiple Function Platforms	Remote	25% Per Year	100.0	125.0	212.5	287.5	337.5	350.0	375.0	387.5	412.5	450.0	3037.5
		50% Per Year	100.0	137.5	237.5	325.0	375.0	400.0	412.5	437.5	475.0	512.5	3412.5
		50% Per 2 Yr.	100.0	125.0	150.0	150.0	212.5	162.5	237.5	200.0	250.0	237.5	1825.0
	Manned	25% Per Year	100.0	175.0	300.0	400.0	462.5	487.5	512.5	550.0	587.5	625.0	4200.0
		50% Per Year	100.0	250.0	437.5	587.5	687.5	712.5	750.0	787.5	850.0	912.5	6075.0
		50% Per 2 Yr.	100.0	125.0	262.5	262.5	350.0	287.5	387.5	325.0	437.5	387.5	2925.0
Expendable Satellite	N/A	N/A	37.5	87.5	112.5	125.0	112.5	137.5	150.0	212.5	262.5	287.5	1525.0

Table 6-6. Program Element Requirements and Costs

TRAFFIC MODEL	CHARACTERISTIC	PLATFORM PROGRAMS								EXPENDABLE SATELLITE PROGRAM
		SINGLE-FUNCTION PLATFORMS (25% PER YEAR)		MULTIPLE-FUNCTION PLATFORMS						
				REMOTE			MANNED			
		REMOTE	MANNED	25%	50%	50%/2 YR	25%	50%	50%/2 YR	
BASELINE TRAFFIC MODEL	TOTAL HARDWARE END ITEMS									
	EXP. SATELLITE									113
	CSM	63	63	18	18	18	18	18	18	-
	SSM	128	128	53	53	53	53	53	53	-
	RSU	9	-	3	3	2	-	-	-	-
	SSM	6	-	6	6	4	-	-	-	-
	CM	-	9	-	-	-	3	3	2	-
	SSM	-	6	-	-	-	9	9	6	-
	SPACECRAFT COSTS*									
	NONRECURRING	96.0	148.9	96.0	96.0	96.0	148.9	148.9	148.9	1506.3
	RECURRING	1159.3	1268.7	379.7	538.4	350.2	421.7	580.4	378.2	1026.2
	TOTAL	1255.3	1417.6	475.7	634.4	446.2	570.6	729.3	527.1	2532.5
NEW TRAFFIC MODEL	TOTAL HARDWARE END ITEMS									
	EXP. SATELLITE									316
	CSM	239	239	66	66	66	66	66	66	-
	SSM	478	478	159	159	159	159	159	159	-
	RSU	17	-	7	7	3	-	-	-	-
	SSM	16	-	14	14	6	-	-	-	-
	CM	-	17	-	-	-	7	7	3	-
	SSM	-	15	-	-	-	21	21	9	-
	SPACECRAFT COSTS*									
	NONRECURRING	96.0	148.9	96.0	96.0	96.0	148.9	148.9	148.9	914.0
	RECURRING	3037.7	3235.6	1119.8	1544.1	1037.8	1217.6	1641.9	1079.8	2429.0
	TOTAL	3133.7	3384.5	1215.8	1640.1	1133.8	1366.5	1790.8	1228.7	3343.0

*SPARES INCLUDED IN PLATFORM PROGRAMS

Table 6-7. Baseline Traffic Model Program Comparison Summary

PROGRAM CHARACTERISTIC	PLATFORM PROGRAMS: SINGLE-FUNCTION PLATFORMS (25% PER YEAR): REMOTE	SINGLE-FUNCTION PLATFORMS (25% PER YEAR): MANNED	MULTIFUNCTION PLATFORMS: REMOTE: 25 PERCENT PER YEAR	MULTIFUNCTION PLATFORMS: REMOTE: 50 PERCENT PER YEAR	MULTIFUNCTION PLATFORMS: REMOTE: 50 PERCENT PER 2 YR	MULTIFUNCTION PLATFORMS: MANNED: 25 PERCENT PER YEAR	MULTIFUNCTION PLATFORMS: MANNED: 50 PERCENT PER YEAR	MULTIFUNCTION PLATFORMS: MANNED: 50 PERCENT PER 2 YR	EXPENDABLE SATELLITE
SHUTTLE/TUG FLIGHTS									
DELIVERY ONLY	16	21	11	11	14	15	15	16	44
DELIVERY + SERVICE	34	46	7	8	6	6	6	4	-
SERVICING ONLY	125	136	71	76	36	96	152	72	-
TOTAL	175	203	89	95	56	117	173	92	44
PEAK SHUTTLE FLIGHTS/YEAR	22	25	11	11	10	14	21	17	6
SPACECRAFT DENSITY									
REGION IV	32		7						64
REGION III	15		4						24
REGION II	8		3						12
REGION I	8		4						13
TOTAL	63	63	18	18	18	18	18	18	113
TOTAL HARDWARE END ITEMS									
CSM	63	63	18	18	18	18	18	18	-
SSM	128	128	53	53	53	53	53	53	-
RSU	9	-	3	3	2	-	-	-	-
SSM	6	-	6	6	4	-	-	-	-
CM	-	9	-	-	-	3	3	2	-
SSM	-	6	-	-	-	9	9	6	-
COSTS ($M)									
NONRECURRING	1105.0	1157.9	1105.0	1105.0	1105.0	1157.9	1157.9	1157.9	2515.3
RECURRING	3975.8	4435.2	2121.2	2354.9	1679.2	2513.2	3371.9	2157.2	2403.8
TOTAL	5080.8	5593.1	3226.2	3459.9	2784.2	3671.1	4529.8	3315.1	4919.1

Table 6-8. New Traffic Model Program Comparison Summary

PROGRAM CHARACTERISTIC	PLATFORM PROGRAMS								
	SINGLE-FUNCTION PLATFORMS (25% PER YEAR)		MULTIPLE-FUNCTION PLATFORMS						
			REMOTE			MANNED			
	REMOTE	MANNED	25 PERCENT PER YEAR	50 PERCENT PER YEAR	50 PERCENT PER 2 YR	25 PERCENT PER YEAR	50 PERCENT PER YEAR	50 PERCENT PER 2 YR	EXPENDABLE SATELLITE
SHUTTLE/TUG FLIGHTS									
DELIVERY ONLY	36	47	30	32	36	43	42	41	122
DELIVERY + SERVICE	76	104	19	23	16	17	17	10	-
SERVICING ONLY	281	307	194	218	94	276	427	183	-
TOTAL	393	458	243	273	146	336	486	234	122
PEAK SHUTTLE FLIGHTS/YEAR	85	99	36	41	19	50	73	31	23
SPACECRAFT DENSITY									
REGION IV	49	→	16	→	→	→	→	→	70
REGION III	23	→	13	→	→	→	→	→	39
REGION II	66	→	14	→	→	→	→	→	86
REGION I	101	→	23	→	→	→	→	→	121
TOTAL	239	239	66	66	66	66	66	66	316
TOTAL HARDWARE END ITEMS									
CSM	239	239	66	66	66	66	66	66	-
SSM	478	478	159	159	159	159	159	159	-
RSU	17	-	7	7	3	-	-	-	-
SSM	16	-	14	14	6	-	-	-	-
CM	-	17	-	-	-	7	7	3	-
SSM	-	15	-	-	-	21	21	9	-
COSTS ($M)									
NONRECURRING	732.0	784.9	825.0	825.0	825.0	877.9	877.9	877.9	1,550.0
RECURRING	9,557.2	10,567.6	5,789.3	6,588.6	4,494.8	7,049.6	9,348.9	5,636.8	5,972.2
TOTAL	10,289.2	11,352.5	6,614.3	7,413.6	5,319.8	7,927.5	10,226.8	6,514.7	7,522.2

7.0 REFERENCE

5-1 Integrated Operations/Payloads/Fleet Analysis Final Report. The Aerospace Corporation, Aerospace Report No. ATR-72(7231)-1, Volume III (August 1971).

APPENDIX: TRANSPORTATION SYSTEM CHARACTERISTICS

Emphasis in this study was placed on the volume and performance constraints of the shuttle and the reusable tug. The shuttle characteristics are based on its definition at preliminary requirements review; tug characteristics are derived from the TOPSS study. Both a single tug and a dual tug are defined. The characteristics of expendable payload delivery systems (kick stages) also are discussed briefly.

SPACE SHUTTLE

The dimensions of the shuttle orbiter used in this study are shown in Figure A-1. Included in the figure is the volume of the cargo bay occupied by a reusable tug. The total usable volume in the cargo bay for all payloads is between Stations (X_o) 582 and 1302. The tug occupies the volume between Stations 882 and 1302. A 10-inch clearance is required between Stations 582 and 592 for rotation of the tug out of the orbiter bay. Therefore, the maximum overall payload length is 290 inches, between Stations 592 and 882.

The orbiter volume for payloads with and without a docking module is shown in Figures A-2 and A-3. In cases where manned servicing missions are considered, the docking module (Figure A-3) must be used for shirtsleeve crew transfer from the orbiter to the crew module. If suited (EVA) crew transfer is acceptable, the docking module need not be provided and the crew module could extend to shuttle orbiter Station 592 as shown in Figure A-2. The preferred mode, however, is shirtsleeve transfer. Therefore, the maximum payload length with the tug is 210 inches.

The general characteristics of the manned payload servicing configuration in the cargo bay are shown in Figure A-4. The concept adopted for the programmatic analyses was that the manned reusable tug consists of the reusable unmanned tug with the addition of a crew module and the spares storage modules necessary for manned servicing of geosynchronous platforms. The basic crew module has an overall length of 101 inches. In addition, the basic spares module with a length of 36 inches must be carried on all servicing missions. Additional spares modules are only 28 inches long. A 16-inch adapter to connect tug and spares module, also is required. The minimum total length when using a crew module is thus 153 inches and would extend from orbiter Station 729 to Station 882. A maximum of three spares modules can be carried on manned servicing missions when the docking module is used. Additional spares modules can be carried only if the docking module is removed; this would require that crew transfer from the shuttle orbiter to the crew module be performed EVA.

The payload volume available in the shuttle cargo bay with the remote servicing unit is illustrated in Figure A-5. The overall length of the unmanned remote servicing unit is 72 inches. This includes the 16-inch adapter, the basic 36-inch spares unit, and the 20 inches required for the servicing unit. Using the 28-inch spares modules, the payload length for one to four-tier (1-4) spares modules is shown in Figure A-6. Even with a four-tier spares module, 145 inches remain in the shuttle cargo bay for accommodating payloads.

The final consideration is the volume available in the cargo bay when delivering the first-stage tug (Tug A) for a dual tug mission. A technique for performing the on-orbit assembly is illustrated in Figure A-7. For this concept, Orbiter B with Tug B and the crew module is launched first. The tug and crew module are separated from Orbiter B and maintain attitude stabilization while Orbiter A with Tug A and a payload are launched to low-altitude earth orbit. Orbiter A then performs rendezvous with Tug B, rotates Tug A out of the orbiter bay, and docks Tug B with the crew module to Tug A using the shuttle manipulator. The payload delivered by Orbiter A is then manipulated to the end of the crew module. Upon completing the on-orbit assembly operations, the entire payload delivery system with its payload is separated from Orbiter A and Tug A initiates the necessary maneuvers for transfer to geosynchronous orbit. Tug A completes part of the geosynchronous transfer orbit insertion maneuver and returns to Orbiter A for recovery and return to earth.

The payload length which can be carried with Tug A is shown in Figure A-8. As shown in Figure A-7, Tug A requires a tug-to-tug interstage which provides the necessary structural interface for the dual-tug mission mode. This interstage is approximately 110 inches long. Allowing a 10-inch clearance for rotation of the tug out of the shuttle cargo bay and an additional 10-inch clearance between the payload and orbiter Station 582, the maximum allowable payload length is 170 inches.

TUG PAYLOAD CAPABILITIES

The reusable tug used for this study was the high-technology tug defined in the recently completed TOPSS study performed by Rockwell for MSFC (Reference A-1). This tug has an overall length of 35 feet and the weights shown in Table A-1. The weight statement was provided by MSFC for use in the Rockwell study. The tug end-boost weight is 6303 pounds for purposes of performance computations. There are 650 pounds of mission consumables including fuel cell reactants, APS attitude control propellant, and APS translation propellant. For the TOPSS reference mission, the tug payload weight was 3000 pounds round trip and a 1462-pound tug/shuttle interface was required for accommodating the tug in the orbiter cargo bay. Based on a gross weight limit of 65,000 pounds at shuttle liftoff, the allowable usable MPS propellant is 53,585 pounds. As noted in the table, however, the MPS is sized for a maximum usable propellant loading of 56,000 pounds. For the purpose of performance calculations, 390 pounds of APS propellant were added to the usable MPS propellant and all performance calculations were performed using an "MPS equivalent ΔV".

The corresponding weight statement for the dual tug mode is shown in Table A-2. For the dual tug mode, a tug-to-tug adapter must be included. As a result, the end-boost weight of Tug A is increased from 6303 to 6603 pounds, with the corresponding decrease in usable MPS propellant. For performance calculations, however, the weight statements are based on the definition of the available weight for MPS equivalent mission propellant plus payload. In all cases, the limiting weight at shuttle liftoff is 63,000 pounds.

Two weight statements are shown for Tug B in Table A-2. The nominal case (Tug B_{nom}) includes a 1300-pound payload penalty for the docking module. In this case, the maximum MPS equivalent mission propellant plus payload is less than the allowable 56,338 pounds of equivalent MPS mission propellant which the tug is capable of accommodating. If the shuttle docking module is not included, the equivalent MPS mission propellant plus payload can be 56,923 pounds, which is 585 pounds greater than the maximum allowable equivalent MPS propellant of 56,338 pounds.

The resultant payload capabilities of the single and dual tug are shown in Figures A-9 and A-10. In Figure A-9, the payload capability for delivery and return of payloads is shown as a function of the on-orbit ΔV assuming no payload is carried during the on-orbit maneuvers. As can be seen, the payload capability is limited by tug propellant below a payload weight of 3000 pounds. For payloads above 3000 pounds, the payload capability is limited by the maximum shuttle payload weight at liftoff of 65,000 pounds.

In Figure A-10, the outbound and return payload capabilities of the dual tug are presented as a function of the on-orbit ΔV assuming, in this case, that the return payload is carried through the on-orbit maneuvers. The data presented in the figure are based on the assumption that only one shuttle is launched with a mission payload (the other contains the tug and crew module). For the data presented in this figure, Orbiter A contains Tug A only. The effect of performing on-orbit assembly with mission payloads in both Orbiter A and Orbiter B is shown in Figure A-11. These data are based on no on-orbit ΔV and correspond to the upper bound shown on the previous curve if Tug A is delivered without a mission payload in the cargo bay of Orbiter A. Comparison of Figures A-10 and A-11 shows that a relatively significant payload capability increase can be realized by carrying payloads in both shuttle cargo bays and performing on-orbit assembly.

EXPENDABLE STAGES

Physical characteristics and performance capability data were compiled for several "kick stages" expected to be available on or before the shuttle IOC date. These are upper stages from current booster systems which have been modified to be compatible with the shuttle cargo bay environment and safety considerations related to the presence of the shuttle flight crew. They include the Delta, Agena, Transtage, and Centaur. All except the Centaur use space-storable propellants. The Centaur uses cryogenics (LO_2, and LH_2). The important characteristics for these stages, including geosynchronous payload capabilities, are summarized in Table A-3.

These data were obtained from NASA (Reference A-2) and reflect the net payload delivered after allowances for the payload interface adapter. Estimated weight for the interconnect and adapter structure between the combined stage/payload and the shuttle also is shown. All of these stages were performance-limited in their geosynchronous delivery capability, (i.e., their combined liftoff weight with full-up tanks, maximum payload, and their respective shuttle adapter weights was less than the 65,000-pound capability specified for the shuttle). It also should be noted that these are expendable stages, suitable only for delivery-type missions; they could not perform rendezvous, servicing, or retrieval missions.

Table A-1. Tug Weight Statement for Performance Calculations (Single Tug)

Item		Weight (lb)	Cumulative Weight (lb)
Dry weight		4,665	
Contingency		558	
			5,223
Nonusable fluids		950	
			6,173
Propellant reserve		130	
Tug end-boost weight			6,303
Mission consumables		650	
Fuel cell reactants (lb)	60		
APS attitude control (lb)	200		
	260		
APS translation ΔV^1 (lb)	390		
	650		
			6,953
Usable MPS propellant[1,2,3]		53,585	
			60.538
Tug/EOS interface		1,462	
			62,000
Payload (Round-Trip Mission)		3,000	
Gross weight at EOS liftoff			65,000

1. Usable propellant with $\Delta V_{MPS\ EQUIV} = 53,585 + 390 = 53,975$ lb

2. MPS sized for a maximum usable propellant of 56,000 lb

3. Maximum usable propellant with $\Delta V_{MPS\ EQUIV} = 56,000 + 390 = 56,390$ lb

Table A-2. Tug Weight Statement for Performance Calculations (Dual Tug)

Item	Weight (lb)		
	Tug A	Tug B_{NOM}	Tug B_{MAX}
Dry weight	4,665	4,665	4,665
Contingency	558	558	558
Nonusable fluids	950	950	950
Propellant reserve	130	130	130
Tug-to-tug adapter	300	-	-
Cumulative total	6,603	6,303	6,303
Fuel cell reactants	60	60	60
APS attitude control	200	200	200
Cumulative total	6,863	6,563	6,563
MPS equivalent mission Propellant plus payload	56,572 (56,287)*	55,623 (56,338)*	56,923 (56,338)*
Cumulative total	63,435	62,186	63,486
MPS equivalent assembly propellant	103	52	52
Cumulative total	63,538	62,238	63,538
Tug/EOS interface	1,462	1,462	1,462
Cumulative total	65,000	63,700	65,000
EOS docking module	-	1,300	-
Total	65,000	65,000	65,000

*Maximum allowable propellant.

Table A-3. Kick Stage Performance Summary

Name	Kick Stage Characteristics						Geosynchronous Payload (lb)
	Length/Dia. (ft)	I_{sp} (sec)	Weight (lb)				
			Ignition	Burnout	Payload Adapter	Shuttle Adapter	
DELTA	19.3/4.8	304	12,074	1894	80	1750	1,200
AGENA	20.2/5.0	291	14,930	1448	100	2250	2,250
TRANSTAGE	15.0/10.0	302	27,477	4065	230	3500	3,100
CENTAUR	30.0/10.0	438	34,436	4374	116	4400	12,700

• SHUTTLE TO 100 x 100 N MI, KICK STAGE TO GEOSYNC.

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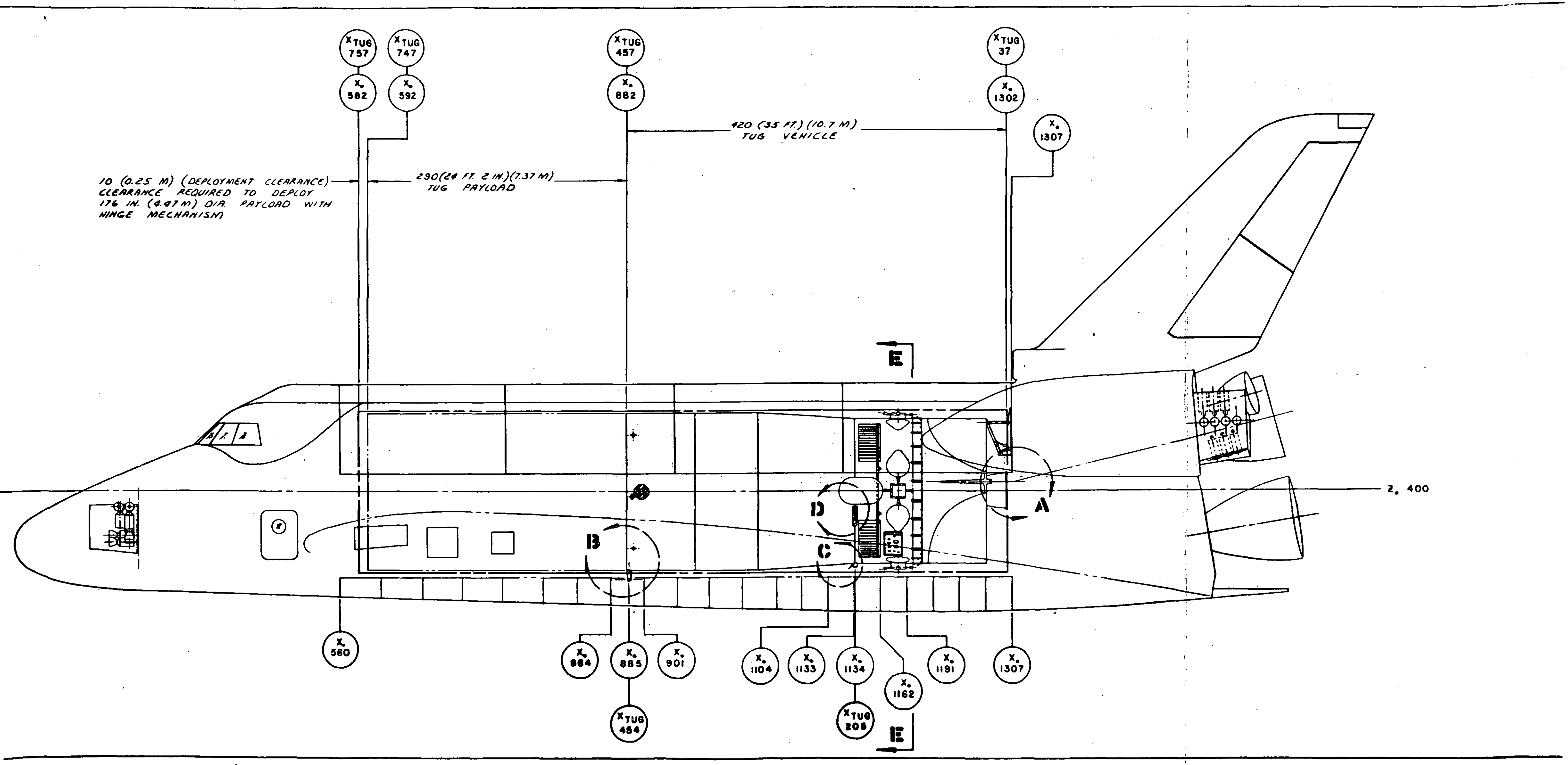

Figure A-1. Shuttle Orbiter Definition

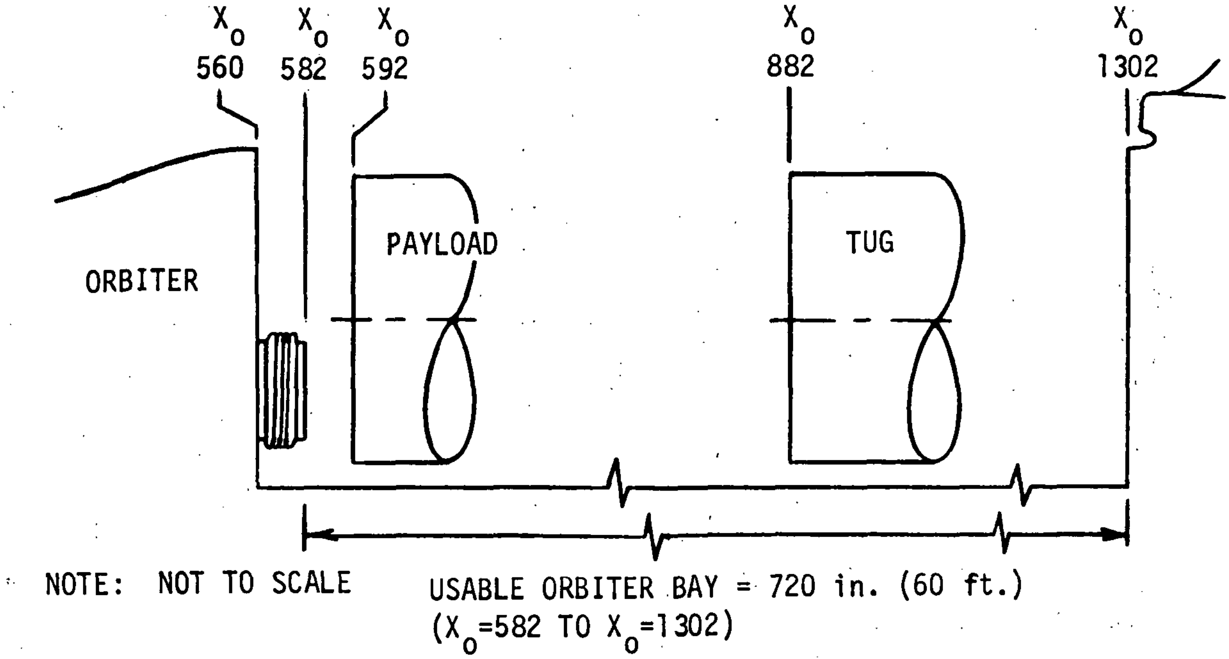

Figure A-2. Usable Orbiter Bay (No Docking Module)

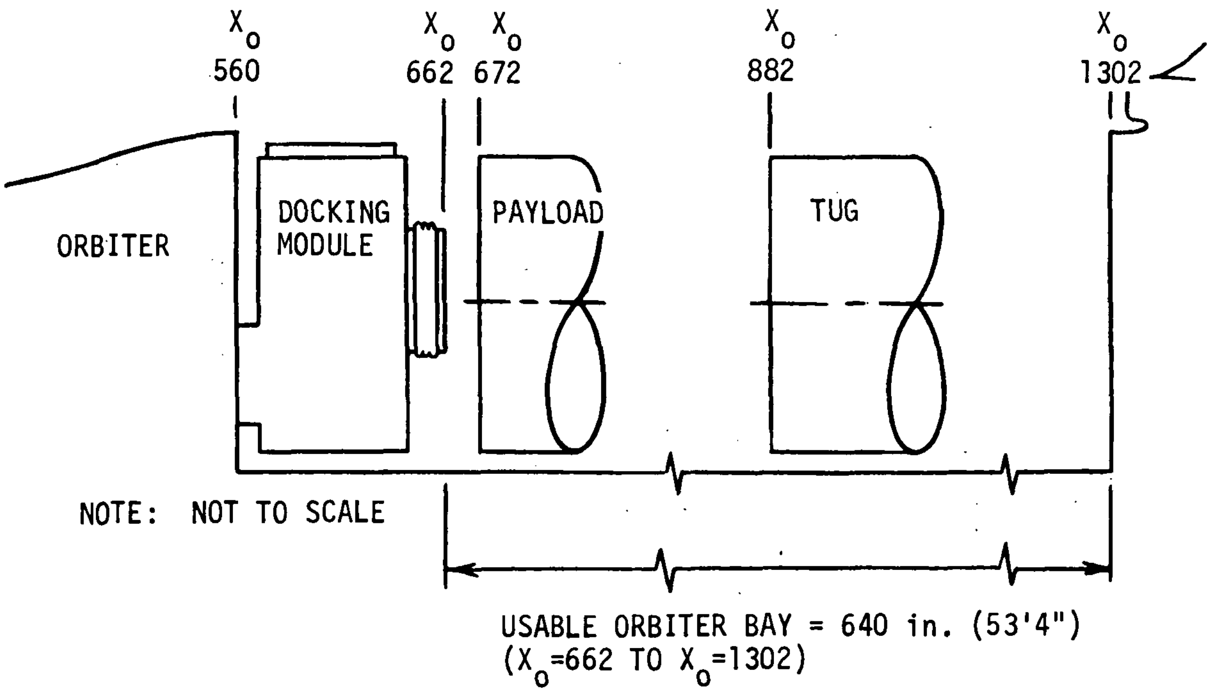

Figure A-3. Usable Orbiter Bay (With Docking Module)

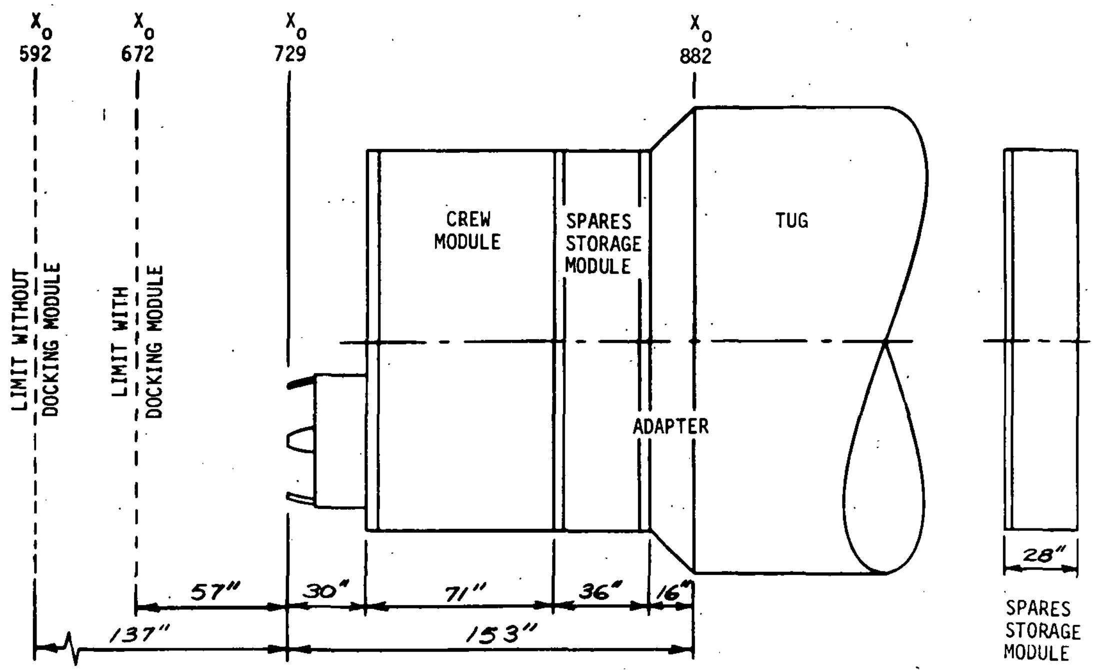

Figure A-4. Manned Payload Servicing System Configuration

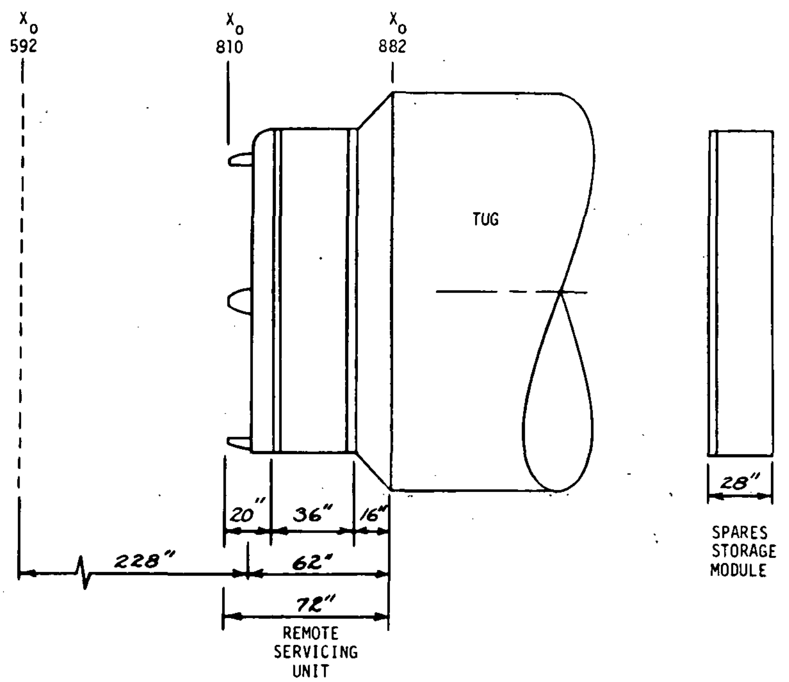

Figure A-5. Remote Payload Servicing System Configuration

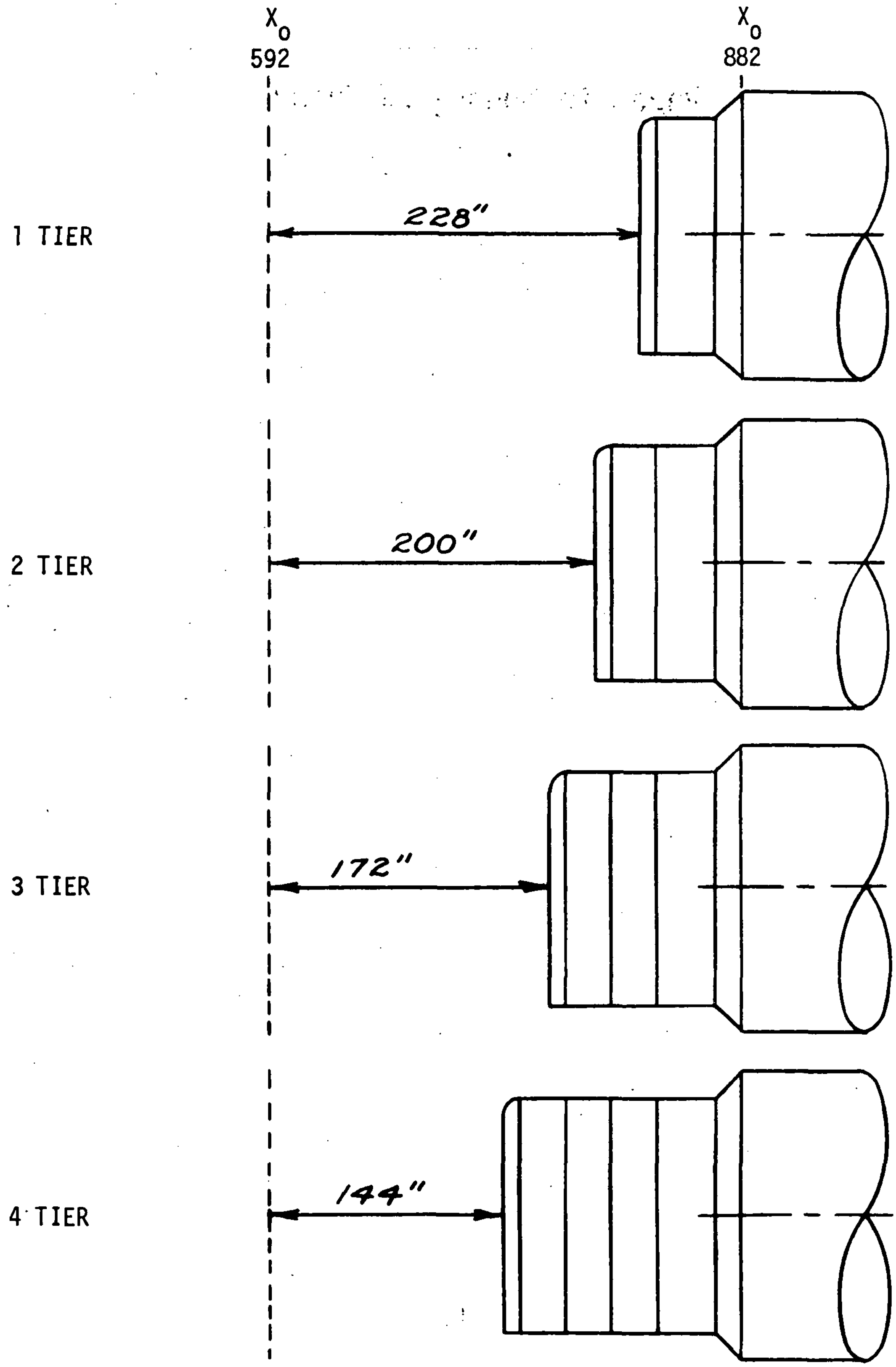

Figure A-6. Allowable Payload Length; Remote Servicing Mode

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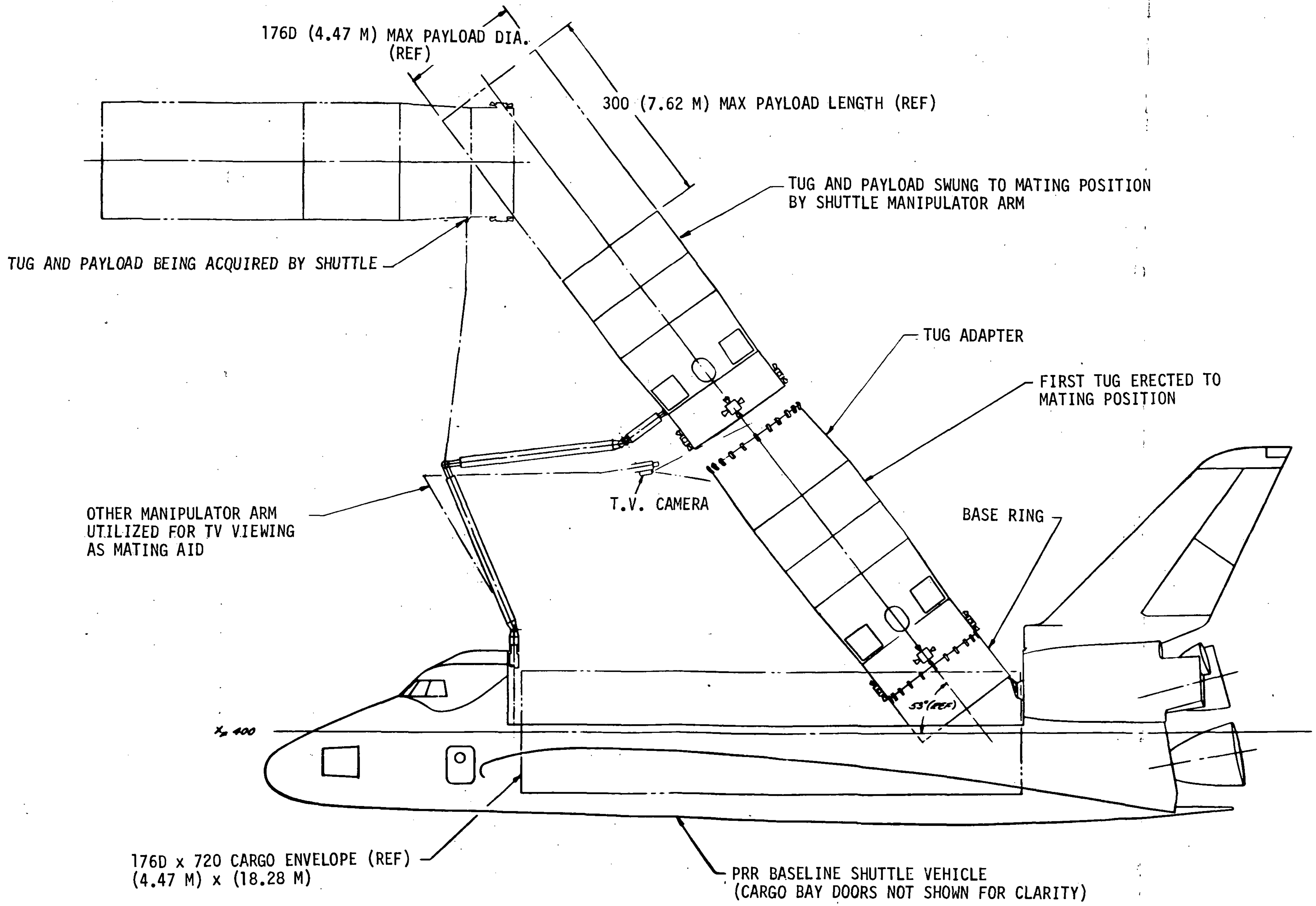
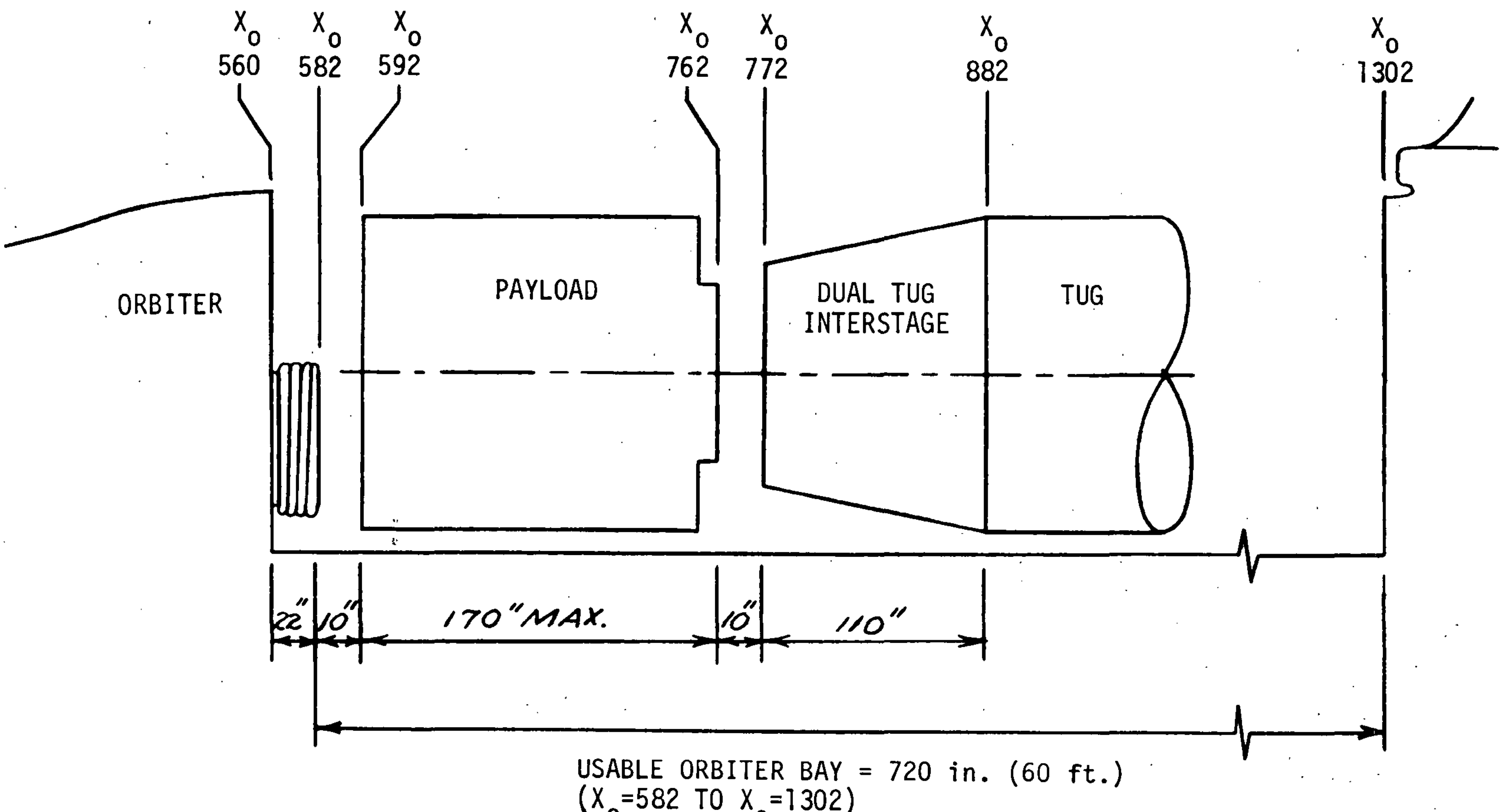


DOCKING BUILD-UP OF TUG TO TUG
UTILIZING MANIPULATOR ARMS

Figure A-7. Tug-to-Tug and Payload Orbital Assembly



NOTE: NOT TO SCALE

Figure A-8. Dual Tug First Stage Delivery Configuration

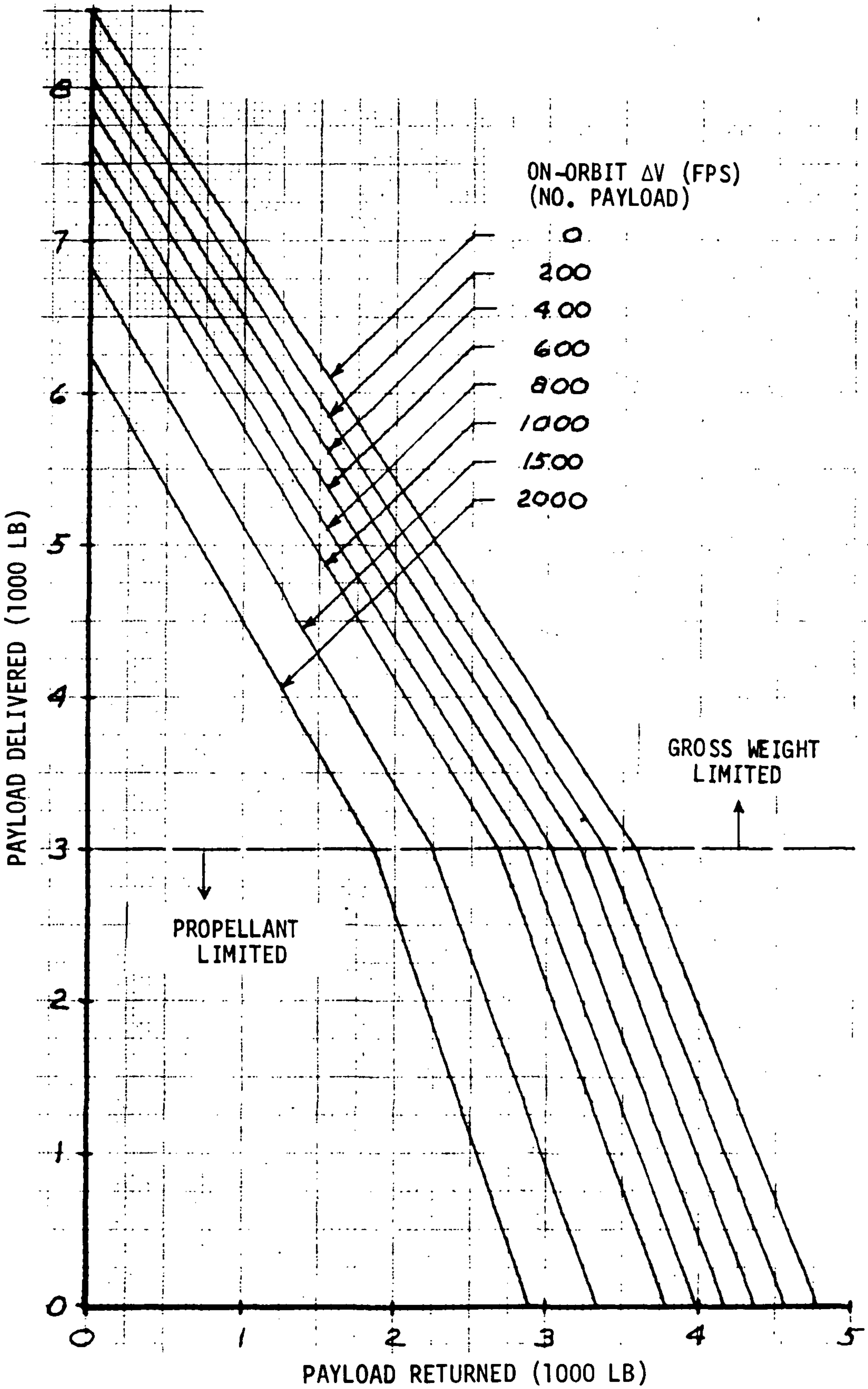


Figure A-9. Single Tug Performance Capability

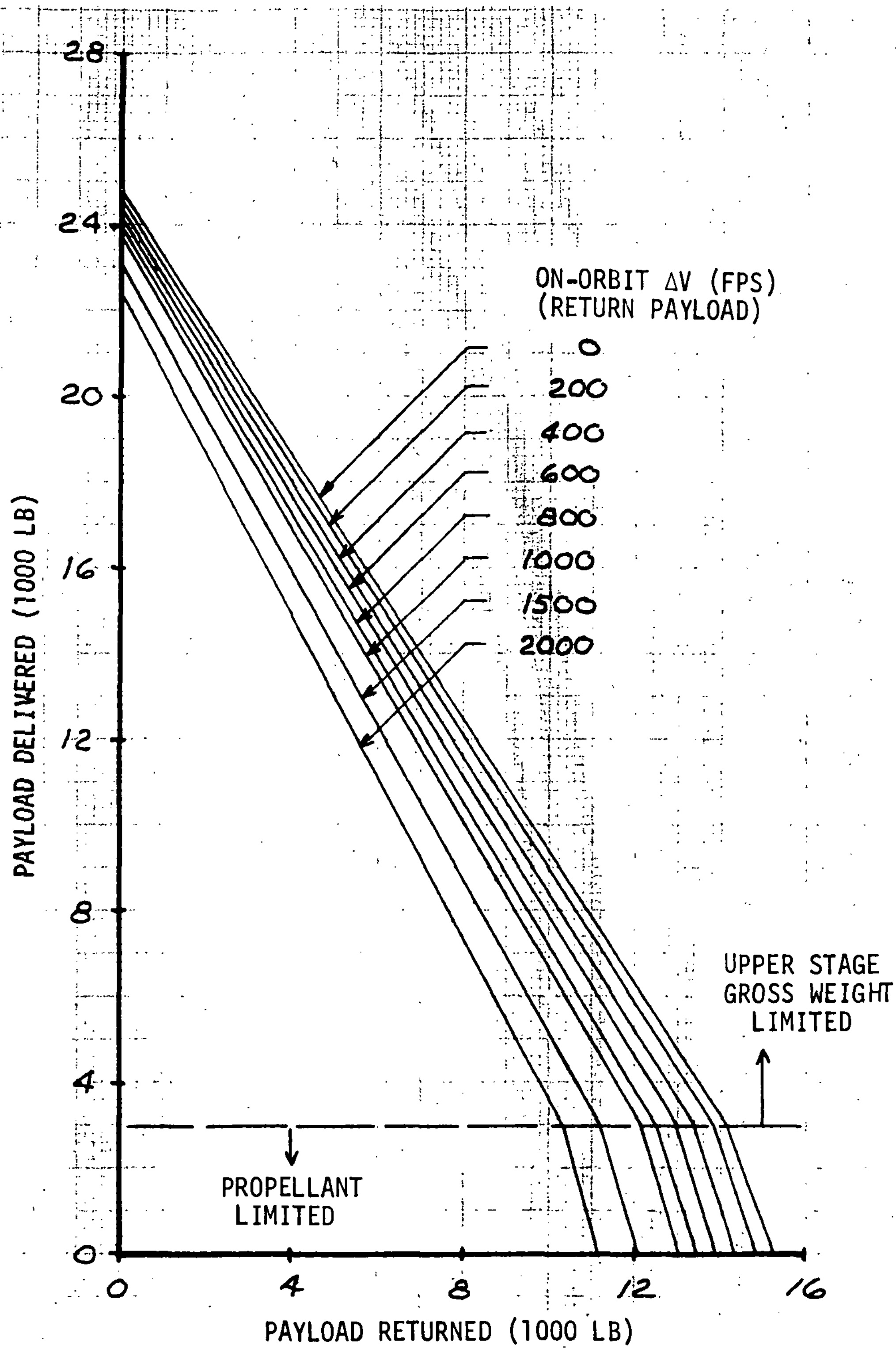


Figure A-10. Dual Tug Performance Capability; Single Mission Payload Launch

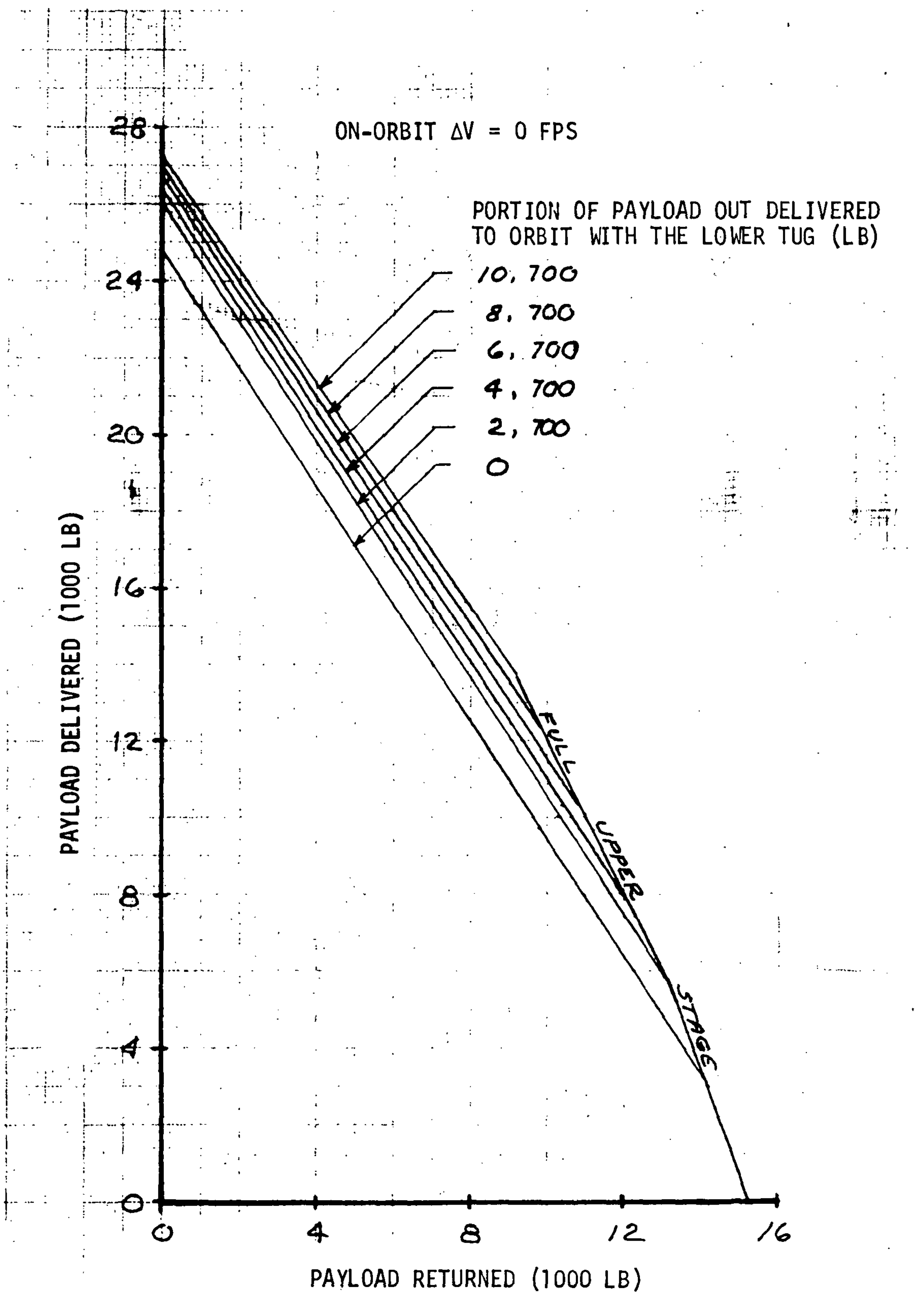


Figure A-11. Dual Tug Performance Capability; Dual Mission Payload Launch

REFERENCES

A-1 Tug Operations and Payload Support Study. Rockwell International, Space Division, SD 73-SA-006, 5 March 1973.

A-2 Launch Vehicle Estimating Factors for Advanced Mission Planning. Document No. NHB 7100.5A, 1972 Edition, NASA Headquarters.