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EARTH OBSERVATORY SATELLITE SYSTEM DEFINITION STUDY

REPORT NO. 6: SPACE SHUTTLE INTERFACES/ UTILIZATION

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EARTH OBSERVATORY SATELLITE SYSTEM DEFINITION STUDY

REPORT NO. 6: SPACE SHUTTLE INTERFACES/ UTILIZATION

Prepared For

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CONTENTS

CONTENTS (Cont)

CONTENTS (Cont)

CONTENTS (Cont)

ILLUSTRATIONS

ILLUSTRATIONS (Cont)

TABLES

TABLES (Cont)

ABBREVIATIONS AND ACRONYMS

ACS	Attitude and Control Subsystem
C & W	Caution and Warning
CDH	Communications & Data Handling
dB	Decibel
DHG	Data Handling Group
DNT	Descending Node Time of Day
EOS	Earth Observatory Satellite
EPS	Electrical Power Subsystem
FSS	Flight Support System
GSE	Ground Support Equipment
HRPI	High Resolution Pointable Imager
IMP	Instrument Mission Peculiar
LPS	Launch Processing System
LRM	Land Resources Mission
MEM	Module Exchange Mechanism
MDM	Multiplex/De-Multiplex
MM	Module Magazine
MSS	Multi-Spectral Scanner
MTBF	Mean Time Between Failures
OAS	Orbit Adjust Subsystem
OBC	On-Board Checkout
OCC	Operations Control Center
OMS	Orbital Maneuvering Subsystem
OOS	Orbit-to-Orbit Shuttle
OTS	Orbit Transfer Subsystem
P/L	Payload
PCM	Pulse Code Modulated
PDRM	Payload Deployment and Retrieval Mechanism
POCC	Payload Operations Control Center
PRPS	Payload Retention and Positioning System
RCS	Reaction Control Subsystem
RMS	Remote Manipulator System

S/C	Spacecraft
SAR	Synthetic Aperture Radar
SPG	Single Point Ground
SPMS	Special Purpose Manipulator System
SRM	Solid Rocket Motor
TM	Thematic Mapper
WBS	Work Breakdown Structure
WTR	Western Test Range

1 - SUMMARY

Three fundamental questions were addressed in the course of this study:

- What are the minimum impacts associated with achieving Earth Observatory Satellite (EOS)-Shuttle compatibility?
- Is the EOS compatible with Shuttle performance capabilities?
- What is the best way to attain the maximum benefits from Shuttle utilization?

Design impact and Shuttle performance were investigated for EOS missions A through F. Shuttle Utilization benefits were studied for EOS-B and EOS-C, which represent two classes of long-term operational spacecraft. These investigations led to the following conclusions:

- Observatory weight impacts, exclusive of orbit transfer subsystem (OTS) considerations, are reasonable
  - 60 to 70 lb for Delivery Only
  - 70 to 80 lb for Deliver/Retrieve
  - 200 to 300 lb for Deliver/Retrieve/Resupply
- EOS program cost impact (non-recurring/recurring) to achieve Shuttle compatibility are minimal compared to total program cost for any projected Shuttle utilization mode
  - \$ 0.5/\$ 0.5 million for Deliver Only
  - \$ 1.6/\$ 0.9 million for Deliver/Retrieve
  - \$ 3.0/\$ 1.3 million for Deliver/Retrieve/Resupply
- Shuttle performance, in conjunction with the EOS OTS is adequate for all EOS mission concepts except SEOS, which requires a Tug
- All EOS configurations studied, including the necessary support and resupply equipment, meet Shuttle volume and center of gravity constraints
- High EOS subsystem and instrument redundancy is cost-effective compared to total program costs in all Shuttle utilization modes
- For all EOS programs entailing on-orbit operating lifetimes in excess of 2 to 3 years, Resupply is the preferred Shuttle utilization mode. For shorter duration programs, Deliver is marginally preferred

- High cost, high weight payloads magnify the desirability of Resupply for long-term operational programs

- Resupply cost benefits can be significantly increased by reducing resupply system (i.e., module exchange mechanism and module magazine) weight, assuming shared Shuttle transportation costs

- Shuttle flights should be initiated on demand of a disabled spacecraft in all modes rather than on a regularly scheduled basis

- Proportional Shuttle transportation costs (multiple user) favor low Shuttle parking orbit plus EOS OTS

- A single EOS-C spacecraft program is more effective than a two EOS-B spacecraft program

- Additional study is warranted for:

  - EOS deploy and retrieve using shuttle payload deploy and retrieve mechanism (PDRM) without the flight support system (FSS) positioning platform

  - The use of the Shuttle manipulator versus the module exchange mechanism (MEM) module replacement for on-orbit resupply

The EOS can achieve Shuttle compatability for Delivery Only or Deliver/Retrieve utilization modes for a nominal weight impact of 60 to 80 lb for the EOS observatory (i.e., basic spacecraft plus instruments and mission peculiar equipment). For on-orbit resupply, the impact increases to 200 to 300 lb, reflecting the incorporation of signal/power disconnects and latches, rollers and tracks associated with spacecraft module replacement. In addition, the orbit transfer subsystem (OTS), entailing multiple Solid Rocket Motor (SRM) installations, must be added to EOS-E for all Shuttle utilization modes. Table 1-1 summarizes the weight impacts, derived from the analysis of Sections 3 and 4, by subsystem, for each mission-oriented EOS configuration considered. But, utilizing Shuttle, the OTS required for mission orbit circularization can be deleted from the conventionally launched EOS-C, resulting in a reduction in spacecraft launch weight of approximately 230 lb. Additional SRMs must be added for all modes of EOS-E operations, resulting in the weight impacts cited in Table 1-1. Excluding the OTS impacts, the weight variations among EOS configurations reflect the mechanization of varying instrument complements.

The design impact analysis indicated that for Deploy and Retrieval, consideration should be given to deletion of the FSS positioning platform, relying on the Orbiter manipulator to translate the EOS to and from its retention cradle. In addition, a simplified latching mechanism requiring latching forces of less than 10 lb suggests that the Orbiter manipulator may be a viable alternative to the Special Purpose Manipulator System (SPMS) currently baselined. Although additional study is necessary to determine the technical merits and/or disadvantages of these or similar alternatives, reductions in program cost are possible. For example, reducing FSS (including resupply mechanisms) weight to the recently projected level of 1900 lb (1000 for FSS plus 900 for Resupply) will reduce EOS-B 10-year program cost by $3, 6, and 11 million for Deliver, Retrieve, and Resupply, respectively.

Table 1-1 Shuttle Compatibility – Observatory Weight Impact Summary

SUBSYSTEM	EOS						WEIGHT IMPACT, LB		
	A	B	C	D	E	F	DELIVER	RETRIEVE	RESUPPLY
COMM AND DATA HANDLING	X	X	X	X	X	X	26	26	26
ELECTRICAL POWER	X	X	X		X	X	10	10	55
				X			10	10	59
ATTITUDE & CONTROL	X	X	X	X	X	X	0	0	0
STRUCTURE/MECHANISM	X	X					27	32	133
			X				27	32	152
				X			27	42	176
					X		27	38	187
						X	24	30	133
THERMAL CONTROL	X	X	X	X	X	X	0	0.4	18.4
PROPULSION	X	X		X		X	4	4	4
			X				−293(2)	−293(2)	−293(2)
					X		209	609	609
INST/MISSION PEC (1)	X	X	X	X	X	X	0	0	0
TOTALS	X	X					67	72	236
			X				−230(2)	−225(2)	−42(2)
				X			67	82	283
					X		272(2)	683(2)	895(2)
						X	64	70	236

NOTES: (1) IMPACT INCLUDED IN BASIC SPACECRAFT VALUES
(2) INCLUDES THE IMPACT ASSOCIATED WITH OTS

T6-1

The changes associated with achieving the minimum acceptable level of Shuttle compatibility for an EOS-B-class spacecraft, i.e., having the High Resolution Pointing Imager (HRPI) and Thermatic Mapper (TM), result in the cost impacts reflected in Table 1-2, ranging from $1.1 million for Deliver only to $4.3 million for Resupply to Develop and produce a single spacecraft. Shuttle Flight Support System (FSS) and resupply system costs

Table 1-2 Shuttle Compatibility - EOS-B Program Cost Impact Summary

ELEMENT	SHUTTLE COMPATIBILITY COSTS NON-RECURRING (RECURRING), $ (THOUSANDS)		
	DELIVER	RETRIEVE	RESUPPLY
OBSERVATORY	536 (548)	1,612 (919)	3,052 (1,272)
FLIGHT SUPPORT SYSTEM	4,900 (2,100)	4,900 (2,100)	4,900 (2,100)
RESUPPLY MECHANISM	0	0	10,000 (2,500)

T6-2

are identified but are not included in the impact value since these items are considered to be of general applicability to a wide range of Shuttle users, including payloads other than EOS. The cost impact of achieving minimum Shuttle compatibility is minor when compared to overall program cost. Additional cost information is contained in Subsection 4.6.

Each of the EOS configurations studied is also compatible with Shuttle performance and volume constraints as described in Section 5. Table 1-3 shows that only the EOS-F (SEOS) mission cannot be accommodated by the Shuttle alone, or the Shuttle in combination with the EOS OTS. EOS-F necessitates the use of a Space Tug. Although not considered economically attractive, a Tug can also be used for any of the missions requiring an OTS. With the addition of OTS, two spacecraft Shuttle flights can be accomplished for both EOS-A and EOS-B. While EOS-C lies within the performance capability of the OTS for dual spacecraft missions, its length is prohibitive. The follow-on missions (EOS-D, -E and -F) were not evaluated for dual operations, although EOS-E (Tiros O), which is typical of a two-satellite program, is achievable using OTS.

Table 1-3 Shuttle Performance Compatibility Summary

CONFIGURATION	DELIVER		RETRIEVE		RESUPPLY	
	SINGLE S/C	DUAL S/C	SINGLE S/C	DUAL S/C	SINGLE S/C	DUAL S/C
EOS-A (MSS, TM)	SHUTTLE	SHUTTLE PLUS OTS	SHUTTLE	SHUTTLE PLUS OTS	SHUTTLE	SHUTTLE PLUS OTS
EOS-B (HRPI, TM)	SHUTTLE	SHUTTLE PLUS OTS	SHUTTLE	SHUTTLE PLUS OTS	SHUTTLE	SHUTTLE PLUS OTS
EOS-C (HRPI, 2 TM, SAR)	SHUTTLE	NOT APPLIC	SHUTTLE	NOT APPLIC	SHUTTLE	NOT APPLIC
EOS-D (SEASAT B)	SHUTTLE		SHUTTLE		SHUTTLE	
EOS-E (TIROS O)	SHUTTLE PLUS OTS		SHUTTLE PLUS OTS		SHUTTLE PLUS OTS	
EOS-F (SEOS A)	SHUTTLE PLUS TUG		SHUTTLE PLUS TUG		SHUTTLE PLUS TUG	

T6-3

Each EOS configuration, together with its supporting complement of FSS and resupply provisions, will fit within the Shuttle allowable payload volume without violating center of gravity constraints, as shown in Table 1-4. Only EOS-C, with an overall length of 39 ft, will not permit the installation of two spacecraft simultaneously.

Based on the analysis of Section 6, the optimum mode of Shuttle utilization is dependent upon the desired spacecraft program lifetime (i.e., operating time on-station). Figures 1-1 and 1-2 show that for programs beyond two to three years in duration, regardless of spacecraft weight and cost, Resupply is the optimum Shuttle mode. For shorter duration programs, there is little cost difference between utilization modes, except that Deploy only is slightly more economical. Retrieval of the entire spacecraft entails similar transportation costs, but encounters higher refurbishment and logistics costs than on-orbit Resupply. In all modes, Shuttle flights should be initiated only when spacecraft status requires it to achieve maximum cost-effectiveness. Study has shown that selection of Shuttle operating orbit has a great influence on EOS transportation costs. Direct Shuttle ascent to the required EOS mission orbit may eliminate the need for an OTS, but significantly increases operational costs. If a Shuttle flight can be shared with other payloads, and the transportation costs apportioned among the users, EOS program costs can be significantly reduced. A proportional transportation cost structure, regardless of formulation employed, favors minimum altitude Shuttle parking orbits in combination with the incorporation of an OTS for all EOS missions.

Table 1-4 Shuttle Installation Compatibility Summary

CONFIGURATION	DELIVER		RETRIEVE		RESUPPLY	
	SINGLE S/C	DUAL S/C	SINGLE S/C	DUAL S/C	SINGLE S/C	DUAL S/C
EOS-A (MSS, TM)	YES	YES	YES	YES	YES	YES
EOS-B (HRPI, TM)	YES	YES	YES	YES	YES	YES
EOS-C (HRPI, 2 TM, SAR)	YES	NO	YES	NO	YES	NO
EOS-D (SEASAT B)	YES	X	YES	X	YES	X
EOS-E (TIROS O)	YES	X	YES	X	YES	X
EOS-F (SEOS)	YES	X	YES	X	YES	X

T6-4

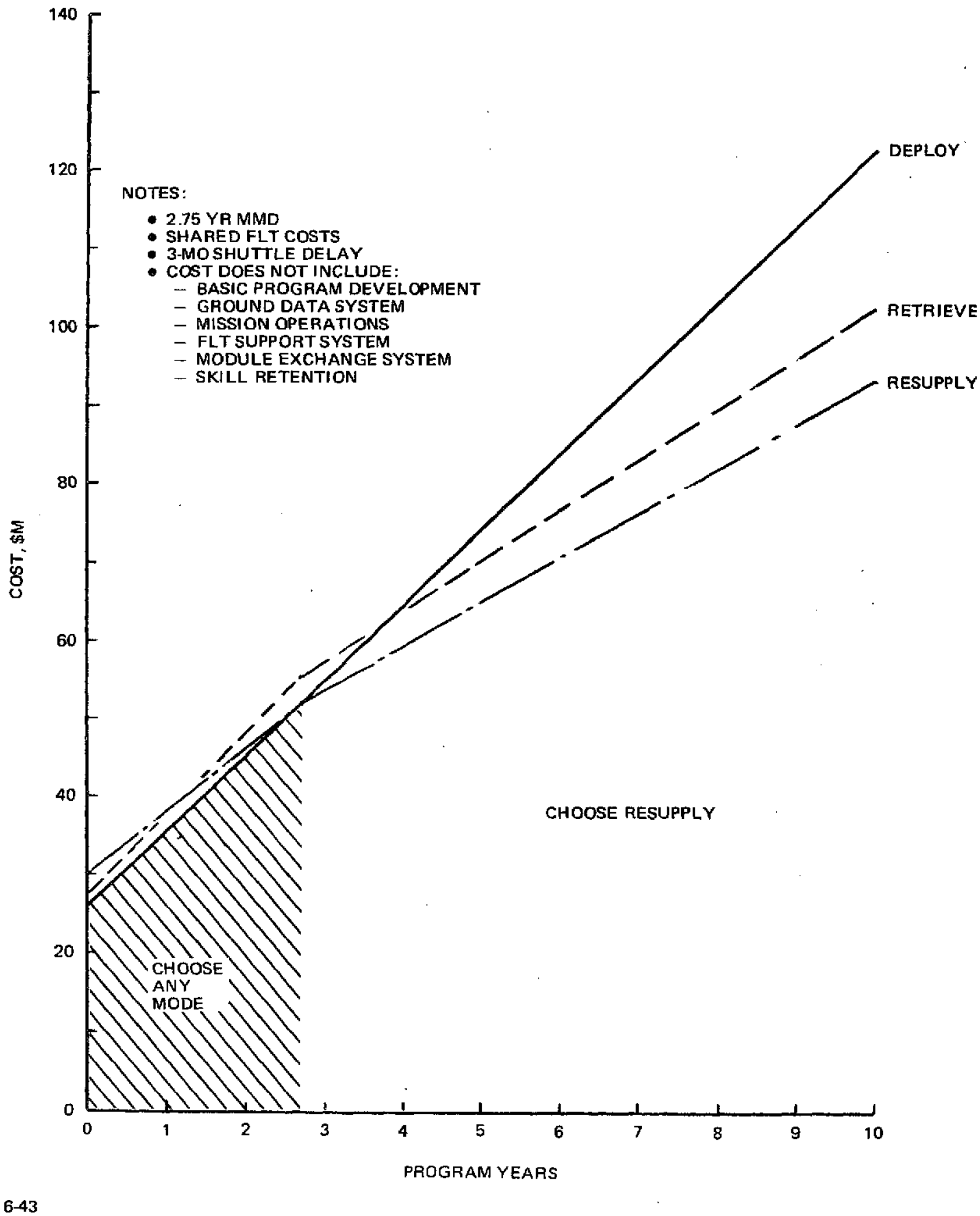


Fig. 1-1 Shuttle Utilization Costs, EOS-B

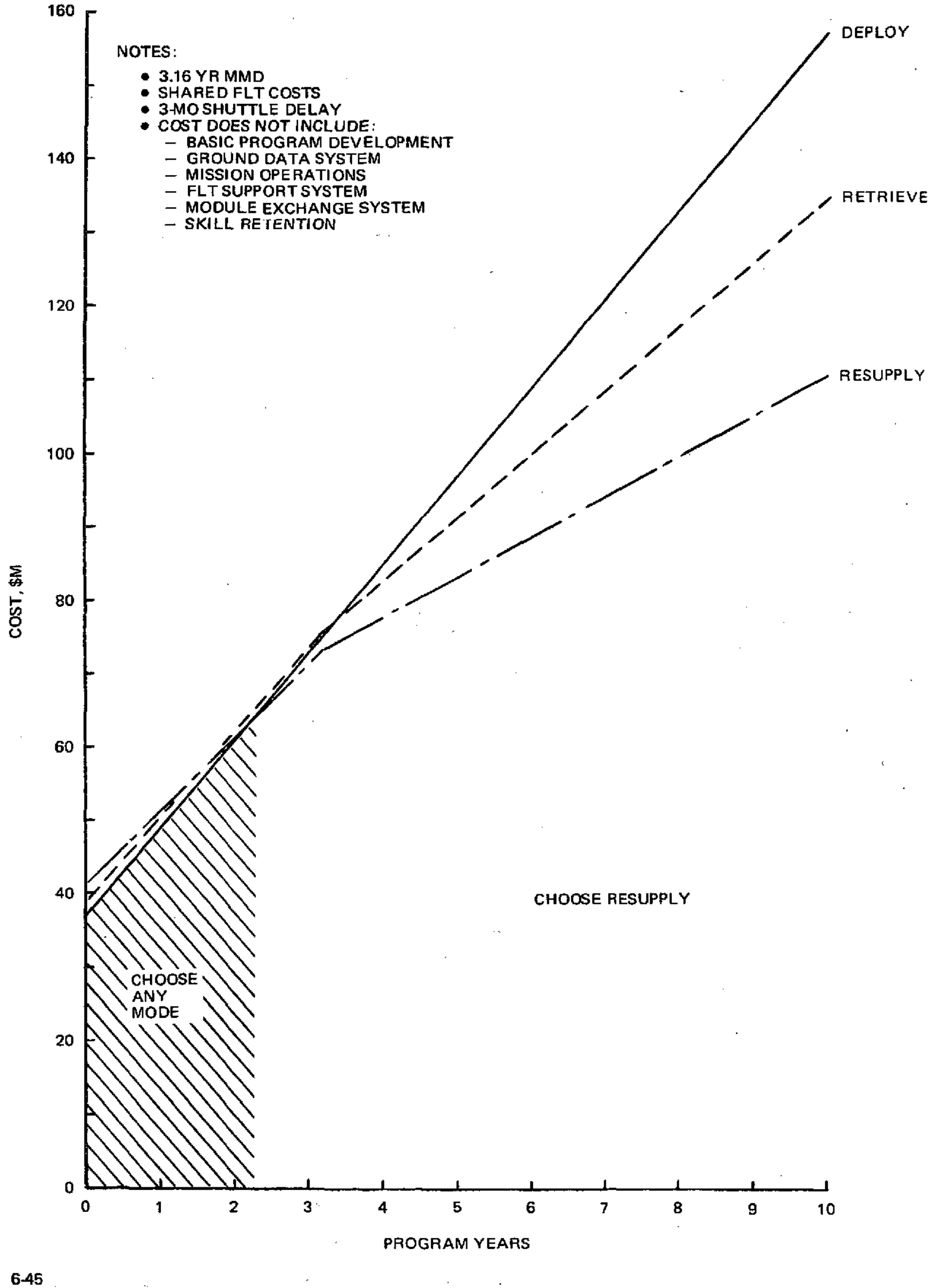


Fig. 1-2 Shuttle Utilization Costs, EOS-C

2 - INTRODUCTION

2.1 PURPOSE

One of the major objectives of the EOS System Definition Study, as stated in RFP SOW Subsection 1.2-1, is:

> "To define optimized operating techniques for the Space Shuttle era, e.g., to allow earth observations research to be sustained and refreshed through the 1980's."

The purpose of Report No. 6 is to support this objective by determining the economic impacts and benefits of using Shuttle to support EOS operations for:

- Launch only (Deliver mode)
- Launch plus Retrieval (Retrieve mode)
- Launch plus Resupply plus Retrieval (Resupply mode)

2.2 APPROACH

This study is structured to assess the impacts of achieving EOS-Shuttle compatibility and determine the potential benefits of Shuttle utilization.

As shown in Fig. 2-1, this entails a three-pronged effort. One major thrust is to determine the impact of achieving the minimum acceptable level of Shuttle compatibility. To achieve this, the additional capabilities (requirements) necessary to enable the EOS to utilize Shuttle in each potential mode (i.e., Deliver, Retrieve, and Resupply) are determined, and the associated design changes and resultant cost increments are identified (Sections 3 and 4). The second activity assesses the mission suitability of the resultant Shuttle-compatible EOS configurations relative to Shuttle performance, volume, and center of gravity envelopes (Section 5). In the third effort, variations in Shuttle utilization techniques are evaluated to determine the optimum way of exploiting the Shuttle's capabilities.

Insight into the impacts and benefits of Shuttle utilization involves a wide range of variables. To permit sufficient depth-or-cut in this study, a continuous operational Land Resources Mission (LRM) using an EOS-B class spacecraft has been emphasized throughout.

Mission requirements and mission suitability, including the effects of multiple space-

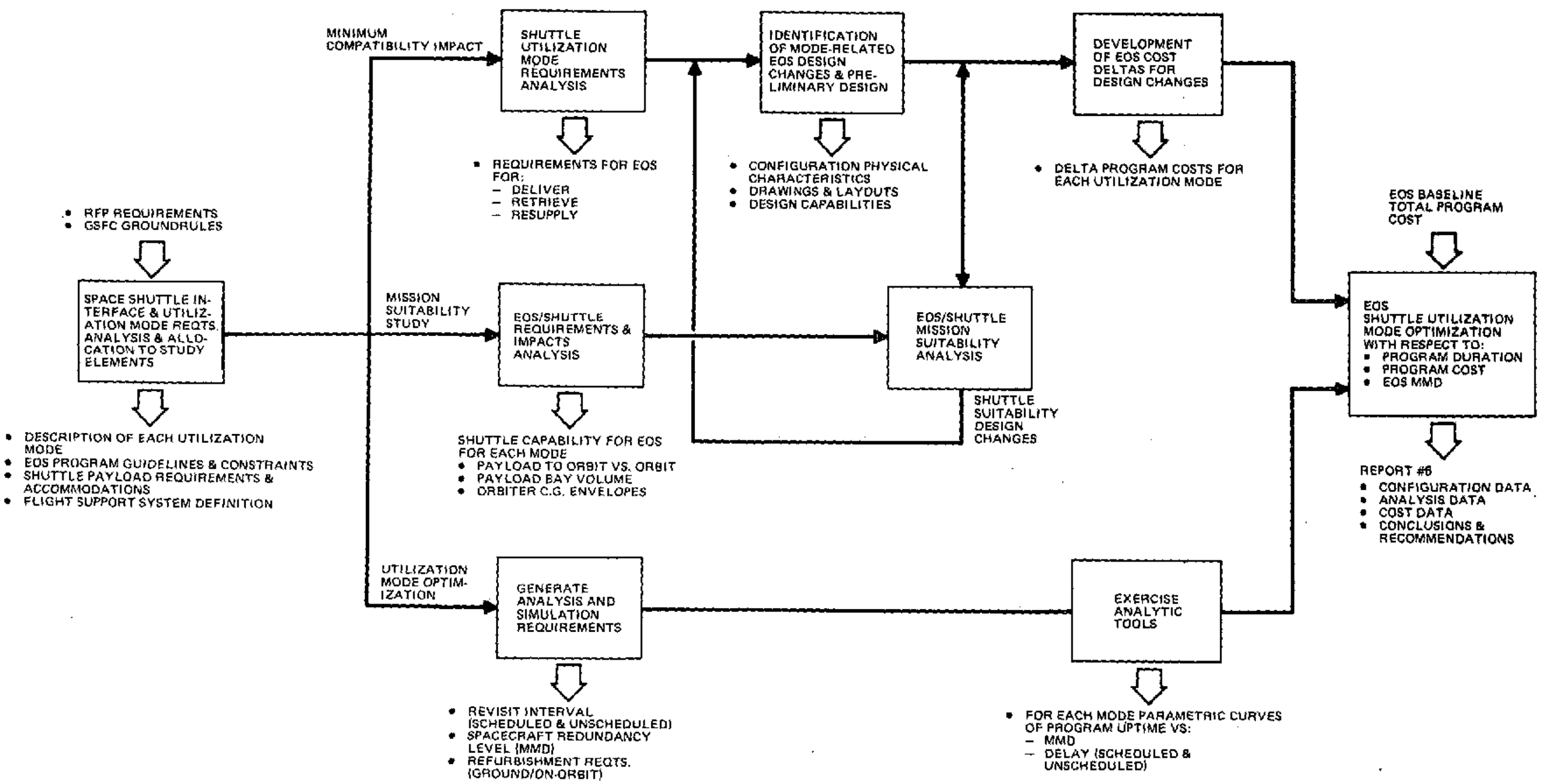


Fig. 2-1 EOS Space Shuttle Interfaces/Utilization Study Approach

craft missions, are addressed for the full spectrum of missions. Spacecraft requirements stress Mission B although major factors in all missions (e.g., an orbit transfer capability required for Mission E/Tiros O) are considered. A range of instrument/mission peculiar requirements are provided by addressing Missions A, B, and C. Basic requirements for Shuttle compatibility are insensitive to the one vs multiple spacecraft considerations and, therefore, only the single spacecraft mode has been considered for all design elements.

Design impact is assessed primarily against Mission B, but unique requirements reflected by Missions A, B, and C are addressed. The Flight Support System design is assessed relative to the unique design characteristics of the Grumman EOS concept and alternative approaches to providing EOS support are suggested where such approaches offer the potential for weight or cost benefits.

The preliminary results reflected in the Shuttle Compatibility Study, Reference 1, indicated that Resupply had the most pronounced impact on spacecraft design and cost. Accordingly, particular attention has been paid to the Resupply concept with respect to potential weight and cost impact.

Detailed program costs have been developed for the design changes necessary to achieve EOS-B compatibility with Shuttle operations. Non-recurring and recurring unit costs have been determined, including development, test, ground support and logistics, and integration efforts.

To provide correlation between Shuttle compatibility requirements and resultant design changes, a common reporting format, Table 2-1, has been utilized in "Requirements Analysis" (Section 3) and "Design Impact Analysis" (Section 4). Each entry is correlated to the EOS mission configuration to which it applies. For example, Requirement 1 applies to all missions, while Requirement 2 applies only to EOS-E. A requirement (or design change) is noted under the first Shuttle mode to which it applies and applies to all subsequent modes unless otherwise noted. In Table 2-1, Requirement 1 is applicable to all three Shuttle modes, while Requirement 2 addresses only the Retrieve and Resupply modes. Requirement 4 is defined initially for Deliver. That requirement is modified for Retrieve and Resupply. Where appropriate, clarifying remarks are included. For each requirement identified in Section 3, there is a corresponding design change noted in Section 4. Thus, there exists a one-to-one correlation between the requirements and design impact analysis.

Mission suitability is addressed in terms of performance, volume, and center of gravity compatibility with both Shuttle and conventional launch vehicle capabilities. Em-

Table 2-1 Element Incremental Requirements or Design Changes

DISCIPLINE	EOS MISSION						SHUTTLE MODE			REMARKS
	A	B	C	D	E	F	DELIVER	RETRIEVE	RESUPPLY	
SUBELEMENT (if any)	X	X	X	X	X	X	1. REQUIREMENT OR DESIGN CHANGE →	→	→	FUNCTIONAL ELEMENT: BASIC SPACECRAFT
					X			2. REQUIREMENT OR DESIGN CHANGE →	→	
	X	X	X	X	X				3. REQUIREMENT OR DESIGN CHANGE	CLARIFYING STATEMENT
	X	X	X				4. REQUIREMENT OR DESIGN CHANGE	4. REQUIREMENT OR DESIGN CHANGE →	→	

T6-5

phasis has been placed on verifying that the EOS missions can be accomplished, rather than optimizing operational techniques. Circular vs elliptical Shuttle orbits have been explored.

Potential variations in Shuttle utilization techniques are addressed in "Shuttle Utilization", Section 6. Due to the number of variables involved, a baseline analysis has been conducted, assuming a single spacecraft mission initiated in 1980 and continuing through the decade. The analysis considers the influence on each potential utilization mode of variables such as:

- Scheduled/unscheduled Shuttle flights
- Ground/on-orbit refurbishment
- Spacecraft redundancy level.

The effect of variation in instrument/mission peculiar equipment price and weight is reflected by including two classes of spacecraft (EOS-B and -C) in the analysis. The multiple spacecraft question is addressed against this broad scope analysis for Mission B only. A supporting issue, spacecraft redundancy, reflects the effects of variations in design life and the resultant influence on replacement (i.e., deploying a new satellite on-orbit), retrieval, and resupply approaches.

The question of Shuttle utilization, and the related system modifications, require additional study based on firm design and operational concepts. This study is structured to provide a foundation upon which the necessary follow-on studies can be planned and implemented.

2.3 GROUNDRULES, GUIDELINES, AND ASSUMPTIONS

For consistency, a set of groundrules, guidelines, and assumptions were established for general application throughout the study. These are:

- Emphasize EOS-B
- Define the changes necessary to achieve the minimum acceptable level of Shuttle compatibility
- The Flight Support System (FSS) analysis is based on the characteristics and capabilities defined in Reference 2
- The Shuttle becomes available for EOS support in CY-1983
- All EOS configurations will be initially placed in mission orbit using a conventional launch vehicle
- Single spacecraft programs are assumed unless otherwise noted

- Shuttle parking orbit is assumed to be 200 n mi, circular
- Shuttle performance capabilities shall be based on carrying the required payload through all mission burns to provide for safe return in the event the payload cannot or should not be deployed
- For Resupply, the capability to retrieve and return to earth the on-orbit spacecraft is to be maintained to accommodate a non-repairable situation
- For Resupply, no expended modules are jettisoned in orbit. The same complement that is carried to orbit for resupply operations is returned to earth for refurbishment.

The analysis of Shuttle utilization, Section 6, imposes specific assumptions unique to its approach. These are summarized in Subsection 6.1.2.

3 - REQUIREMENTS ANALYSIS

This section addresses the requirements for achieving EOS capability with each of the three potential modes of Shuttle utilization. It has been assumed that the EOS system will be configured for initial delivery by a conventional launch vehicle. Consequently, the requirements reflect the minimum additional capabilities/constraints considered necessary to convert to Shuttle operations.

In-depth analysis was restricted to EOS-B, currently considered representative of a long-term operational LRM mission, to permit a reasonably detailed assessment. Continuity of operation is considered the driver requirement in such an operational program. Since the basic spacecraft is common to all missions, significant mission-to-mission variations will be evident primarily in the Instrument/Mission Peculiar Equipment. In general, however, results from the EOS-B analysis can be considered representative of the effects which will extend to the various complements of Instrument/Mission Peculiar Equipment which comprise the front-end of the Observatory. To ensure that major implications to the EOS program are identified, top level mission variations which present potentially significant perturbations to the baseline approach have been considered (e.g., EOS-F necessitates the use of a Tug).

Mission requirements have been identified for the entire current mission model to provide a point-of-reference for ensuing analyses and to enable the results of the EOS-B oriented analysis to be related to other missions.

The question of Shuttle compatibility influences the Observatory, Shuttle, and Ground Operations. For convenience in this study, the Observatory has been addressed as:

- Basic Spacecraft - comprised of the four standard subsystem modules (CDH, ACS, EPS, and Propulsion) and supporting structure which are insensitive to mission objective
- Instrument/Mission Peculiar Equipment - comprised of those modules/assemblies forward of the EOS upper bulkhead, (sta 100) which vary mission-to-mission.

In addition, the total interface between EOS and Shuttle was considered to be reflected in the Flight Support System (FSS). Consequently, the FSS element has been structured in accordance with the content of Reference 2 and includes the complement of equipment normally associated with the FSS, the resupply system, and the Shuttle crew, software, and support services.

Ground Operations associated with EOS-Shuttle compatibility have been addressed in terms of:

- Pre/Post-Flight Operations - comprised of the facilities, equipment, and personnel associated with spacecraft logistics, handling, check-out, and refurbishment
- Mission Operations - comprised of the resources necessary for planning and supporting the conduct of the missions.

For convenience, the differences between conventional launch vehicle and Shuttle-induced environments have been considered separately from the EOS system elements since they have general applicability.

3.1 MISSION REQUIREMENTS

Six candidate EOS missions, A through F, as summarized in Table 3-1, were considered for this study. For maximum utility, the Shuttle should be capable of satisfying each of the missions in the model, either in its basic configuration or with planned augmentation of its inherent capability. In addition, Shuttle compatability should not drive the Spacecraft configuration to a state which forces the initial delivery to a higher performance, and thus a more costly, conventional launch vehicle. Accordingly, the mission requirements of Table 3-1 include not only the mission orbit characteristics, but the maximum delivery capabilities of the launch vehicle assigned to meet the initial delivery schedule. Instrument complements are also identified for reference.

An additional reference mission, α, has been constructed to meet the unique needs of the Shuttle utilization analysis discussed in Section 6. This mission, characterized in Table 3-1, represents a generalized EOS program, sustained throughout the era of Shuttle operations, requiring a single spacecraft on orbit at any given time. Both EOS-B and -C have been included as representative spacecraft to permit consideration of a range of spacecraft costs and weights.

As shown in Table 3-1, the mission selected for in-depth analysis, EOS-B, is very representative of the primary EOS missions (A, B, and C). Missions D, E, and F are all follow-on's and are not sufficiently defined for in-depth analysis, although major functions which are peculiar to these missions, such as the use of a Tug, have been investigated.

Table 3-1 EOS Mission Requirements

MISSION DESIGNATION	INSTRUMENT COMPLEMENT	NOMINAL ORBIT ALT (nmi)	INCL (deg)	INITIAL DELIVERY LAUNCH VEHICLE	MAX DLVR CAPABILITY (lb)	LAUNCH DATE
A	MSS, TM	366	98.1	DELTA 2910	2660	1979
B	HRPI, TM	366	98.1	DELTA 3910	3730	1981
C	HRPI, 2 TM, SAR	366	98.1	TITAN III B	5150	1980
D	SEASAT B	324	90	DELTA 2910	2825	1982
E	TIROS O	450	98.7	DELTA 3910	3550	1982
F	SEOS A	19,323	0	TITAN III C 7	4700	1981
α	HRPI, TM	380.8	98.2	N/A	N/A	PRE-1983
	HRPI, 2 TM, SAR	380.8	98.2	N/A	N/A	PRE-1983

T6-6

3.2 BASIC SPACECRAFT

The preliminary analysis of Shuttle compatibility requirements previously reported in Reference 1, has been re-examined to ensure completeness and accuracy, concentrating on EOS-B. Additional emphasis was placed on thermal control and on-board software requirements.

Although in-depth analysis has been limited to EOS-B, the basic spacecraft is of standard design and, therefore, is insensitive to mission variations. The only significant exception is the Orbit Transfer Subsystem (OTS), which because of its unique involvement with the Orbit Adjust/Reaction Control functions, has been included in the analysis of the basic spacecraft rather than Instrument/Mission Peculiar Equipment (subsection 3.3). The OTS, considered in combination with the Orbit Adjust Subsystem (OAS) and Reaction Control Subsystem (RCS) (see Propulsion, subsection 3.2.6), varies in accordance with mission orbit characteristics. As a safeguard, however, all missions were reviewed for top-level variations which could result in major deviations.

To facilitate ensuing design impact analyses, requirements for common functions (e.g., mechanical latches and blind connectors for Resupply) have been consolidated within the discipline where they would most likely be implemented. This consolidation includes the related functions from both Basic Spacecraft and Instrument/Mission Peculiar Equipment elements.

3.2.1 COMMUNICATIONS AND DATA HANDLING

The major drivers for Communications and Data Handling (CDH) compatibility with Shuttle are the needs to provide fail-operational Orbiter command override capability and to provide for monitoring and control of EOS parameters critical to the safety of the Orbiter and its crew. While the EOS is attached to or in the immediate vicinity of the Orbiter, the Orbiter crew must be alerted to the presence of any potentially hazardous condition aboard EOS, and must have the capability to take appropriate action to alleviate this condition. Of the requirements identified for CDH Shuttle compatibility, Table 3-2, only Requirements 4, 6, and 7 address other than these driving requirements.

The EOS functions considered essential for relay to the Orbiter crew have been compiled as a preliminary caution and warning (C & W) list, shown in Table 3-3. Of the 12 functions comprising this list, four are associated with the OTS, unique to EOS-E, two with the OA/RCS, and six with the Solar Array in EPS. The status of each function is to be relayed to the Orbiter crew and, for each function, a single command corresponding to appropriate corrective action is to be provided for. Inadvertent OA/RCS thruster firing in or around the Orbiter could result in a hazardous condition, either due to the exhaust plume itself or the resultant vehicle dynamics. Appropriate C & W indicators and corresponding fail-operational command override capabilities were considered to cover this contingency. Based on the analysis of the propulsion discipline (subsection 3.2.6), however, it has been concluded that the potential thruster-firing hazard can be alleviated by operational procedures.

It has been assumed that the C & W function must be maintained throughout Resupply operations, including the period when the CDH and EPS modules are being replaced and are physically removed from the vehicle. In this event, the CDH capabilities for data/command processing and routing cannot be used for the C & W function, and appropriate provisions (e.g., parallel wiring runs) must be incorporated in the spacecraft to maintain the necessary capability. This need is reflected in Requirement 8 of Table 3-2.

Requirement 4 is considered marginal as a mandatory requirement, but has been included to enable the ground to supplement the C & W functions on a continuous basis. It may be operationally acceptable to have periods of telemetry blackout during these mission phases.

The physical removal and replacement of the CDH module are covered by Requirements 6 and 7.

3.2.2 ELECTRICAL POWER

The additional Electrical Power Subsystem (EPS) functional requirements associated with achieving Shuttle compatibility have been identified and are listed in Table 3-4. In

Table 3-2 Communications Data Handling Incremental Requirements

FUNCTIONAL ELEMENT: BASIC SPACECRAFT

DISCIPLINE	EOS MISSION						SHUTTLE MODE			REMARKS
	A	B	C	D	E	F	DELIVER	RETRIEVE	RESUPPLY	
1. COMM & DATA HANDLING	X	X	X	X	X	X	1. Provide for immediate relay to the Orbiter crew, EOS parameters critical to Shuttle system and range safety operations while the EOS is: a. Attached to the Orbiter b. In the vicinity of the Orbiter		1. Same plus provided for C&W monitoring of EOS modules while in storage aboard the orbiter.	Critical parameters are as defined in the Caution and Warning list, Table 3-3
							2. Provide for command override of critical EOS functions by the Orbiter crew while the EOS is: a. Attached to the Orbiter b. In the vicinity of the Orbiter			Assume a command rate of 2.4 Kbps attached and 2 Kbps separated.
							3. Provide for fail operational design of EOS critical data transmission and command receipt while the EOS is: a. Attached to the Orbiter b. In the vicinity of the Orbiter			
							4. Provide for the relay of EOS status data to the ground through the Orbiter while the EOS is: a. Attached to the Orbiter b. In the vicinity of the Orbiter			Orbiter may occlude EOS line-of-sight to gnd station during near-in opns or while attached. a. Assume 16 Kbps status data and 256 Kbps FM wideband data. b. Assume 16 Kbps data rate with S-band, phase modulation in 2200-2300 MHz band.
							5. Provide for transfer from hardwire to RF comm, and vice versa of TM, CMD, and Cntl capability.			
									6. Provide for remote attachments and release of CDH module from supporting structure in a manner compatible with MEMS resupply concept.	Antennas, which are external to module, are passive devices that need not be designed for replacement.
									7. Provide disconnection and restoration of module signal/power circuit interfaces.	
									8. Provide for monitoring & control for EOS system and subsystem safety during replacement of C&DH and EPS modules.	Assumes that EOS cannot be made completely dormant during resupply opn's (e.g., maintain htr pwr to critical components).

T6-7

Table 3-3 EOS Caution and Warning Functions

SUBSYSTEM	MEASUREMENT	TYPE	MISSION						SHUTTLE MODE		
			A	B	C	D	E	F	DELIVER	RETRIEVE	RESUPPLY
Orbit Adjust/ Reaction Cntl.	Hydrazine Tank #1 Press	Caution	X	X	X	X	X	X	X	X	X
	Hydrazine Tank #2 Press	Caution	X	X	X	X	X	X	X	X	X
Orbit Transfer Note:	SRM Safe & Arm Device #1	Warning					X		X	X	X
	SRM Safe & Arm Device #2	Warning					X		X	X	X
	SRM Safe & Arm Device #3	Warning					X			X	X
	SRM Safe & Arm Device #4	Warning					X			X	X
Electrical Power	Solar Array Safe & Arm Device #1	Warning	X	X	X	X	X	X	X	X	X
	Solar Array Safe & Arm Device #2	Warning	X	X	X	X	X	X	X	X	X
	Solar Array Safe & Arm Device #3	Warning	X	X	X	X	X	X	X	X	X
	Solar Array Safe & Arm Device #4	Warning	X	X	X	X	X	X	X	X	X
	Solar Array Safe & Arm Device #5	Warning	X	X	X	X	X	X	X	X	X
	Solar Array Safe & Arm Device #6	Warning	X	X	X	X	X	X	X	X	X

T6-8

general, the identified requirements are within the scope of normal or conventional EPS design practice and do not pose any unique or complex design solutions. A possible exception is reflected in Requirement 4, which is intended to eliminate combined spacecraft structure currents and corresponding electromagnetic interference. This requirement is common to all Shuttle payloads and consideration should be given to a common solution.

Introduction of survival mode operations, Requirement 5, extends the necessary on-orbit life of the EPS from the baseline two years to five years. The total of five years was selected to accommodate the interval between the scheduled initial launch of the first EOS (EOS-A in 1979) and the availability of the WTR to support Shuttle polar orbit launches (1983) plus one year for Shuttle scheduling constraints. It has been assumed that while in the survival mode, the EOS will be virtually quiescent, resulting in a minimum power demand. The net requirement, then, is for the EPS to provide power for two years of normal observatory operation plus three years of substantially reduced activity levels.

Table 3-4 Electrical Power Incremental Requirements (Sheet 1 of 2)

FUNCTIONAL ELEMENT: BASIC SPACECRAFT

DISCIPLINE	EOS MISSION						SHUTTLE MODE			REMARKS
	A	B	C	D	E	F	DELIVER	RETRIEVE	RESUPPLY	
ELECTRICAL POWER	X	X	X	X	X	X	1. Provide for EOS power during prolonged stay in Orbiter P/L bay of up to 24 hours prior to deployment and prior to return.			a. Assumed worst case condition b. Requirement for return under Deliver is the result of Shuttle operational constraints
							2. Provide for connection of Orbiter power of EOS			
							3. Provide for routing of Orbiter power to EOS equipment			
							4. Provide for isolation of EOS negative power bus from structural ground while on Orbiter power.			
								5. Provide for additional 3 years operation in powered down survival mode.		Accommodate wait time for Shuttle launch in response to failed or inoperative status
								6. Provide for static discharge/equalization of potential between Orbiter and EOS prior to capture.		
								7. Provide for retracting and securing solar array.		Implementation should include a back-up capability. Jettison of entire array is acceptable.
									8. Provide for remote disconnection and restoration of Solar Array, including drive mechanism, signal/power circuit interfaces.	

T6-9(1)

Table 3-4 Electrical Power Incremental Requirements (Sheet 2 of 2)

FUNCTIONAL ELEMENT: BASIC SPACECRAFT

DISCIPLINE	EOS MISSION						SHUTTLE MODE			REMARKS
	A	B	C	D	E	F	DELIVER	RETRIEVE	RESUPPLY	
ELECTRICAL POWER (Contd.)	X	X	X	X	X	X			9. Provide for remote disconnection and restoration of Power Module signal/power circuit interfaces.	
									10. Provide for remote disconnection and restoration of signal/power circuit interfaces among all EOS modules	Mechanization of signal/power interfaces for entire S/C is provided by EPS.
									11. Provide for remote attachment and release of Solar Array, including drive mechanism, from supporting structure in a manner compatible with MEM resupply concept.	
									12. Provide for remote attachment and release of Power Module from supporting structure in a manner compatible with MEM resupply concept.	
									13. Provide for remote arming and disarming of input/output power to/from Power Module.	
									14. Provide for remote enabling/disabling of power to individual EOS modules.	Desirable to control power to each module independently to facilitate replacement operations.
									15. Provide for the routing of essential power to spacecraft equipment while the EPS module is removed.	Assumes the power must be provided for critical functions (e.g., temp cntl) at all times.

T6-9(2)

The requirement for static discharge or equalization of charge potential between the EOS and Orbiter during retrieval (Requirement 6) has been tentatively identified as an EOS requirement. Since a similar requirement is implied for all payloads retrieved from orbit by the Orbiter, it is apparent that a common solution is desirable.

As reflected in Requirement 10, the requirements for interruption and restoration of all circuits among observatory modules/assemblies have been consolidated under EPS. Implementation of these requirements should be standardized. The requirement implies that connections should be self-aligning and positive latching with minimum forces to facilitate design and operation of the resupply function. Requirement 14 supplements Requirement 10 in that it ensures that the appropriate power circuits are dead-faced during connector mating/demating to eliminate the danger of arcing. Although an alternative approach might be to eliminate all spacecraft power during module replacement, it has been assumed that because of C & W and potential thermal maintenance requirements, a level of sustaining power will be necessary throughout the operations.

3.2.3 ATTITUDE CONTROL

The Attitude Control Subsystem (ACS) provides the intelligence for observatory maneuvering and stabilization, and contains both primary and backup modes of controlling attitude, inertia wheels and magnetic torquers, respectively. Due to the design requirements imposed on the baseline spacecraft (i.e., non-Shuttle-compatible) to meet mission objectives, the inherent capabilities of the ACS are adequate to meet virtually all needs for Shuttle compatibility. The additional requirements which are imposed are listed in Table 3-5.

Control of the EOS-E OTS burns was not considered as a potential requirement. The guidance and control accuracies needed for OTS operations do not differ significantly from those required for OTS and OAS maneuvers on the spacecraft designed for conventional launch vehicles.

Acquisition of the EOS by the Orbiter mounted Remote Manipulator System requires that the spacecraft be stabilized to the limits reflected in Requirement 2. It has been assumed that the Shuttle will be able to maneuver as required to effect EOS capture, so the EOS will not have to attain any particular inertial orientation.

3.2.4 STRUCTURE/MECHANISMS

The Shuttle compatibility requirements associated with Structure and Mechanisms listed in Table 3-6 represent three basic functions:

Table 3-5 Attitude Control Incremental Requirements

FUNCTIONAL ELEMENT: BASIC SPACECRAFT

DISCIPLINE	EOS MISSION						SHUTTLE MODE			REMARKS
	A	B	C	D	E	F	DELIVER	RETRIEVE	RESUPPLY	
ATTITUDE CONTROL	X	X	X	X	X	X	1. Provide back-up capability for maintaining EOS attitude.	1. Same, plus maintain stable attitude for s/c survival for 3 years.		a. To insure fail-safe operation while in close proximity to Orbiter during docking opn's. b. To provide survival capability in the event of loss of primary attitude control mode.
								2. Maintain S/C attitude at $\pm 1^\circ$ and $\pm 1^\circ$/sec in back-up mode.		To support acquisition by PDRM.
									3. Provide for attachment and release of ACS module from supporting structure in a manner compatible with MEMS resupply concept.	3-axis magnetometer pkg must be mounted apart from ACS module. Since it is a passive device with high reliability, it is not considered a replaceable element.
									4. Provide for remote disconnection and restoration of signal/power circuits to/from ACS module.	

Table 3-6 Structure/Mechanisms Incremental Requirements

FUNCTIONAL ELEMENT: BASIC SPACECRAFT

DISCIPLINE	EOS MISSION						SHUTTLE MODE			REMARKS
	A	B	C	D	E	F	DELIVER	RETRIEVE	RESUPPLY	
STRUCTURE/MECHANISMS	X	X	X	X	X	X	1. Provide for the Shuttle induced ascent, descent, and landing environments defined in subsection 3.7.			Shuttle operational constraints dictate that in the event a P/L cannot or should not be deployed, it must be returned to landing.
	X	X	X	X	X		2. Provide for structural attachment to the FSS cradle.			
						X	3. a. Provide for mating to the FSS Positioning Platform. b. Provide for mating to the Space Tug P/L interface.			The current FSS baseline uses the same platform for EOS deploy, retrieve and resupply, necessitating 3 passive docking probes on the EOS lower bulkhead. The same arrangement is applicalbe to Tug.
	X	X	X	X	X	X	4. Provide a structural attachment for the Orbiter PDRM coincident with the EOS longitudinal center of gravity location.			The attachment device must be a rigid structure capable of holding the S/C stable in 6 DOF.
							5. Provide for emergency release of all EOS/FSS physical connections.			To ensure that no mechanical hang-ups will prevent safe Orbiter entry and landing.
	X	X	X	X	X	X		6. Provide mechanisms for retracting and securing all deployable spacecraft appendages.		Individual requirements are cited in the appropriate Basic Spacecraft and Instrumental/Mission Peculiar disciplines (subsections 3.2 and 3.3 respectively).
									7. Provide MEM's resupply concept compatible mechanisms for remote structural attachment and release of the individual S/C, Instrument, and Mission Peculiar Modules/Assemblies listed in Table 3-7.	

T6-11

- Interfacing with the FSS
- Retracting all deployable appendages to fit within the allowable Orbiter payload bay envelope for retrieval
- Replacing observatory modules and assemblies.

For this study, it has been assumed that the FSS defined in Reference 2 applies. This baseline FSS has been developed to support EOS deployment, retrieval, and resupply. Consequently, the necessary interfaces for Deliver apply equally to all Shuttle modes. The approach taken in this analysis was to identify the requirements on the EOS to achieve compatibility with the baseline FSS. Alternative approaches which deviate from the baseline are discussed under Design Impact in subsection 4.1.4 and under Flight Support System requirements (subsection 3.4) and Design Impact (subsection 4.3).

Thus far, no requirement has been identified by the FSS developers for emergency release of physical connections with the spacecraft. Since safe Orbiter entry necessitates secured payloads and closed payload bay doors, it is apparent that provisions must be made to ensure that no physical mulfunction will preclude meeting this condition. It is equally apparent that this is a constraint which applies to all Shuttle payloads, not just EOS. Although it is expected that emergency release will be provided by the FSS, the requirement has been cited for EOS to emphasize its criticality. The subject is discussed further in the sections dealing with FSS requirements and design, subsections 3.4 and 4.3, respectively.

For conventional launch vehicle and Shuttle delivery, once the spacecraft appendages are deployed, they need never be retracted again. With the introduction of retrieval, applicable to both Retrieve and Resupply Shuttle modes, it becomes necessary to retract or remove these appendages to conform to the available payload bay envelope and to secure them for the entry environment, as reflected in Requirement 6. The spacecraft components needing retraction are indicated and correlated to individual missions in Table 3-7. All module/assembly requirements from both the basic Spacecraft and Instrument/Mission Peculiar Equipment have been compiled in Requirement 7 because of their common implementation.

Because of lack of adequate definition of a Tug vehicle, it has been assumed, based on our previous studies, that EOS-F will interface with the Tug at the lower bulkhead in a manner identical to the interface with its assigned initial launch vehicle. It has been further assumed that a Tug-oriented support system, not the FSS, will be used for EOS-F. Consequently, no compatibility requirements related to FSS interfaces have been defined.

Table 3-7 In-Flight Replaceable Modules/Assemblies

NOTE: DEPLOYABLE ELEMENTS NOTED BY (*) MODULE	EOS MISSION A (LRM)	B (LRM)	C (LWRM)	D (SEASAT-B)	E (TIROS-O)	F (SEOS)
BASIC SPACECRAFT						
POWER	X	X	X	X	X	X
ATTITUDE CONTROL	X	X	X	X	X	X
COMMUNICATIONS/DATA HANDLING	X	X	X	X	X	X
ORBIT ADJUST/RCS/OTS	X	X	X	X	X	X
MISSION PECULIARS						
HIGH RESOLUTION POINTABLE IMAGER (HRPI)		X	X			
THEMATIC MAPPER (TM)	X	X	2			
MULTI-SPECTRAL SCANNER (MSS)	X					
X-BAND ANTENNA	2	2	2	2	2	2
KU-BAND ANTENNA *	X	X	X	X	X	
INSTRUMENT MISSION PECULIAR MODULE	X	X	X	X	X	X
SYNTHETIC APERTURE RADAR			X			
SOLAR ARRAY & DRIVE *	X	X	X	2	X	X
LARGE EARTH SURVEY TELESCOPE (LEST)						X
MICROWAVE SOUNDER *						X
ADVANCED ATMOSPHERIC SOUNDER AND IMAGING RADIOMETER *						X
ALTIMETER				X		
SCATTEROMETER *				X		
LASER RETROREFLECTOR				X		
INFRARED SCANNER				X		
COHERENT RADAR EXPERIMENT *				X		
SPACE ENVIRONMENTAL MONITOR					X	
SCANNING MULTICHANNEL MICROWAVE RADIOMETER *					X	
ADVANCED VERY HIGH RESOLUTION RADIOMETER					2	
MICROWAVE RADIOMETER/SCATTEROMETER ELECTRONICS *					X	
MICROWAVE RADIOMETER/SCATTEROMETER ANTENNA					X	
ADVANCED TIROS OPERATIONAL VERTICAL SOUNDER					X	
CLOUD PHYSICS RADIOMETER					X	

T6-12

It is currently understood that, if required, EOS-F will be resupplied by a Tug-carried resupply system. Although such a system will apparently be significantly different than the present baseline (Reference 3), no definition is currently available. It has been assumed, therefore, that the mechanical interfaces for Resupply reflected in Requirement 7 will be identical for both Shuttle-mounted and Tug-mounted resupply concepts.

3.2.5 THERMAL CONTROL

The additional Thermal Control requirements arising from Shuttle compatibility are listed in Table 3-8. Requirement 2 addresses the need to maintain spacecraft equipment at adequate temperature levels to preclude damage during the 3-year survival mode while conserving power. As all applicable modules have thermostatically controlled heater circuits to maintain minimum operating temperature (nominally $+50^{\circ}F$), simply turning off equipment will result in higher heater cycling rates to compensate for reduced equipment heat dissipation, and will not yield an adequate reduction in electrical power demands. The need for a second set of thermostats, set at the equipment survival temperature limit (nominally $-40^{\circ}F$) is implied. A similar requirement, Requirement 3, has been identified for the individual modules carried up to and down from resupply operations. It has been assumed that while these modules are stowed, they will have to be maintained above the survival temperature levels to preclude damage. Further analysis of the ascent, descent, and on-orbit payload bay thermal environment is needed to verify the need for active thermal control (i.e., heaters), but the requirement has been listed pending this analysis.

The baseline spacecraft is designed for thermal balance with all modules in place. During resupply operations, however, individual modules will be removed from the spacecraft, exposing internal structure to ambient conditions, thereby upsetting the thermal balance. Requirement 4 establishes a need to maintain the balance with and without the full complement of modules installed, and implies additional thermal blankets to provide thermal closure for all structural areas exposed to space with modules removed.

3.2.6 PROPULSION

Due to commonality of function and encapsulation in a common spacecraft module, the Orbit Adjust Subsystem (OAS), Reaction Control Subsystem (RCS), and Orbit Transfer Subsystem (OTS) have been treated together under the heading of Propulsion. The Shuttle compatibility requirements applicable to Propulsion are listed in Table 3-9.

Table 3-8 Thermal Incremental Requirements

FUNCTIONAL ELEMENT: BASIC SPACECRAFT

DISCIPLINE	EOS MISSION						SHUTTLE MODE			REMARKS
	A	B	C	D	E	F	DELIVER	RETRIEVE	RESUPPLY	
THERMAL CONTROL	X	X	X	X	X	X	1. Provide for maintenance of S/C thermal control while exposed to the Orbiter P/L Bay environment defined in subsection 3.7.			
								2. Provide for the maintenance of acceptable equipment temperatures during survival mode of operation		Assumes that for survival, the S/C will be powered down, maintaining only those capabilities required to insure S/C survival without additional damage until the Shuttle can retrieve or service the S/C.
									3. Provide for the maintenance of acceptable temperature levels in replacement/replaced modules while in Orbiter stowage.	
									4. Provide for the maintenance of S/C thermal balance during module/assembly replacement operations.	

T6-13

Table 3-9 Propulsion Incremental Requirements

FUNCTIONAL ELEMENT: BASIC SPACECRAFT

DISCIPLINE	EOS MISSION A	B	C	D	E	F	SHUTTLE MODE: DELIVER	RETRIEVE	RESUPPLY	REMARKS
PROPULSION - Orbit Adjust - Reaction Control - Orbit Transfer	X	X	X	X	X	X	1. Provide for propellant tank pressure relief while attached to or in the vicinity of the Orbiter.			To protect the Orbiter and its crew from potentially hazardous overpressure conditions.
							2. Provide for fail-safe control of thruster operation while attached to or in the vicinity of the Orbiter.			a. To protect against uncontrolled s/c rotational or translational dynamics while in the near vicinity of the Orbiter (i.e., during deployment and retrieval opns). b. To protect against a "failed-on" thruster while attached to the Orbiter.
							3. Provide for propellant tank retention of fluids under the crash load environment defined in subsection 3.7			
					X	X	4. Provide for EOS transfer from Shuttle parking orbit to mission orbit.	4. Same plus provide for EOS transfer from mission orbit to Shuttle parking orbit.		EOS-E and -F mission altitudes are beyond Shuttle capability.
	X	X	X	X	X	X			5. Provide for remote attachment and release of the Propulsion module (OAS/RCS/OTS) from supporting structure in a manner compatible with the MEMS resupply concept.	
									6. Provide for remote disconnection and restoration of signal/power circuits to/from the Propulsion module.	

The Propulsion module contains the only pressurized elements and toxic fluids (N_2H_4) aboard the spacecraft. As a result, the bulk of the compatibility requirements address crew safety as reflected in Requirements 1, 2 and 3. Nominal propellant storage tank operating pressure is 400 psi. As Orbiter payload bay wall temperature can reach $200^{o}F$, there is a chance of overpressure with attendant danger of rupture. To insure that no such condition develops to endanger the Orbiter and its crew, a requirement for overpressure protection, Requirement 1, has been imposed. Based on our prior studies of Tug-Shuttle interfaces, it appears that, for Shuttle descent, a tank pressure of 20 psi will eliminate all danger of implosion. Requirement 1, therefore, implies that prior to initiation of Shuttle descent, the propellant tank pressurant should be vented down to approximately 20 psi.

Although the propellants used for OAS and RCS are toxic (N_2H_4), small quantities are involved. The maximum carried on any mission is approximately 46 lb, while the minimum is only 23 lb. In addition, the propellants are contained by bladders within the small diameter tanks. Accordingly, it was deemed adequate to qualify the tankage for the maximum load conditions expected in the Shuttle mission profile, the crash loads defined in subsection 3.7.2, as reflected in Requirement 3. Dumping of residual propellants remains a viable alternative, if necessary.

The mission suitability analysis, Section 5 of this report, indicates that inherent Shuttle capability is inadequate to achieve the required mission orbits for EOS-E or EOS-F in any Shuttle mode, Deliver, Retrieve, or Resupply. This dictates the inclusion of some form of performance augmentation for each of these missions (Requirement 4). EOS-A, -B, -C, and -D can be adequately accommodated by Shuttle in any of the three modes of utilization.

During analysis of the required C & W functions (subsection 3.2.1) there was concern that an inadvertant OA/RCS thruster firing in or around the Orbiter could result in a hazardous condition because of plume impingement on the resultant spacecraft dynamics. While the EOS is attached to the Orbiter, the isolation valve controlling the 0.1 lb and 5 lb thrusters can be closed, preventing inadvertant firing of these jets. During this interval, the 1.0 lb jets provide a backup to the primary mode of spacecraft attitude control, the inertia wheels. In the event a 1.0 lb jet fails on, the resultant vehicle dynamics are sufficiently low rate to permit the corresponding isolation valve to be closed, and, if required, the 0.1/5.0 lb thruster isolation valve opened. Thus, there is adequate inherent protection against inadvertant jet firings.

3.2.7 ON-BOARD SOFTWARE

Potential Shuttle compatibility requirements on software include caution and warning function, spacecraft checkout and initialization, and control of OTS maneuvers. As shown in Table 3-10, the OTS control related requirements were eliminated from consideration. The initial launch of EOS-E requires using an OTS to provide mission orbit circularization. The software characteristics to achieve these maneuvers are deemed adequate for the Shuttle related OTS maneuvers. The only viable approach to EOS-F is to employ a Tug to achieve the necessary mission orbit (i.e., equatorial geosynchronous). Because the initial launch will be achieved by a Titan III C 7 - a vehicle which will insert the EOS directly into mission orbit - the delivery entails an entirely passive EOS, identical to a Tug delivery. The EOS will also be passive for a Tug retrieval. Consequently, no significant software changes are anticipated for OTS operations.

Although the baseline EOS includes appropriate provisions for checkout and initialization upon insertion into mission orbit, in combination with ground-based mission operations, no requirements exist for the C & W functions associated with manned operations or for operational verification following on-orbit module replacement. In addition, it is conceivable that because of the unique capabilities of the Shuttle for standing by during initial on-orbit checkout and actually participating in payload command, control, and checkout, it may be advantageous to modify the EOS software to exploit these capabilities. Accordingly, the only requirements imposed against software for Shuttle compatibility (Table 3-10) relate to these considerations.

3.3 INSTRUMENT/MISSION PECULIAR EQUIPMENT

In this area of the study, analysis was limited to EOS-A, -B, and -C because of the relatively good definition of associated equipment. Based on current understanding of the follow-on missions (EOS-D, -E, and -F), it appears that the same Shuttle compatability requirements will be applicable and that no major unique requirements will arise.

The Instruments and Mission Peculiar Equipment contain no elements which affect safety-of-flight or the ability of the Observatory to survive until retrieval or resupply. The significance of Shuttle compatibility, then, is directed solely at the operation and survivability of the Instrument/Mission Peculiar Equipment itself.

The requirements for Shuttle compatibility are listed in Table 3-11. Of these, all but Requirements 2 and 7 are common to the Basic Spacecraft requirements contained in Subsection 3.2, and the discussion contained therein is equally applicable.

Table 3-10 On-Board Software Incremental Requirements

FUNCTIONAL ELEMENT: BASIC SPACECRAFT

DISCIPLINE	EOS MISSION						SHUTTLE MODE			REMARKS
	A	B	C	D	E	F	DELIVER	RETRIEVE	RESUPPLY	
ON-BOARD SOFTWARE	X	X	X	X	X	X	1. Provide for sensing, processing and transmission of Caution & Warning signals			Required C&W parameters are as defined in the Caution and Warning list, Table 3-2
							2. Provide for pre-separation EOS checkout and initialization.			
									3. Provide for verification of replacement module opn and integrated spacecraft opn.	

T6-15

Table 3-11 Instrument/Mission Peculiar Equipment Incremental Requirements

FUNCTIONAL ELEMENT: INSTRUMENT/MISSION PECULIAR EQUIPMENT

DISCIPLINE	EOS MISSION						SHUTTLE MODE			REMARKS
	A	B	C	D	E	F	DELIVER	RETRIEVE	RESUPPLY	
INSTR/MISSION PECULIAR EQUIPMENT	X	X	X				1. Provide for the Shuttle induced ascent, descent, and landing environments defined in subsection 3.7.			
							2. Provide for protection of instrument radiator and optical surfaces from Orbiter RCS plume impingement.			Orbiter RCS plume envelope is depicted in Fig. 3-1.
								3. Provide for equipment on-orbit survival for a period of 3 years in addition to the nominal 2 year design life.		Accommodate on-orbit wait until Shuttle retrieval or resupply mission can be effected.
								4. Provide for the retraction and securing of deployable appendages, including aperture doors.		
									5. Provide for remote attachment and release of individual modules/assemblies from supporting structure in a manner compatible with MEMS resupply concept.	The applicable replaceable equipments for each mission are listed under Mission Peculiars in Table 3.7
									6. Provide for remote disconnection and restoration of signal/power circuits among replaceable modules/assemblies.	
									7. Provide for acceptable geometric alignment of equipment following module/assembly replacement.	Specific alignment accuracies are TBD.

Of particular concern to the instruments is the potential for condensate and particulate contamination of critical surfaces from Orbiter RCS thruster exhaust plumes. As shown in Fig. 3-1, the spacecraft will be particularly susceptible to plume impingement while erected on the FSS Positioning Platform, and during the initial phases of deployment and the terminal phases of retrieval. Current instrument designs show that the radiator and optical apertures of the TM and HRPI are provided with movable doors. The MSS radiator is also equipped with a movable cover, but its optical aperture is not. There appears to be sufficient area sensitive to contamination to warrant the inclusion of Requirement 2 to achieve Shuttle compatibility.

Equipment installations are normally aligned and calibrated prior to launch. The removal and replacement of equipment during on-orbit resupply can alter the relative alignment of equipment and spacecraft, thereby affecting Observatory mission accuracies. Hence, Requirement 7 has been imposed to ensure that mission effectiveness is not compromised as a result of mechanical tolerances of replacement mechanisms and manufacturing deviations among modules.

3.4 FLIGHT SUPPORT SYSTEM

This section addresses the requirements imposed upon the Shuttle by the presence of the EOS. For purposes of this study, the Flight Support System (FSS) has been assumed to include all supporting functions required by the EOS while operating in conjunction with the Shuttle. This approach is consistent with the FSS definition provided in Reference 2 which has been used as the point-of-reference for the ensuing analysis. Figure 3-2 depicts the FSS hardware elements considered. The order of presentation for the analysis is:

- Payload Retention and Positioning
- Payload Deployment and Retrieval
- Payload Resupply
- Ancillary Orbiter Support

In light of previous and on-going FSS design efforts, the requirements defined in this section have been limited to those reflecting a necessary deviation from the baseline design to accommodate the unique characteristics of the Grumman design approach for EOS. Where appropriate, alternate approaches have been suggested which may lead to simpler, lighter, and/or less costly solutions to the total FSS function. The FSS baseline, as currently defined, is a full capability system, having been designed to accommodate EOS deployment, retrieval, and resupply functions. Neither the Deliver nor Retrieve

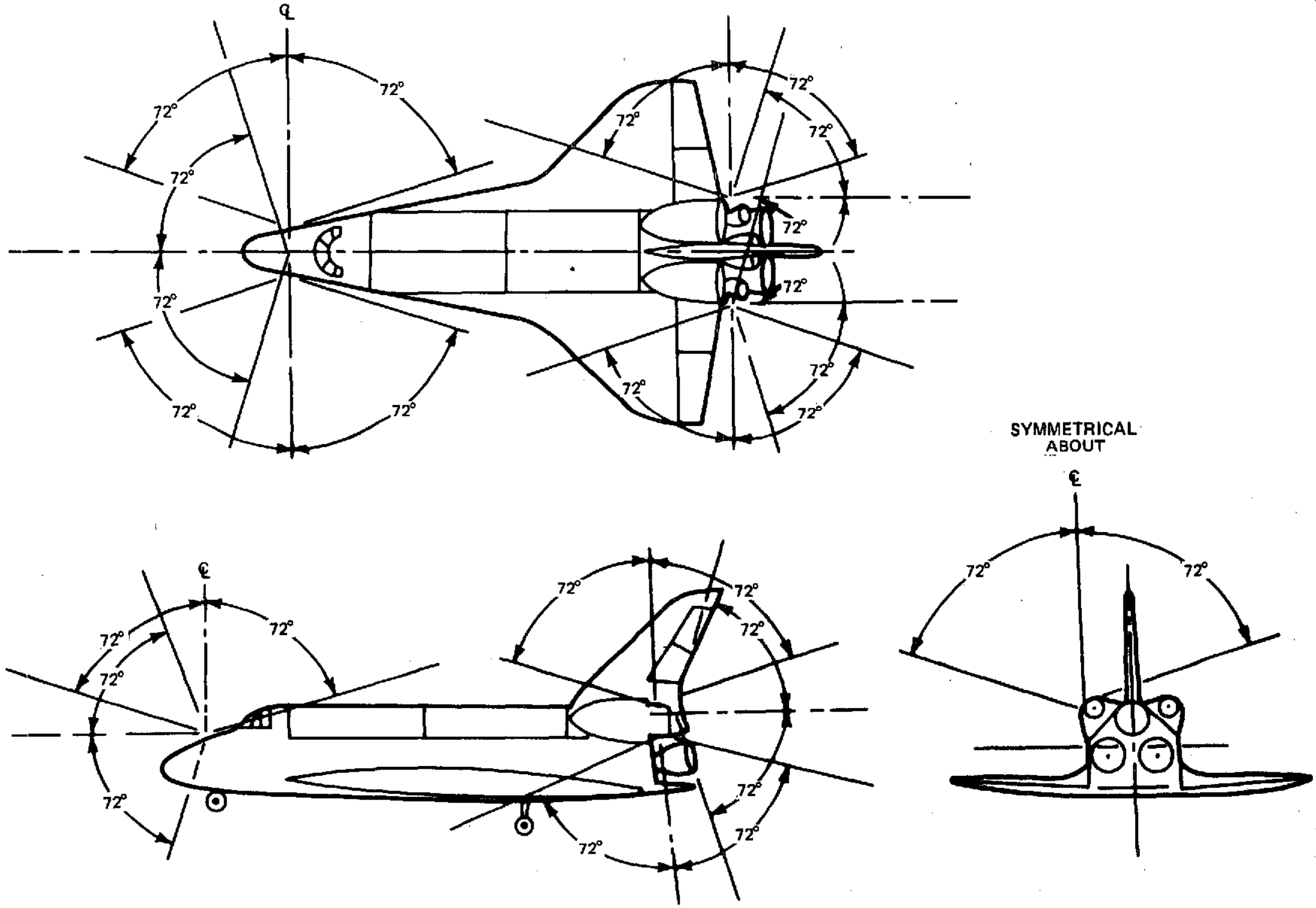


Fig. 3-1 Orbiter RCS 95% Gas Phase Plume Envelope

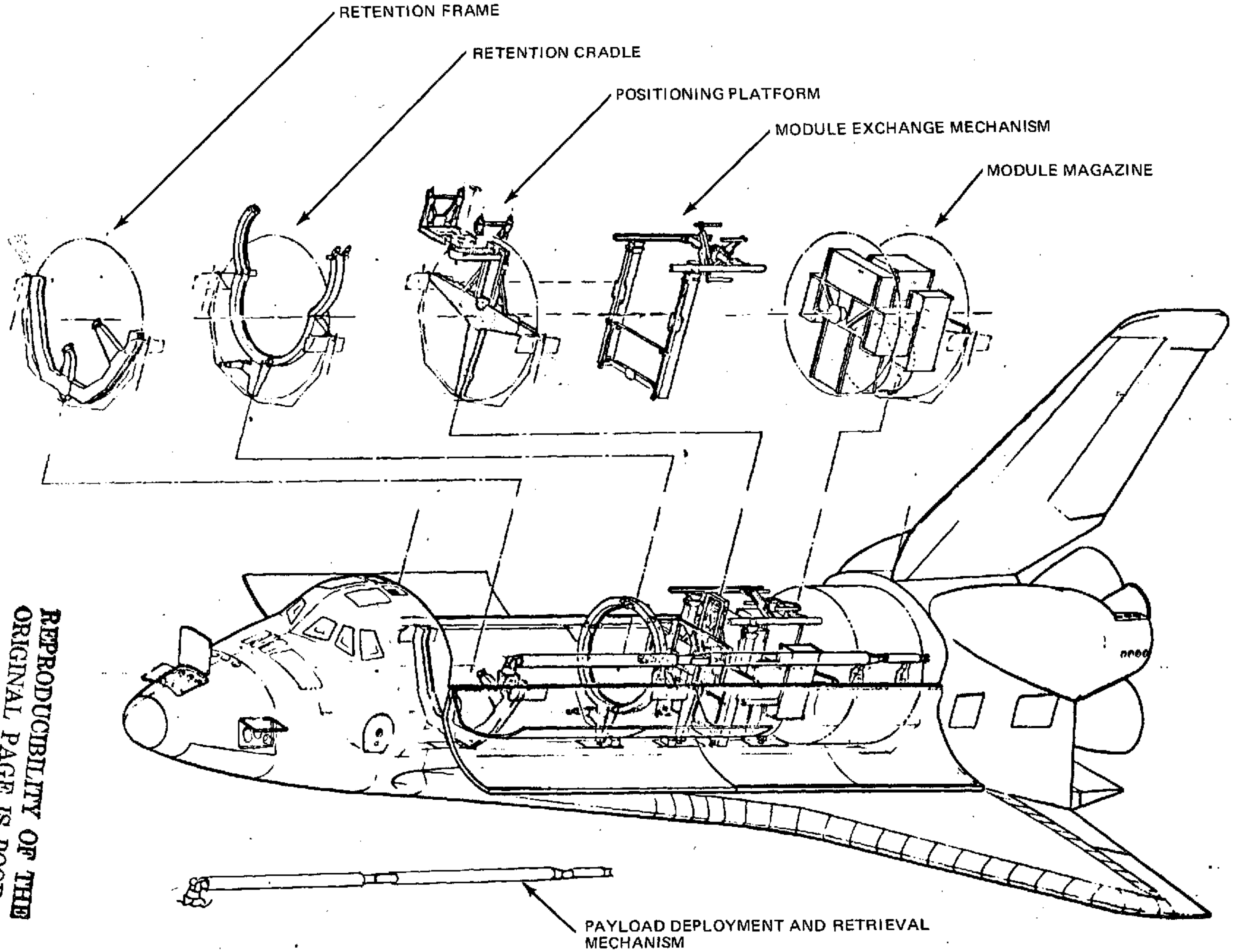


Fig. 3-2 Flight Support System Hardware Pictorial

Shuttle utilization modes require full capability. Accordingly, in this section only, requirements have been included for the deletion as well as for the addition and/or modification of capabilities.

3.4.1 PAYLOAD RETENTION AND POSITIONING

The baseline FSS Payload Retention and Positioning System (PRPS) is comprised of the Retention Cradle and Positioning Platform for all projected Shuttle utilization models. In the Resupply mode, when large assemblies such as the solar array or SAR antenna are to be exchanged, the PRPS complement includes the Retention Frame. Each of these assemblies are depicted in Fig. 3-2.

The deviations from the baseline FSS configuration resulting from the Grumman EOS design approach are reflected in Table 3-12. Since the EOS is intended to be a general purpose vehicle, the range of spacecraft weight and geometry is likely to be significant. Accordingly, as stated in Requirement 1, the PRPS should provide the inherent flexibility to accommodate the full range of mission candidates. From an EOS standpoint, the predominant variations among mission concepts occur forward of the upper bulkhead, in the Instrument/Mission Peculiar Equipment complements. Here, the lengths vary from 12 ft for EOS-A to 34 ft for EOS-C. Based on the present FSS concept, however, this variation does not present any problems. The critical dimension - the length of the basic spacecraft - which establishes the spacing between the Retention Cradle and the Positioning Platform, is constant at approximately five feet for all missions. Slight variations in depth of the Propulsion (OAS/RCS/OTS) module resulting from integration of SRM's for EOS-E can be accommodated by the stand-off design of the Positioning Platform. It has been assumed that EOS-F, which requires a Tug for mission achievement, will be accommodated as a Tug payload and will not utilize the FSS at all.

In Table 3-12, Requirement 3 has been identified to guarantee that the EOS does not interfere with safe Orbiter entry and landing. It seems apparent that this requirement will be mandated for all Orbiter payloads, and appropriate provisions will be incorporated into any physical connections. To date, however, no such requirement or equivalent has been factored into Orbiter or FSS designs. It is included in the PRPS requirements here to highlight its criticality.

Only two deviations from the baseline FSS design are considered mandatory for compatibility with the Grumman EOS design. As reflected in Requirement 4, the EOS provides for discrete attachment points on the upper bulkhead. The FSS baseline Retention Cradle is designed to interface with a continuous circumferential transition ring, an

Table 3-12 Payload Retention and Positioning Incremental Requirements

FUNCTIONAL ELEMENT: FLIGHT SUPPORT SYSTEM

DISCIPLINE	EOS MISSION						SHUTTLE MODE			REMARKS
	A	B	C	D	E	F	DELIVER	RETRIEVE	RESUPPLY	
Payload retention and positioning	X	X	X	X	X		1. Provide EOS structural support throughout Shuttle ascent and descent for the range of EOS physical characteristics defined in Tables 5-1 and 5-2			a. Ascent and descent reqmt for all modes dictated by Shuttle abort considerations b. Investigate approaches to Deliver and Retrieve two S/C on same flt.
						X	2. Provide for structural support of EOS-F while it is attached to the Space Tug.			Reqmt is unique to EOS-F
	X	X	X	X	X		3. Provide for emergency release of all EOS-FSS physical connections			Current FSS baseline does not identify this or equivalent reqmt. Intent is to ensure that no mechanical hang-up will prevent Orbiter entry and landing.
							4. Accommodate EOS structural interface with Orbiter via discrete attach points on EOS fwd bulkhead.			Current FSS baseline is configured to pick up EOS via a continuous, circumferential transition ring at the EOS fwd bulkhead
							5. Revise positioning platform to interface with EOS via three docking mechanisms			a. Current FSS baseline is configured for a 4-point pickup. b. For Deliver and Retrieve modes, investigate alternate approaches, including positioning with Orbiter manipulator instead of positioning platform.
							6. Delete spacecraft indexing provisions from positioning platform.		6. Not applicable	Spacecraft indexing is required only for Resupply.

T6-17

early EOS design approach. In addition, the baseline Positioning Platform design entails a four-point docking interface with the EOS lower bulkhead. The basic EOS structure has a triangular cross-section, necessitating a three-point interface. This is reflected in Requirement 5.

The most significant effects on FSS design arise from the opportunity for simplification for the Deliver and Retrieve modes (i.e., if resupply operations are not included). As indicated by Requirement 6, the indexing feature of the Positioning Platform is not required for either Deliver or Retrieve modes, offering potential simplification of platform design by its deletion for FSS systems dedicated to these modes. Indexing cannot be deleted for Resupply with the current resupply system concept. An even more significant simplification may be realized by considering totally different FSS approaches for Deliver and Retrieve. For example, there appears to be no major obstacle to using the Orbiter manipulator to remove the EOS directly from the Retention Cradle to effect deployment. Such an approach would reduce EOS-related Orbiter payload weight ($\approx$1400 lb) and payload length ($\approx$5 ft), thereby enhancing the possibility of shared flights with attendant reduction in individual user transportation costs. This approach appears equally viable for EOS retrieval.

At present, deployment of two EOS vehicles on a single Shuttle flight would require two sets of cradles and Positioning Platforms with associated weight and cost penalties. Mission Suitability analyses (Section 5) indicates that two EOS-A or EOS-B can be physically accommodated within the Orbiter payload bay, and that, with the incorporation of OTS, performance is adequate to meet mission requirements. It is recommended that future FSS design activities consider the two-spacecraft condition, since any approach which reduces payload chargeable weight and volume encourages multiple user Shuttle flights, with resultant reduction in individual user costs.

3.4.2 PAYLOAD DEPLOYMENT AND RETRIEVAL

The Orbiter-mounted Payload Deployment and Retrieval Mechanism (PDRM), also called Remote Manipulator System (RMS), provides the capability for deploying and retrieving Shuttle payloads in general and is not unique to EOS. In the baseline FSS deploy concept, the PDRM removes the EOS from the Positioning Platform and positions it for release. For retrieval and resupply, the PDRM captures the free-flying EOS and returns it to the Positioning Platform, engaging the probe and drogue docking mechanisms constituting the EOS-Positioning Platform interface. The EOS design, with the addition of a manipulator attach fitting aligned with the vehicle longitudinal center of gravity location (see subsection 3.2.4), is completely compatible with the current PDRM design concept. Consequently, there are no EOS-unique requirements applicable to the PDRM.

The most significant implication of EOS-Shuttle compatibility relative to the PDRM concept is the potential for eliminating the Positioning Platform entirely for deliver or retrieve. This would necessitate using the PDRM to remove the EOS from the Retention Cradle (or equivalent mounting provisions), positioning the spacecraft clear of the Orbiter mold line for extention of appendages and initial checkout, and final release. For retrieval, the sequence is reversed. Based on the planned utilization of the PDRM throughout the Shuttle program, there appears to be no major constraint to this concept. It is recommended, however, that the capability be verified for the projected range of EOS weights (Table 5-1) and geometries.

3.4.3 PAYLOAD RESUPPLY

In the current FSS baseline definition, payload resupply is accomplished via the Special Purpose Manipulator System (SPMS) which is comprised of the Module Exchange Mechanism (MEM) and Module Magazine (MM), installed in the Orbiter payload bay as shown in Fig. 3-1. The Retention Frame, included in the PRPS complement (subsection 3.4.1), provides the stowage for large assemblies beyond the capability of the MM. The resupply provisions, of course, apply only to the resupply mode.

As shown in Table 3-13, only four requirements have been identified to achieve EOS SPMS compatibility. The resupply of EOS-F, if required, is currently envisioned to be performed by a Tug-mounted resupply system, as yet undefined. Accordingly, none of the cited requirements are considered applicable to EOS-F.

Requirement 1 reflects a difference in the module latching concept between the current MEM baseline and Grumman design. The Grumman approach entails a single operator for all latch mechanisms, plus two holding fixtures on each module. This concept offers less complex mechanization of the spacecraft modules and, with the single operator and lower latching forces, also offers the potential for simplifying the MEM terminal device. The mechanization of the Grumman latch concept is further discussed in subsection 4.1.4.

Based on current estimates listed in Table 3-7, the number of replaceable modules on any given spacecraft ranges from a low of 11 for EOS-A, -B, and -F, to a high of 17 for EOS-E. Since it is highly improbable that all modules will require replacement on

Table 3-13 Payload Resupply Incremental Requirements

FUNCTIONAL ELEMENT: FLIGHT SUPPORT SYSTEM

DISCIPLINE	EOS MISSION						SHUTTLE MODE			REMARKS
	A	B	C	D	E	F	DELIVER	RETRIEVE	RESUPPLY	
MODULE EXCHANGE	X	X	X	X	X				1. Revise the MEM terminal device to interface with a single latch operator plus two holding fixtures on each module.	Results in simpler and lighter S/C mechanization, and MEM terminal device.
MODULE STOWAGE	X	X	X	X	X				2. Provide for the retention of the complement of replaceable EOS modules contained in Table 3-7.	Retention provisions for large assemblies such as SAR antenna, solar arrays, and steerable antennas are included in the payload retention and positioning function (i.e., the retention frame).
									3. Provide for maintenance of critical component temperatures throughout the period of stowage	
									4. Provide for the monitoring and relay to the Orbiter of C&W signals listed in Table 3-3 from the Propulsion and solar array storage locations throughout the period of storage.	

T6-18

any given flight, we used the 95th percentile of the probability-weight distribution to determine that the Shuttle capability was not exceeded (see subsection 6.1.4). The 95th percentile complement includes a combination of standard subsystem modules, instrument packages, and no more than one large irregular assembly such as solar array or antenna. Pending further definition of EOS design, mission planning, and resupply techniques, it is suggested that Requirement 2 be interpreted tentatively as necessitating stowage provisions (i.e., the Module Magazine and Retention Frame) for the following EOS-C complement which would provide for about 95% of the resupply missions when resupply occurs at the completion of Mean Mission Duration (MMD).

- Standard subsystem module - 3 units
- 1 Propulsion module
- Instrument package - 3 units
- Large assemblies (e.g., solar array) - 1 unit

The individual spacecraft modules/assemblies are susceptible to the same constraints as the integrated spacecraft insofar as safety of flight and survival and concerned. During the period of time that modules are carried in module stowage, either before installation in or after removal from the spacecraft, provisions must be made to accommodate these functions. As reflected by Requirement 3, certain modules contain temperature sensitive equipment and must be maintained within prescribed bounds. A similar requirement has been imposed for spacecraft survival (subsection 3.2.5), implying a common solution to the requirements.

The EOS design features which necessitate C & W monitoring/control of the integrated spacecraft are inherent in the individual modules. Accordingly, Requirement 4 imposes the need for appropriate accommodations in the stowage provisions. Based on current analysis, only the Propulsion module and the solar array contain elements potentially hazardous to the Orbiter.

3.4.4 ANCILLARY ORBITER SUPPORT

Review of the Orbiter Data Processing, Communications, and Electrical Power provisions allocated for payload support described in Reference 2 has indicated that no deviations are necessary to achieve EOS-Shuttle compatibility. As previously stated, requirements for static discharge and system grounding are common to all Shuttle payload, and solutions which would obviate the need for individual mechanizations on each payload are desirable.

3.5 PRE/POST FLIGHT OPERATIONS

3.5.1 INTRODUCTION

The efforts associated with pre/post flight operations are essentially a logistics and support function, of which the elements are:

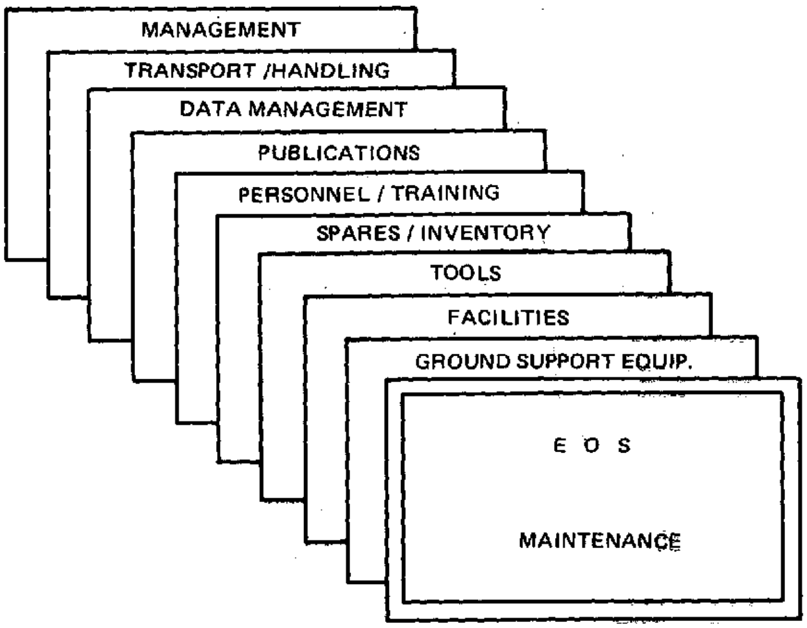
- Management
- Ground Support Equipment
- Data Maintenance
- Publications
- Personnel/Training
- Spare/Inventory
- Tools
- Facilities
- Transportation

With the introduction of a Shuttle as the launch vehicle for the EOS, little cost impact would be imposed upon the GSE and logistics area of the program, given the Shuttle as the initial launch vehicle requirement, without retrieval or resupply. However, for this study, it has been assumed that the GSE and logistics elements are initially designed for Mission B, with a Delta 3910 launch vehicle, and the investigation has been to determine the impact of transitioning to Shuttle launch, retrieve, and resupply.

For delivery only, the GSE and logistics elements requiring modification to support a Shuttle launch in lieu of a Delta, are few. However, when the Shuttle is utilized as a vehicle which not only delivers an EOS, but returns at a later date to retrieve or resupply it, the entire mission concept changes. Mission operations continue for indefinite periods, dependent upon planned retrieval/resupply or unscheduled maintenance requirements. Long term ground maintenance and EOS refurbishment are introduced as new elements requiring an investment in facilities, equipment and manpower in a total on-going logistics and support program.

3.5.2 LONG TERM LOGISTICS AND SUPPORT

Figure 3-3 depicts the elements of long term logistics support. The costs for these elements are assumed under the total operations cost. Skill retention costs (presently not estimated), particularly in the area of S/C maintenance, refurbishment and spares upkeep, will require further study and tradeoffs in the future. Detailed plans for the execution of skill retention will be essential to an orderly long term program operation. Costly delays (Shuttle flight delay) can result from inadequate planning and execution.



6-14 **Fig. 3-3 EOS Maintenance Elements**

3.5.3 FUNCTIONAL FLOW DIAGRAMS

First cut, top level, retrieval and resupply functional flow diagrams were developed, Fig. 3-4 and 3-5, to provide a baseline of Shuttle/EOS activity for use in the development of the logistics and support requirements and impact assessment. A short description of the function performed in each element of the functional flow follows:

A. Retrieve (Fig. 3-4)

1. Determine Retrieval Requirement - Scheduled/Unscheduled

   This function is performed by program management and mission operations personnel. Program management determines the scheduled effort based on predetermined mission scenarios, while mission operations, from the control center, determine the unscheduled effort based on the analysis of the condition of the orbiting EOS.

2. Remove Replacement EOS From Inventory

The retrieval mission may require the replacement of the EOS currently in orbit. For such a mission, an EOS is removed from storage. Inventory control participation will be required for this activity as well as for resolution and implementation of the question of how often, if at all, the EOS in storage should be powered-up and tested.

3. Transport to Maintenance Facility

The EOS is moved to the payload maintenance area for checkout and maintenance functions.

4 & 5. Perform EOS Pre-Launch C/O & Maintenance Actions

A pre-launch C/O and integration effort is performed. Items that are found discrepant will be replaced at the module level. The replaced items will then enter the maintenance loop to be recycled to either storage or installation in another EOS, independent of the continuing EOS checkout activity.

6. Move to Orbiter Loading Area

The entire EOS is now moved to the Orbiter payload loading facility. Payloads are installed in the Orbiter prior to moving to the launch pad. This operation differs from a Delta launch, where the EOS would be installed on the launch vehicle at the pad.

7. Install EOS into Flight Support System (FSS)

NASA is providing the FSS for all Shuttle payloads. The EOS is now installed and secured into the FSS.

While in the Orbiter, EOS uplink command and downlink communications required for launch checkout will be via the Orbiter communication link. No EOS checkout will be required after installation in the Orbiter until the Orbiter is mated to the booster, and then moved to the launch pad as a Shuttle.

8. Perform Launch Checkout

The Shuttle is moved to the launch pad. The EOS launch checkout procedure is identical to that performed during a Delta launch (except for the added Orbiter communication interface). For a Delta Launch, EOS radiates or is hardlined to a reradiating antenna which interfaces with the Test & Integration Station. In the Orbiter, the EOS provides unmodulated data to the Orbiter through a GSE connector and hardline to

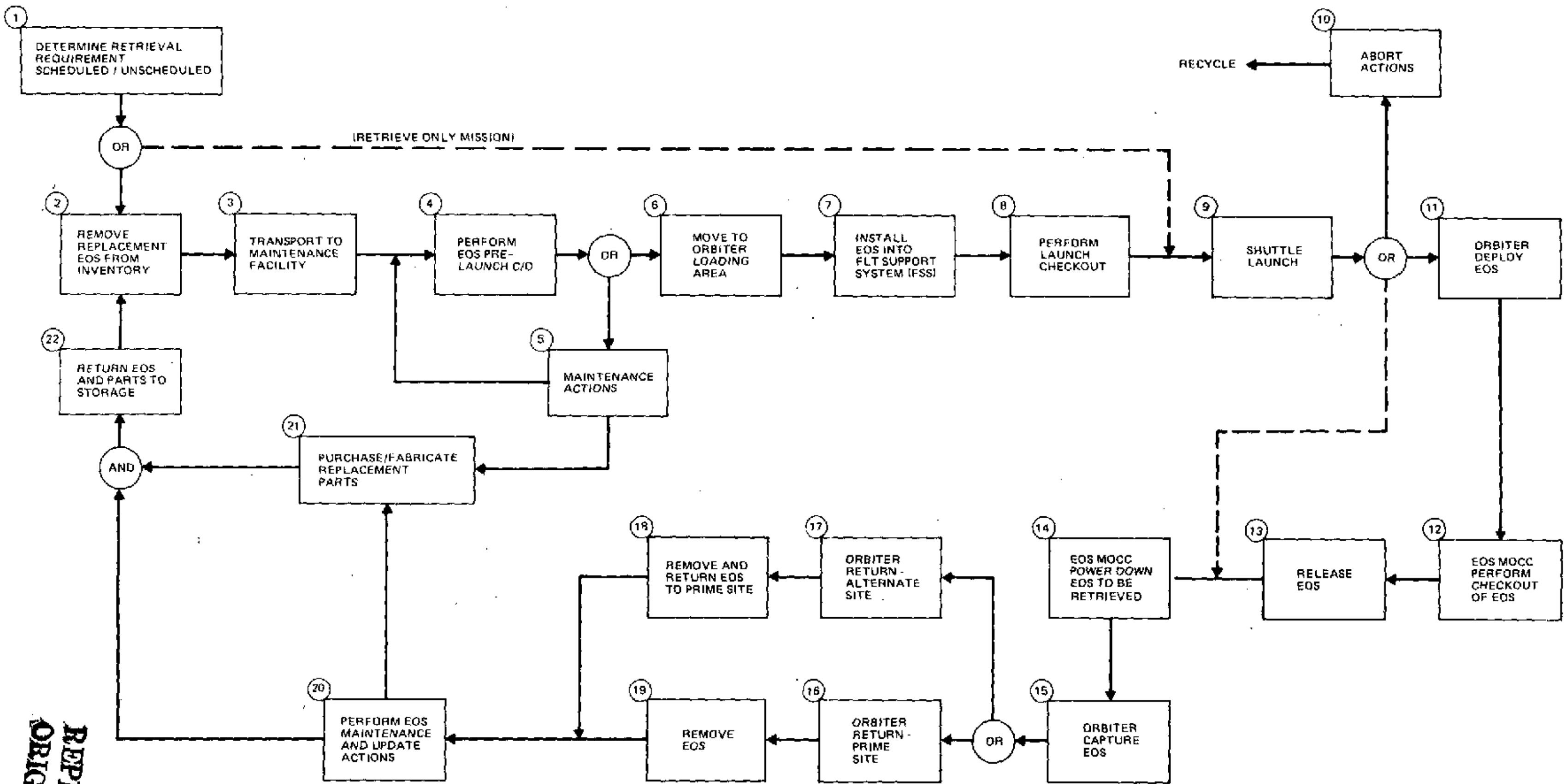


Fig. 3-4 Retrieve Mission – Logistics and Support Functional Flow

Orbiter communication. The GSE connector on the EOS is the same as that used for S/C buildup. Uplink commands are interfaced to the Orbiter uplink, and the Orbiter provides the baseband signals to the EOS.

9. Shuttle Launch

Shuttle launch checkout is performed with monitor only of EOS parameters.

10. Abort Actions

There are two identical abort possibilities: abort of the entire Shuttle, and abort of the Orbiter alone. In either case, the Orbiter returns to earth, either to the prime landing site or to a remote site, and pyro devices and propellants are removed. If at a remote site, the EOS will be removed and shipped back to the prime landing site for recycle into the next scheduled flight.

11. Orbiter Deploy EOS

The FSS positions the EOS external to the cargo bay in preparation for checkout prior to release.

12. EOS POCC Perform Checkout of EOS

With the EOS clear of the cargo bay but secured, communication to POCC is now possible through NASCOM. Checkout proceeds in the same manner as in a Delta launch, except the EOS can be returned if in a failed condition. Checkout can be performed using POCC up-data links as described in Subsection 4.1.7.

13. Release EOS

Orbiter releases the replacement EOS. For mission E, the kick stage places EOS into its higher orbit, then circularizes it and another checkout is now performed. The Orbiter proceeds to the EOS to be retrieved, if required.

14. EOS POCC Power Down EOS to be Retrieved

The EOS about to be retrieved is commanded to a safe condition prior to its capture. For Mission E, a kick stage has de-orbited the EOS to the lower "capture" orbit and circularized prior to initiation of the Shuttle launch.

15. Orbiter Capture EOS

Capture maneuvers are performed by the Orbiter. EOS POCC is not involved, except in a monitoring function.

16. Orbiter Return-Prime Site

The Orbiter returns to the prime landing site. All returns are considered safe returns. Orbiter then goes through a "safing" cycle prior to payload removal. EOS is then removed.

17. Orbiter Return - Alternate Site

Orbiter is unable to return to the prime site, but safely lands at an alternate site. The Orbiter and payload are transhipped to the prime site.

18. Remove and Return EOS to Prime Site

The EOS is removed from the Orbiter at the alternate site and shipped independently of the Orbiter to the Prime site.

19. Remove EOS

The EOS is removed from the Orbiter at the prime site.

20. Perform EOS Maintenance and Update Actions

The EOS goes through either: (1) a maintenance cycle to place it back into its original condition; or (2) is updated to a new mission (i.e., Instrument/Mission Peculiar Equipment) configuration. These actions are dependent upon the program scenario.

21. Purchase/Fabricate Replacement Parts

Replacement of discrepant parts will be by purchase or fabrication by a contractor. It is assumed that the EOS program will maintain the spare parts inventory but not provide a parts repair/fabrication capability.

22. Return EOS and Parts to Storage

The EOS is checked out and spare parts are returned to storage until required for the next mission or maintenance action.

B. Resupply (Fig. 3-5)

1. Determine Resupply Requirement - Scheduled/Unscheduled

Module replacement is determined by program management on a schedule based on the program scenario, or when informed of a spacecraft failure by the POCC.

2. Remove EOS Module From Inventory

Modules are selected from inventory. Inventory control and the problem of maintaining modules in a ready state are involved.

3. Transport to Maintenance Facility

The modules are moved to the module maintenance facility. This may or may not be the same facility where an entire EOS is maintained and checked out.

4. Verify Module Operation

The module is checked out to verify its operation. Tests will be performed to the same level as performed prior to final installation into an EOS.

5. Install in Special Purpose Manipulator System (SPMS)

The modules are installed into the SPMS and a test of the mechanism is performed. The modules may require delivery to a special loading area for installation into the SPMS.

6. Move SPMS to Orbiter Loading Area

The SPMS is moved, with EOS modules installed, to the Orbiter loading area and placed into the Orbiter.

7. Shuttle Launch

The Shuttle is moved to the launch pad. No launch checkout of the EOS modules are performed. Shuttle is launched after its checkout.

8. Abort Actions

Same as in A-10.

9. Orbiter Capture EOS

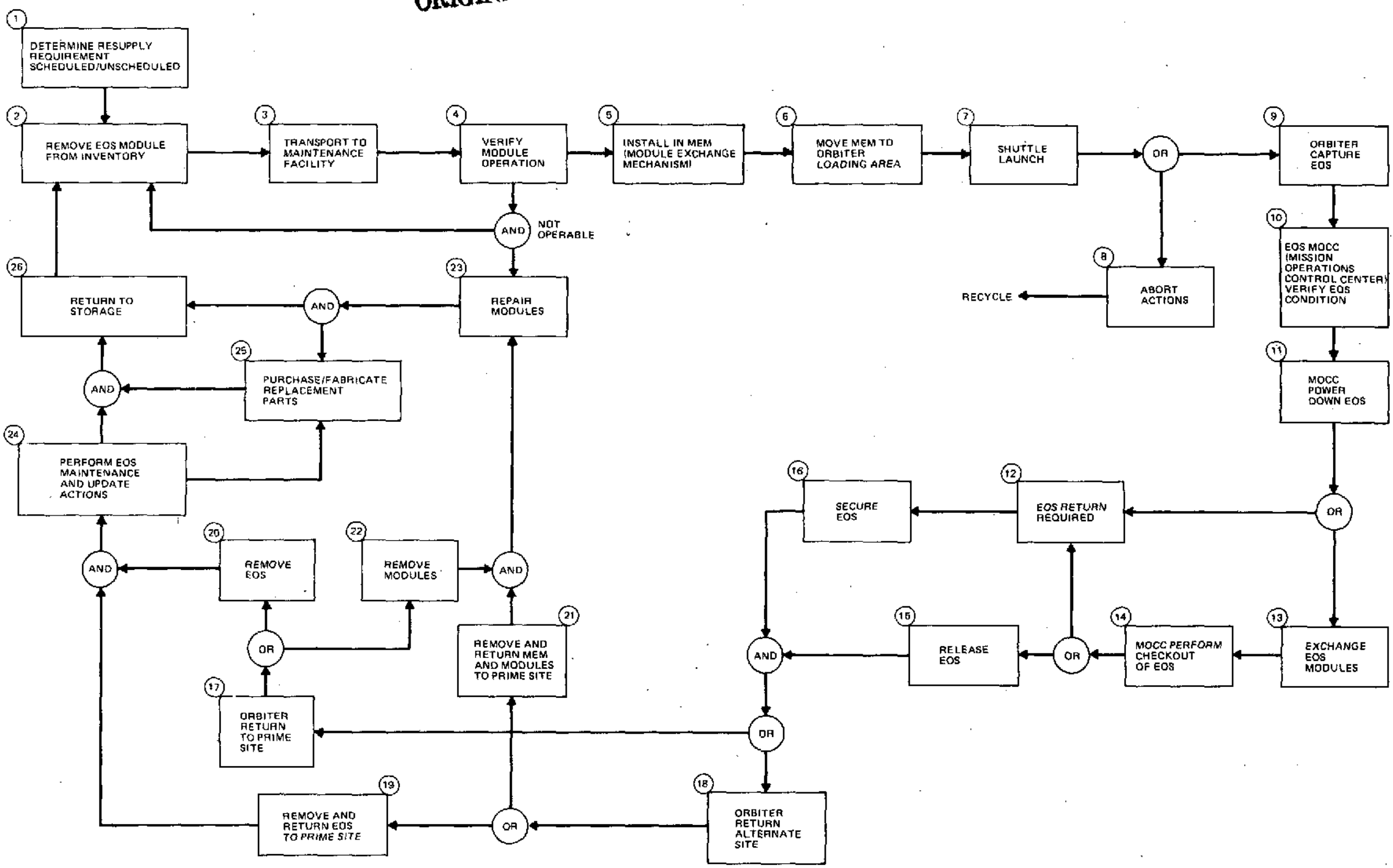
The Orbiter maneuvers to capture the EOS. If the EOS orbit exceeds the Orbiter's, then EOS POCC would first command the EOS kick stage to de-orbit to the Orbiter level.

10. EOS POCC Verify EOS Condition

The EOS, possibly in conjunction with Shuttle control, performs a checkout as described in A-12. It is possible that the checkout would detect a failure requiring an EOS return.

11. POCC Power Down EOS

The EOS is commanded to a power down condition to ready it for an exchange of modules, or a return to earth.



6-16

Fig. 3-5 Resupply Mission – Logistics and Support Functional Flow

12. EOS Return Required

Should the checkout of the EOS reveal a failure requiring its return, the Orbiter will prepare for the sequence of securing the SPMS and maneuver to secure the EOS.

13. Exchange EOS Modules

The SPMS, under Orbiter command, performs an exchange of modules.

14. POCC Perform Checkout of EOS

After module exchange is complete, the EOS is again checked out as described in A-12. It is possible that an EOS return to earth condition results from the checkout at this point. If so, the efforts in B-12 are now performed.

15. Release EOS

When checkout indicates a full up condition, the EOS is released by the Orbiter.

16. Secure EOS

If checkout indicates that the EOS is to be returned to earth, then the EOS is secured in the FSS.

17. Orbiter Return to Prime Site

Same as in A-16, except that modules are now the prime items returned.

18. Orbiter Return to Alternate Site

Same as in A-17.

19. Remove and Return EOS to Prime Site

If the mission required the return of the EOS, it would now be shipped to the prime site, as in A-18.

20. Remove EOS

For an Orbiter prime site landing, the EOS is now removed and taken to the maintenance facility.

21. Remove and Return SPMS and Modules to Prime Site

For a successful resupply mission in which the Orbiter returns to an alternate site, the removal of the SPMS and EOS modules at the alternate site is performed. These are then shipped back to prime site, as a single SPMS unit. The modules are then removed for the SPMS.

22. Remove Modules

The SPMS is first removed from the Orbiter and then the modules are removed from the SPMS.

23. Repair Modules

The returned modules are checked out and returned to operable condition.

24. Perform EOS Maintenance and Update Actions

Same as A-20.

25. Purchase/Fabricate Replacement Parts

Same as A-21.

26. Return to Storage

The repaired modules or EOS and all spares are returned to storage.

3.5.4 REQUIREMENTS

3.5.4.1 GSE

Table 3-14 lists all the GSE presently recognized as being required to support the EOS program from factory through launch on a Delta, and has been further identified as to location or test in which they are used. This table, in conjunction with a review of Fig. 3-4 and 3-5, resulted in the selection of Shuttle GSE required, as shown in Table 3-15.

- Deliver (Ref. Table 3-15)
  - All equipment listed in Table 3-14 under Pre-Launch Operations and Launch are required for a Shuttle launch
  - The major change in operation is the installation of the EOS into the Orbiter in the Payload/Orbiter Facility, instead of on a Titan at the launch pad. The Titan installation is with the EOS in a vertical position as it is lowered on to the Titan. For the Shuttle, the EOS is in a horizontal position as it is lowered into the Orbiter cargo bay
  - An interconnect cable is required to interface EOS communication to the Shuttle link while installed in the cargo bay.
- Retrieve (Ref. Fig. 3-4 and Table 3-15)

  The elements in the Retrieval Functional Flow (Fig. 3-4) that have no effect on GSE are:

Table 3-14 Ground Support Equipment Utilization

DEVELOPMENT & QUAL

Equipment	MODULE FAB & ASSEMBLY	MODULE MASS REP. & INSTALLATION	MODULE STRUCT. DEV & ACOUSTIC QUAL	MODULE THERMAL VACUUM DEV. TEST	S/C STRUCTURE FAB & ASSEMBLY	MODULE & INSTR MASS REP. INSTALL.	STRUCTURE LOADS ACCEL TEST	ACOUSTIC TEST (LRM CONFIG)	MECHANICAL VIBRATION & SHOCK	MODEL SURVEY	RECONFIG INSTR MASS REPS	MODEL SURVEY	MECHANICAL VIBRATION & SHOCK	ACOUSTIC TEST	SEPARATION & DEPLOYMENT QUAL TEST	MODULE WIRING / COMPONENT INTEGR	INST INTEGR & OBS FUNCT TEST	ACOUSTIC VIBRATION / PYRO SHOCK	THERMAL VACUUM, INCLUDING EMC	POST T/V SEP TESTS
ELECTRICAL																				
1. TEST & INTEGRATION STATION																●	●	●	●	●
2. BREAKOUT BOX SET																●	●	●	●	●
3. BATTERY CONDITIONER																				
4. TEST BATTERY SET																	●	●	●	●
5. S/C POWER SET & CABLES																	●	●	●	●
6. RANGING TEST ASSEMBLY																●				
7. PYRO TEST SET																		●		
8. INTERFACE CABLE SET																	●			
9. SOLAR SIMULATOR																	●			
10. INSTRUMENT INTERFACE SIMULATOR																	●			
11. UMBILICAL SIMULATOR																	●			
12. DITMICO PROGRAM & CABLE SET																●				
13. POWER MODULE C/O BENCH																●				
14. C & DH MODULE C/O BENCH																●				
15. ACS MODULE C/O BENCH																●				
16. PROPULSION C/O BENCH (RCS)																●				
17. DCS SIMULATOR																	●	●	●	●
18. S/C MONITOR & CONTROL																	●	●	●	●
19. IMP MODULE C/O BENCH																●	●			
MECHANICAL																				
1. INTERFACE ADAPTER SET							●	●	●	●	●	●	●	●	●			●	●	●
2. HOIST BAR & SLING SET	●	●			●	●	●	●	●	●	●	●	●	●	●		●			
3. SUPPORT DOLLY VERTICAL S/C					●	●				●		●			●		●			●
4. SUPPORT DOLLY - HORIZONTAL							●	●	●				●	●				●	●	
5. ACCESS WORK STAND - S/C					●	●											●			●
6. SKIN STORAGE RACK																				
7. WT & CG FIXTURE - S/C						●														
8. MASS SIMULATOR SET		●				●														
9. SUPPORT DOLLY - S/C MODULES			●	●												●				
10. SHIPPING CONTAINERS S/C MODULES																				
11. S/C COVER SET																				
12. HUMIDITY CONTROL KIT																				
13. SHIPPING CONTAINER - SOLAR ARRAY																				
14. SOLAR ARRAY INST & DEPLOY, FIX															●					
15. TRANSPORTERS																				
16. INDICATING ACCELEROMETER KIT																				
17. PYRO INST. TOOL KIT																	●			
18. STAGE MOTOR INST FIXTURE																				
19. EOS/SHUTTLE SIMULATOR ADAPTER															●					
20. TIE DOWN KIT SET																				
21. BATTERY SHIPPING CONTAINER																				
22. BATTERY INSTALLATION TOOL																				
FLUID																				
1. GN_2 CONDITIONING UNIT																	●	●	●	●
2. GN_2 REGULATION UNIT																	●	●	●	●
3. VOLUMETRIC LEAK DETECTOR																	●	●		●
4. RCS VACUUM TEST CART																	●	●		
5. FLUID DIST SYS, GRUMMAN																	●	●		
6. PRESSURE MAINTENANCE UNIT																				
7. GN_2 STORAGE SYS (TRANSPORTER)																				
8. GN_2 MANIFOLD & SUPPLY PLATFORM																				
9. FLUID DIST SYS, LAUNCH SITE																				
10. PROPELLANT TRANS ASSEMBLY																●			●	
11. MASS SPECTROMETER LEAK DETECTOR																	●			

FLIGHT S/C EGR

Equipment	MODULE FAB ASSY & WIRING	COMPONENT INSTALLATION & INTEGR	S/S FUNCTIONAL C/O	MODULE ENVIRONMENTAL ACCEPT. TEST	POST ENVIRONMENTAL TEST MODULE C/O	S/C STRUCTURAL FAB & ASSY	S/C WIRING & C/O	S/C MODULE INTEGR & FUNCT C/O	INSTR INTEG & C/O, IMP & OAS INTEGR	OBS SYS TEST & ENC	SEPARATION & DEPLOYMENT MECH C/O	OBS SPECIAL TEST	WORKMANSHIP ACOUSTIC, PACK & SHIP	PRELAUNCH OPERATIONS	LAUNCH
ELECTRICAL															
1. TEST & INTEGRATION STATION		●	●					●	●	●	●	●	●	●	●
2. BREAKOUT BOX SET		●	●	●				●	●	●		●		●	
3. BATTERY CONDITIONER										●				●	
4. TEST BATTERY SET								●	●	●	●			●	
5. S/C POWER SET & CABLES								●	●	●	●	●	●	●	
6. RANGING TEST ASSEMBLY		●													
7. PYRO TEST SET										●					
8. INTERFACE CABLE SET								●	●						
9. SOLAR SIMULATOR									●			●			
10. INSTRUMENT INTERFACE SIMULATOR								●	●						
11. UMBILICAL SIMULATOR										●				●	
12. DITMICO PROGRAM & CABLE SET							●								
13. POWER MODULE C/O BENCH		●	●	●	●										
14. C & DH MODULE C/O BENCH		●	●	●	●										
15. ACS MODULE C/O BENCH		●	●	●	●										
16. PROPULSION C/O BENCH (RCS)		●	●	●	●										
17. DCS SIMULATOR								●	●	●				●	
18. S/C MONITOR & CONTROL								●	●	●	●	●	●	●	
19. IMP MODULE C/O BENCH		●	●	●	●				●						
MECHANICAL															
1. INTERFACE ADAPTER SET										●	●		●	●	●
2. HOIST BAR & SLING SET				●				●		●	●		●	●	●
3. SUPPORT DOLLY VERTICAL S/C						●	●	●	●	●	●	●		●	
4. SUPPORT DOLLY - HORIZONTAL										●			●		
5. ACCESS WORK STAND - S/C						●	●	●	●	●		●			
6. SKIN STORAGE RACK						●	●	●	●						
7. WT & CG FIXTURE - S/C										●					
8. MASS SIMULATOR SET															
9. SUPPORT DOLLY - S/C MODULES	●	●	●	●	●			●							
10. SHIPPING CONTAINERS S/C MODULES													●		
11. S/C COVER SET													●		
12. HUMIDITY CONTROL KIT													●		
13. SHIPPING CONTAINER - SOLAR ARRAY													●		
14. SOLAR ARRAY INST & DEPLOY, FIX											●				
15. TRANSPORTERS													●		
16. INDICATING ACCELEROMETER KIT													●		
17. PYRO INST. TOOL KIT									●						
18. STAGE MOTOR INST FIXTURE								●							
19. EOS/SHUTTLE SIMULATOR ADAPTER											●				
20. TIE DOWN KIT SET													●		
21. BATTERY SHIPPING CONTAINER		●													
22. BATTERY INSTALLATION TOOL		●													
FLUID															
1. GN_2 CONDITIONING UNIT								●	●	●		●		●	●
2. GN_2 REGULATION UNIT								●	●	●		●		●	●
3. VOLUMETRIC LEAK DETECTOR								●	●	●					
4. RCS VACUUM TEST CART								●	●	●					
5. FLUID DIST SYS, GRUMMAN								●	●	●					
6. PRESSURE MAINTENANCE UNIT													●		
7. GN_2 STORAGE SYS (TRANSPORTER)													●		
8. GN_2 MANIFOLD & SUPPLY PLATFORM													●		
9. FLUID DIST SYS, LAUNCH SITE														●	●
10. PROPELLANT TRANS ASSEMBLY															●
11. MASS SPECTROMETER LEAK DETECTOR								●	●	●					

(1)T5-2
3-60
T6-56

Table 3-15 Ground Support Equipment Requirements FUNCTIONAL ELEMENT: PRE/POST FLIGHT OPERATIONS

DISCIPLINE	EOS MISSION						SHUTTLE MODE			REMARKS
	A	B	C	D	E	F	DELIVER	RETRIEVE	RESUPPLY	
GROUND SUPPORT EQUIPMENT	X	X	X	X	X	X	1. Test & Integration Station 2. Breakout Box Set 3. Battery Conditioner 4. Test Battery Set 5. SIC Power Set & Cables 6. DCS Simulator 7. SIC Monitor & Control 8. Interface Adapter Set 9. Hoist Bar & Sling Set 10. Support Dolly - Vertical 11. GN_2 Conditioning Unit 12. GN_2 Regulation Unit 13. Fluid Distribution System 14. Battery Inst. Tool 15. EOS-Shuttle Comm. Interface Cable 16. Shuttle Umbilical Simulator	18. Module Deployment Fixt. 19. IMP Module C/O Bench 20. Pyro Test Set 21. Interface Cable Set 22. Solar Simulator 23. Power Module C/O Bench 24. C&DH Module C/O Bench 25. ACS Module C/O Bench 26. Propulsion C/O Bench 27. Access Work Stand 28. Skin Storage Rack 29. Support Dolly S/C Modules 30. S/C Cover Set 31. Solar Array Inst. 32. Deployment Fixture 33. RCS Module Inst. Fixture volumetric leak detector 34. Mass Spectrometer Leak Detector 35. RCS Vacuum Test Cart		
					X		17. Stage Motor Installation Fixture			

T6-19

- #10 Abort Actions - from initial action to landing. After landing, handling equipment will be required as for any Orbiter landing with an EOS

- #11 Orbiter Deploy EOS

- #12 EOS POCC Perform C/O of EOS

- #13 Release EOS

- #14 EOS POCC Power Down EOS to be Retrieved

- #15 Orbiter Capture EOS

All other elements will require some form of GSE.

The preparation of EOS to flight and its maintenance after a return are similar actions to these performed during EOS factory build-up, integration, checkout and acceptance test. The GSE in Table 3-14 corresponding to these activities are therefore required in support of the Shuttle-compatible EOS, in addition to those already required for delivery. These are listed in the Retrieve column of Table 3-15.

- Resupply (Ref. Fig. 3-5 and Table 3-15)

No additional equipment is listed under Resupply in Table 3-15, as all the GSE required has been previously listed. The Resupply is mainly one of module exchange and maintenance. The module supporting equipment is already required in support of a Retrieve mission. In checking out an entire EOS, module failure would require the same corrective action as in maintenance and preparation of a module for resupply.

3.5.4.2 MANAGEMENT

Management of the entire Logistics and Support program is required on a long term basis for planning administration and control for both the retrieve and resupply programs.

3.5.4.3 TRANSPORTATION/HANDLING

- Transportation and Handling is required between the alternate landing site of the Orbiter and its prime site, for modules installed in the SPMS and the EOS.

- Inter-and intra-plant handling and transportation is required at ETR or WTR for parts, modules and EOS, essentially between the storage area, maintenance area and Orbiter payload loading facility. It is assumed that discrepant payloads are not removed at the Shuttle launch pad, but that the Orbiter is returned to the loading facility.

3.5.4.4 DATA MANAGEMENT

A system for maintenance, storage, and retrieval of EOS data to support a long term logistics and support program is required, including GSE data. Included should be maintenance actions, end item history, preventive maintenance and personnel scheduling, parts ordering and inventory.

3.5.4.5 PUBLICATIONS

Maintenance and repair publications for all EOS maintainable end items such as systems, subsystem (module) and submodule will be required.

3.5.4.6 PERSONNEL/TRAINING

Personnel will be required to maintain the EOS and its components as well as operate and maintain the GSE. Personnel will require training in the performance of this function as well as the training required for updating (new sensors and S/C technology) the EOS and GSE.

3.5.4.7 SPARES/INVENTORY

- Spares to the replaceable module level will be required for the retrieval mission
- Spares to the submodule (repair of modules) and lowest replaceable component level will be required for the resupply mission
- All spares, including a full up of EOS, must be maintained in a "ready" state, consistent with reaching flight status in a time-frame consistent with the Shuttle flight scheduling and preparation cycle. A schedule for removal from storage, power up and checkout, then return to storage, will be required.

3.5.4.8 TOOLS

It is assumed that all tools developed to assemble and integrate the EOS are sufficient to support retrieval and resupply. Maintenance of these tools is required.

3.5.4.9 FACILITIES

A facility for launch preparation and maintenance is required for the EOS, its modules, and repairable end items.

3.6 MISSION OPERATIONS

The overall Payload Operations Control Center (POCC) effort for the EOS is concerned only with maintaining the status and health of the spacecraft. The effort falls into three categories:

- Mission Planning - The coordination of all requests (user and engineering) for EOS operations, and the supervision of contact message development
- Mission Execution - All real-time monitoring and control functions necessary to preserve the health of the spacecraft and effect efficient operation
- Mission Analysis - Reviewing all historical aspects of the mission for failure/anomaly analysis, studies of normal spacecraft performance, and development of improved operating procedures.

Integration of the EOS with Space Shuttle operations does impose new requirements on POCC as shown in Table 3-16, but they are minimal because of the inherent flexibility of the baseline POCC approach established for EOS.

3.6.1 MISSION PLANNING

All mission planning activities will entail extensive interface and data exchange between the POCC effort and Shuttle, and in the case of EOS-F, Tug mission planning disciplines as reflected by Requirements 1 and 2. For Deliver, the EOS mission planning will be essentially identical to that of conventional launch vehicle operations, the principal difference lying in coordinating with a different delivery system agency center. Specific details in the initial flight sequence may vary, but the overall mission operational timeline will be unaffected. Inclusion of the Tug for EOS-F, of course, adds another factor to the planning and scheduling activity, but is not considered to represent any basic change to the anticipated POCC activities.

For Retrieve, however, additional planning is required to accommodate spacecraft reconfiguration and verification in support of Orbiter recovery and return. As a result of the ability to retrieve (e.g., retracting solar arrays), it is likely that the predeployment and deployment operations will be somewhat modified to all but eliminate post-deployment "infant mortality". In other words, initial on-orbit checkout will be structured to be fully accomplished within the 6-day Orbiter on-orbit stay time, so that if the EOS does not function properly, it can be retrieved and returned to earth on the same Shuttle flight.

Resupply entails the same considerations as Retrieve, with the addition of operationally planning the resupply activity itself. Associated with this are the configuring of the spacecraft for module replacement and verifying the operational status of the refurbished vehicle.

3.6.2 MISSION EXECUTION

The requirement for real-time mission operations, simply stated, is the execution of the mission planning deviations identified above. For Shuttle compatibility, this neces-

Table 3-16 Mission Operations Incremental Requirements

FUNCTIONAL ELEMENT: MISSION OPERATIONS

DISCIPLINE	EOS MISSION						SHUTTLE MODE			REMARKS
	A	B	C	D	E	F	DELIVER	RETRIEVE	RESUPPLY	
• MISSION PLANNING	X	X	X	X	X			1. Provide for integrated EOS-Shuttle mission scheduling and planning.		Deliver entails essentially the same operations for either conventional, Shuttle, or Shuttle Tug launches.
						X		2. Provide for integrated EOS-Shuttle-Tug mission scheduling and planning.		
• MISSION EXECUTION	X	X	X	X	X			3. Provide for voice/data links between NASA/GSFC and NASA/JSC.		Links are available, but must be dedicated by NASA/GSFC NASCOM.
						X		4. Provide for voice/data links among NASA/GSFC, NASA/JSC, and the Tug OCC.		

T6-20

sitates providing real-time support and monitoring of the EOS as a joint effort with the Shuttle team at NASA/JSC and, for EOS-F, with the Tug team at, presumably, NASA/MSFC. To achieve this, adequate voice/data links are required among the participating operations control centers. Based on experience with the OAO center and the flexible nature of the planned POCC, integrated activities with other OCC's appear totally within the capability of the OCC operation for the conventionally launched EOS. Consequently, as reflected by Requirements 3 and 4, the only significant incremental requirement is the establishment of the necessary communications links among centers.

3.6.3 MISSION ANALYSIS

There are no significant mission analysis requirements resulting from introduction of Shuttle utilization in any mode. The specification of activities in this area (subsection 3.7.3.1.3.3 of the Ground Segment Specification) is very generic in nature and is equally applicable to Shuttle-oriented EOS operations. Consequently, although individual details of the analysis may vary, no major requirement can be identified at this time.

3.7 ENVIRONMENT

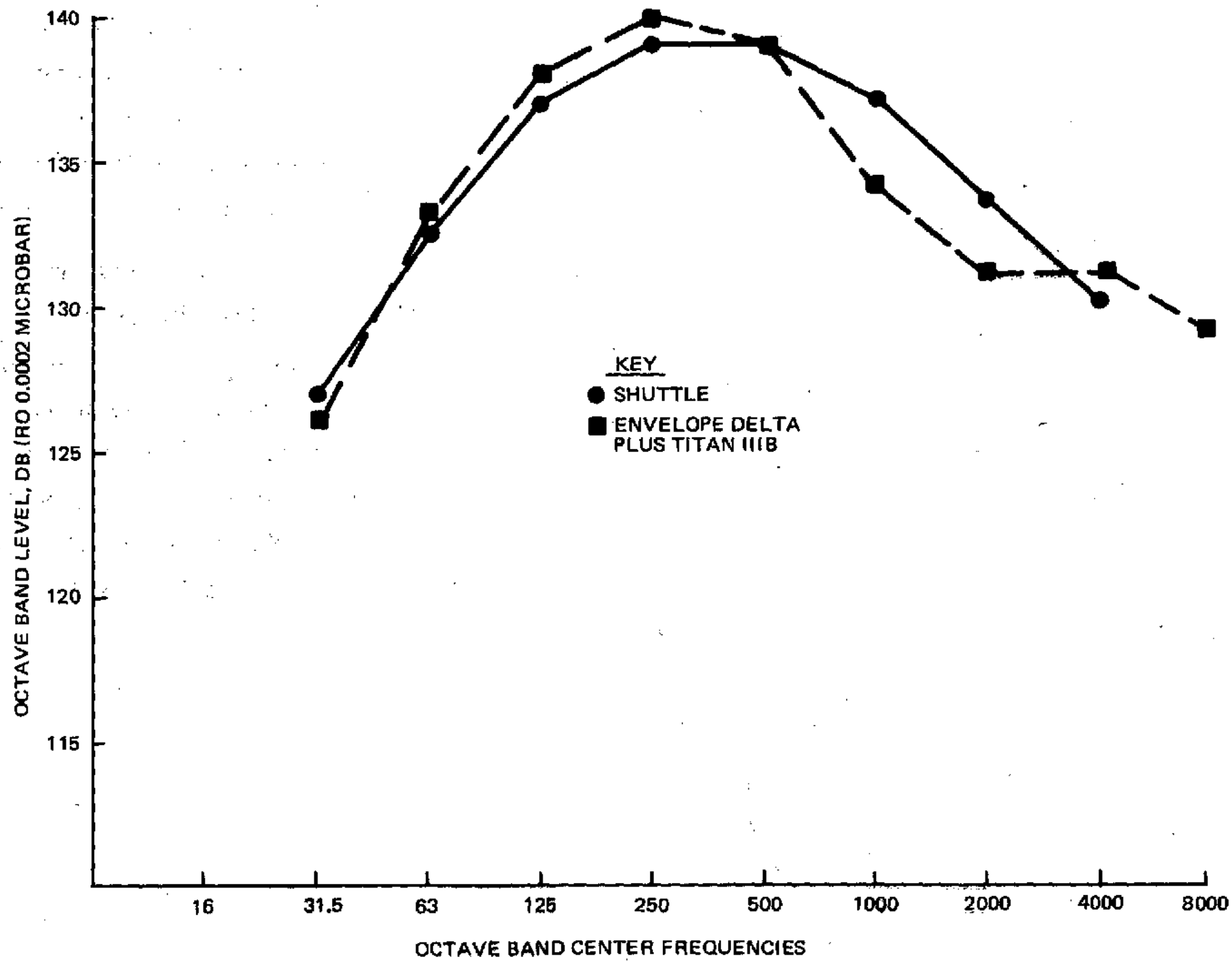
The environment induced by the Shuttle differs from that induced by the conventional launch vehicles assigned for initial EOS delivery. Four aspects of the environment (acoustics, loads, thermal, and contamination) were considered in this study and are addressed in the following paragraphs.

3.7.1 ACOUSTICS

A comparison of the Shuttle and the Delta plus Titan IIIB acoustic spectra (octave band sound pressure levels) is shown in Fig. 3-6. The comparison indicates that the conventional launch vehicle spectra are more severe or within ± 1 dB of the Shuttle environment, except at the 1000 Hz and 2000 Hz octave band center frequencies, where the Shuttle exceeds the Delta-Titan envelope by +3 dB. Although a +3 dB increase in sound pressure level is significant, the resonant frequency responses of structure, panels, and components historically occur at frequencies below 1000 Hz.

3.7.2 LOADS

The launch vehicle structural design load conditions for the EOS basic spacecraft are shown in Table 3-17 for Delta-Titan vehicles. These load factors have been used to obtain member loads and EOS/launch vehicle interface loads, as well as to design the Instrument support structure and its interface with the basic spacecraft. Of primary significance in



6-51

Fig. 3-6 Maximum Expected Flight Acoustic Levels (Internal)

Table 3-17 Limit Load Factors Delta 2910 and 3910 Launch Vehicles

CONDITION	X	Y OR Z
LIFT-OFF	+ 2.9 - 1.0	2.0
MAIN ENGINE CUT-OFF	+12.3	0.65

- THE LOAD FACTORS CARRY THE SIGN OF THE EXTERNALLY APPLIED LOAD
- CONDITIONS INCLUDE DYNAMIC TRANSIENT EFFECTS

T6-21

sizing theEOS structure for the Delta launch vehicle, however, are the stiffness requirements for the longitudinal and lateral directions. The minimum fundamental frequency requirements for the EOS restrained at the EOS/Delta interface shall be greater than 35 Hz in the longitudinal direction, and 15 Hz in the lateral direction. Basic spacecraft structural members are sized primarily by the stiffness needed to meet these frequency requirements.

Table 3-18 depicts the design load factors for the critical conditions in the Orbiter payload bay for both ascent and descent.The load factors in the longitudinal direction are significantly lower than those experienced on the conventional launch vehicle. The lateral load factors, however, are significantly higher for the Orbiter environment in the descent, landing, and crash conditions. The Payload Accommodations Document, Reference 4, does not specifically define a frequency limit for stiffness requirements. Induced environments are given, necessitating calculation of EOS responses considering FSS structural stiffnesses and mass distributions which is not possible at the current level of FSS and EOS design definition.

Table 3-18 Shuttle Payload Bay Limit Load Factors (65 K lb Up, 32 K lb Down)

CONDITION	LINEAR LIMIT LOAD FACTOR		
	X	Y	Z
LIFT-OFF	+0.1 +2.9	+1.0 -1.0	-1.5 +1.5
HIGH-Q BOOST	+1.6 +2.0	+0.5 -0.5	-0.6 +0.6
BOOST – MAX LOAD FACTOR (STACK)	+2.7 +3.3	+0.2 -0.2	+0.3 +0.3
BOOST – MAX LOAD FACTOR (ORBITER ALONE)	+2.7 +3.3	+0.2 -0.2	+0.75 +0.75
ENTRY AND DESCENT PITCH-UP	-1.06 +0.02	0 0	-2.5 +1.0
ENTRY AND DESCENT YAW	-0.75 -0.75	+1.25 -1.25	-1.0 -1.0
LANDING	-1.0 +0.8	+0.5 -0.5	-2.8 -2.2
CRASH	-9.0 +1.5	+1.5 -1.5	-4.5 +2.0

T6-22

3.7.3 THERMAL

Successful EOS thermal design requires precise control of instrument and spacecraft equipment during on-orbit mission phases. Shuttle utilization imposes additional requirement in that non-operating temperature limits must be maintained during retrieval, resupply, and entry phases in the Orbiter and during survival modes on-orbit. The thermal environment associated with some of these Shuttle-related mission phases is more severe than the worst case environment for a conventional launch vehicle.

Equipment and instrument temperatures depend on the heat balance between the vehicle and module external surfaces, and the thermal environment. EOS utilization of Shuttle for delivery, retrieval, and resupply results in two distinct sets of thermal environments, depending on the position of the Shuttle payload bay doors:

(1) Payload Bay Doors Open - the EOS thermal environment can include heat from:

- Radiation emitted by the sun
- Radiation emitted by the earth
- Solar radiation reflected by the earth
- Sign convention follows that of the EOS coordinate system. The load factors carry the sign of the externally applied loads
- Crash accelerations are ultimate. The longitudinal accelerations are directed in all aftward azimuths within a cone of 20 degrees half-angle
  - Specified accelerations shall operate separately
  - Crash landing loads shall be carried through the payload attachment fittings and attachment fasteners
  - Support structure shall be designed to withstand the fastener loads locally
- Ascent and landing conditions include dynamic transient effects, but do not include the dynamic response of the payload.

  In addition, the Shuttle exterior surfaces are sources of radiant heat emission and can reflect heat from the external sources.

(2) Payload Bay Doors Closed - the EOS thermal environment consists of the payload bay wall temperatures and entrapped air temperature during ground, ascent, and descent mission phases.

Knowledge of the extremes of environment heat flux for the entire combined EOS-Shuttle mission profile, therefore, is of primary importance in EOS thermal control system design. Table 3-19 shows the mission phases, associated time durations, and payload bay door positions for a typical Shuttle mission. As shown, various combinations of phases apply to the candidate modes of Shuttle utilization. Variations in mission phase duration are due to contingency operations, the number of replacement modules involved in Resupply, and out-gassing requirements for high voltage components. Worst case combinations of mission time and external environment are required to establish a thermal design reference mission.

For the Shuttle utilization modes, the following spacecraft module thermal control requirements are assumed:

- Operating Limits
  - Deliver - all equipment
  - Resupply - replacement equipment
- Survival Limits
  - Retrieval - all equipment
  - Resupply - expended/malfunctioned equipment

An on-orbit EOS requiring resupply may have some modules operating and others in a survival mode depending on the type of malfunction (e.g., failure of one instrument would not degrade operation of the remaining instruments or the spacecraft; an EPS malfunction, however, could necessitate a powered-down survival mode until replacement of the affected module).

3.7.3.1 ON-ORBIT ENVIRONMENT WITH PAYLOAD BAY DOORS OPEN

Exterior heat fluxes were obtained for a Shuttle mission with a 366 n mi sun-synchronous orbit having a descending node time-of-day (DNTD) varying between 9:30 a.m. and 12 Noon. Maximum and minimum values of exterior absorbed heat fluxes were computed for each subsystem module, assuming a silver-teflon coated skin ($\alpha_s = 0.10$, $\epsilon_{TH} = 0.76$), and compared with the corresponding absorbed flux extremes for the conventional launch vehicle. For the Shuttle mission, no attitude constraints were considered, and it was assumed that the Shuttle/EOS could be in either an earth-pointing or an inertial hold mode.

Space Shuttle thermal conditioning constraints of six hours of attitude hold followed by three hours of "barbeque" are not applicable for the 0930-1200 DNTD's of the basic land

Table 3-19 Typical Shuttle Mission Timeline

MISSION PHASE	SHUTTLE MODE			P/L BAY DOOR POSITION	DURATION (HR)	COMMENTS
	DELIVER	RETRIEVE	RESUPPLY			
PRELAUNCH	X	X	X	CLOSED	78	AIR/GN_2 PURGE PROVIDED BY SHUTTLE
ASCENT	X	X	X	CLOSED	1	
RENDEZVOUS		X	X	OPEN	0.4 – 24	TIME VARIATION DUE TO MISSION ORBIT CONSIDERATIONS
CAPTURE AND DOCK		X	X	OPEN	4.9	
EOS RESUPPLY			X	OPEN	2.1 – 6.2	ASSUMING 1–3 MODULES REPLACED
CHECKOUT AND DEPLOY	X		X	OPEN	5.2	
VERIFY EOS OPN	X		X	OPEN	12.5 – 58.5	TIME VARIATION DUE TO EQUIPMENT OUTGASSING
PREP FOR DESCENT	(X)	X	X	OPEN	0.3 – 24	TIME VARIATION DUE TO MISSION ORBIT CONSIDERATIONS
DESCENT	(X)	X	X	CLOSED	0.8	
TOUCHDOWN TO GROUND PURGE	(X)	X	X	CLOSED	0.5	

(X) MISSION ABORT

T6–23

resources (EOS–A and –B), and land and water resources (EOS–C) missions. Shuttle thermal conditioning could be required for the SEASAT mission (EOS–D) due to the possibly near–terminator orbits (0600 and 1800 DNTD's); however, thermal conditioning reduces the extremes of the thermal environment and, therefore, is beneficial for the spacecraft.

A conventionally launched EOS is an earth-pointing vehicle, with specific attitude (i.e., +Z axis facing earth, +X axis facing along the velocity vector). The range of external absorbed fluxes for the Shuttle mission with unconstrained attitudes, therefore, ar much greater than for a conventionally launched EOS. Table 3–20 lists the maximum and minimum incident and absorbed flux for both a conventional and Shuttle launched land resources mission. The flux data for the Shuttle launch assumes a non-deployed solar array, no degradation of the thermal coating, and no attitude constraints. Examination of the absorbed heat flux values reveal a substantial increase in the ratio of maximum to minimum absorbed heat flux for the Shuttle mission. In particular, certain spacecraft attitudes result in a very low minimum absorbed heat flux. These low-minimum heat fluxes are the primary considerations that must be addressed in defining the impact of Shuttle utilization on the EOS thermal control system.

Table 3-20 Worst Case On-Orbit Heat Flux Comparison

SUBSYSTEM MODULE	LAUNCH VEHICLE	MAXIMUM/MINIMUM HEAT FLUX (BTU/HR FT²)				
		INCIDENT FLUX COMPONENT				ABSORBED (1) FLUX
		DIRECT SOLAR	ALBEDO	EARTH EMISSION	SOLAR ARRAY	
EPS	CONVENTIONAL	5.4/0	20.1/12.3	36.9/31.9	0/0	32.8/25.5
	SHUTTLE	302.3/0	2.2/1.7	20.8/4.9	0/0	46.3/3.9
CDH	CONVENTIONAL	112.5/8.6	17.2/17.3	35.1/31.9	18.5/7.9	64.3/37.7
	SHUTTLE	302.3/0	2.2/1.7	20.8/4.9	0/0	46.3/3.9
ACS	CONVENTIONAL	141.5/109.4	0/0	0/0	0/0	25.5/9.9
	SHUTTLE	302.3/0	2.2/1.7	20.8/4.9	0/0	46.3/3.9

NOTES:

(1) ABSORBED HEAT FLUX BASED ON THE FOLLOWING SILVER/TEFLON SKIN PROPERTIES.

ϵTH = .76
αS = .09 to .18 FOR CONVENTIONAL LAUNCH - ASSUMING DEGRADATION
αS = .10 FOR SHUTTLE LAUNCH - NO DEGRADATION

(2) WORST CASE FLUX BASED ON FOLLOWING CONDITIONS

- SUN SYNCHRONOUS LAND RESOURCES MISSION
- DNTD FROM 0930 to 1200
- ALTITUDE - CONVENTIONAL LAUNCH - 300 to 500 n mi
  - SHUTTLE LAUNCH - 366 n mi
- ATTITUDE - CONVENTIONAL LAUNCH - +Z EARTH ORIENTED, +X IN VELOCITY DIRECTION
  - SHUTTLE LAUNCH - ANY ATTITUDE

T6-24

3.7.3.2 SHUTTLE ENVIRONMENT WITH PAYLOAD BAY DOORS CLOSED

The thermal environment of the EOS when contained within the Orbiter with the payload bay doors closed is based on heat transfer between the EOS and Shuttle elements in the following manner:

- Radiative heat transfer with the payload bay liner, radiator, and structure
- Conductive heat transfer with the local structure at the payload attachment points
- Convective heat transfer with entrapped payload bay air during prelaunch, ascent, entry, and post-landing mission phases.

During on-orbit operations, the Orbiter radiator/payload bay doors are normally open for radiator heat rejection to space, but are closed during the remainder of the mission. Table 3-21 summarizes the design values for the Shuttle interface boundary conditions during the various Shuttle mission phases, as obtained from Reference 5. The actual Shuttle thermal boundary conditions are highly transient and depend significantly on the payload thermal characteristics. Stated values, therefore, represent worst case conditions.

Table 3-21 EOS Thermal Environment, Payload Bay Doors Closed

MISSION PHASE	PAYLOAD LINER/RADIATOR TEMPERATURE (°F)	PAYLOAD BAY AIR TEMP (°F)
PRELAUNCH	40 TO 120	65 TO 85
LAUNCH	40 TO 150	——
ON-ORBIT DOORS CLOSED	(A)	——
ENTRY AND POSTLANDING	100 TO 200	70 TO 200

NOTES:
(A) LOCAL HEAT GAIN BY 100°F PAYLOAD MODULE: +3 TO -4 BTU/HR FT^2
(B) VALUES OBTAINED FROM REFERENCE 6-5.

T6-25

3.7.4 CONTAMINATION

The Orbiter provides a relatively clean environment per the conditions cited in Reference 4. The most significant area of concern lies in the possible impingement of Orbiter RCS exhaust plumes while the EOS is erected on the FSS Positioning Platform or in the near vicinity of the Orbiter following deployment or preceding retrieval. Figure 3-1 depicts the RCS plume patterns. Further discussion is provided in subsection 3.3. This problem can be overcome by operational procedures, such as inhibiting Orbiter upward firing jets during critical EOS operations, without imposing design impacts on either EOS or Shuttle.

4 - DESIGN IMPACT

This section addresses the changes in element design and attendant weight/cost impacts resulting from the additional requirements to achieve EOS compatibility with Shuttle utilization in each of three modes (Deliver, Retrieve, and Resupply) derived in Section 3. To aid in the assessment, a one-to-one correspondence has been maintained between the requirements and the associated design changes by utilizing a consistent topical organization and identical reporting formats, to the greatest extent possible. The sole exceptions to this policy are the Mission requirements (subsection 3.1) which are assesed under Mission Suitability (Section 5) and Environmental requirements (subsection 3.7), which are factored into the Basic Spacecraft (subsection 4.1) and Instrument/Mission Peculiar Equipment (subsection 4.2) disciplines which they affect.

The groundrules, guidelines, and assumptions applied to the requirements analysis of Section 3 have been retained throughout this section to preserve consistency. In general, only EOS-B has been addressed in depth, although peculiarities of the remaining missions in the study mission model, Table 3-1, have been considered for major impacts.

Full programmatic cost impacts of Shuttle utilization in each projected mode of Shuttle utilization have been compiled and spread against individual Work Breakdown Structure elements in subsection 4.6.

4.1 BASIC SPACECRAFT

As with the requirements analysis, the previously reported Shuttle compatibility analysis (Reference 1) has been updated to reflect additional investigation and refinement of the baseline EOS concept accomplished during the intervening period.

The impact of necessary design changes has been identified in terms of incremental weight and hardware procurement cost relative to a non-Shuttle-compatibile EOS, the baseline design. The impact assessments differ from the requirements and design change reporting formats in that the effects are not cumulative as one progresses to the more complex utilization modes; each mode cited reflects the total impact of achieving that level of Shuttle compatibility.

Cost impacts are quoted in terms of the non-recurring and recurring costs associated with procuring the necessary hardware to implement the required design changes. These costs are a primary input to the program-wide Design Cost Impact Assessment made in subsection 4.6.

4.1.1 COMMUNICATIONS AND DATA HANDLING

The design changes necessary to achieve Shuttle compatibility are listed in Table 4-1. It is apparent that the principal impact of Shuttle compatibility for CDH arises from the necessity to provide the redundancy level required to provide a fail-operational command and communications capability to ensure Orbiter safety.

The Orbiter can accommodate PCM data from up to five different attached payloads, providing the sum of their data rates does not exceed 25.6 Kbps. This data is decommutated on-board the Orbiter for monitoring and control of the attached payloads. It is displayed to the Orbiter crew and/or transmitted to the Payload Operations Control Center (POCC) via the Orbiter data link. In turn, payloads are required to accept commands at 2.5 Kbps (28 bit words) via the Orbiter MDM system or at 8 Kbps (128 bit words) via the Orbiter payload signal processor. Commands may be either initiated aboard the Orbiter or relayed from ground control.

The baseline CDH design has a variable selectable interface data rate of 32, 16, 8, 4, 2, and 1 Kbps, all of which, except for the 32 Kbps rate, are compatible with the present Orbiter interface. In addition, the baseline has the capability of accepting a 2.4 Kbps, 28 bit word, command stream. Thus, as indicated in Table 4-1, the EOS baseline design is fully compatible with the command/data format and rate aspects of Requirements 1, 2, and 4.

As currently conceived, the EOS Data Handling Group (DHG) will be operative throughout all EOS-Shuttle mission phases. All C & W functions listed in Table 3-3 are sampled and processed in the normal complement of spacecraft housekeeping data and, therefore, are available via the multiplex system Orbiter interface. To accommodate Requirements 1 and 8 in the Resupply mode, however, it becomes necessary to add dedicated signal and command wires directly from the affected module to the EOS-Orbiter connector to provide the necessary functional capability while the CDH module is being exchanged. This same mechanization provides the capability for monitoring and controlling the C & W functions of individual modules during their transport to or from on-orbit resupply operations, as dictated by Requirement 1. With the addition of this hardwire interface, the command/

Table 4-1 Communications and Data Handling Design Changes

FUNCTIONAL ELEMENT: BASIC SPACECRAFT

DISCIPLINE	EOS MISSION A	B	C	D	E	F	SHUTTLE MODE DELIVER	RETRIEVE	RESUPPLY	REMARKS
COMMUNICATIONS & DATA HANDLING	X	X	X	X	X	X	1. Add dedicated hardwires, including a separable, Orbiter compatible, connection capable of: a. Transmitting selected C&W Signals. b. Receiving selected cmds	1. Add a rematable connector to Deliver design.	1. Route dedicated C&W and cmd wires directly from subsystem modules to Orbiter interface connector.	
							2. Command Override Same as Item 1	2. Command Override Same as Item 1	2. Command Override Same as Item 1	
							3. Fail Safe Ops Add redundant o S-Band X'pndr o Cmd Decoder o Controller/Formatter o Remote Unit o Signal Conditioner			
							4. Data Relay No Change			Baseline S/C design is compatible with Orbiter data relay.
							5. Hardwire/RF Switching No Change			Same switching logic as for ground umbilicals for conventional launch vehicle design approach
									6. Structural Attachment No Change	Attachment mechanisms are covered in Struct/Mech, subsection 4.1.4.
									7. Signal/Power Circuits No CDH Change	Circuit connectors are covered in EPS, subsection 4.1.2
									8. Monitoring and Control Same as Item 1.	

T6-26

data interface is provided for a net impact of approximately two pounds with insignificant cost, as shown in Table 4-2.

To attain the fail-operational capability for command and control imposed by Requirement 3, it is necessary to incorporate CDH redundancy, as cited in Change 3. The dedicated C & W hardwires added in the Resupply mode for Requirement 1 inherently provide a level of redundancy to the multiplex system while EOS is attached to Orbiter. Table 4-2 shows that the satisfaction of Requirement 3 entails the single most significant impact for Shuttle compatibility, 24 pounds and $199 thousand in recurring cost. Since the necessary units are duplicates of the baseline ship set, non-recurring cost impact is minimized.

Requirements 6 and 7 are common to all spacecraft modules and, accordingly, are addressed in EPS (subsection 4.1.2) and Structure/Mechanism (subsection 4.1.4) for implementation.

Table 4-2 Communications & Data Handling Impact Assessment

CHANGE	MISSION						DELIVER			RETRIEVE			RESUPPLY		
							WT	COST ($K)		WT	COST ($K)		WT	COST ($K)	
	A	B	C	D	E	F	(lb)	NON-RECUR	RECUR	(lb)	NON-RECUR	RECUR	(lb)	NON-RECUR	RECUR
• C & W Interfaces	X	X	X	X	X	X	2	25	Insig.	2	25	Insig.	2	25	Insig.
• S-Band X'pndr	X	X	X	X	X	X	5.2		107	5.2		107	5.2		107
• Cmd Decoder	X	X	X	X	X	X	7.8		20	7.8		20	7.8		20
• Controller/Formatter	X	X	X	X	X	X	4		17	4		17	4		17
• Remote Unit	X	X	X	X	X	X	4		10	4		10	4		10
• Signal Conditioner	X	X	X	X	X	X	3		45	3		45	3		45
TOTAL	X	X	X	X	X	X	26	25	199	26	25	199	26	25	199

T6-27

4.1.2 ELECTRIC POWER

Shuttle compatibility requirements for EPS, defined in subsection 3.2.2, can be implemented with reasonable weight and cost impacts. Tables 4-3 and 4-4 respectively summarize the design changes and attendant weight/cost impacts associated with implementing these requirements.

The major impact on EPS design results from Shuttle utilization in the Resupply mode. Module replacement necessitates the use of special, self-aligning, blind-mate connectors of a type currently utilized on the F-14A weapon rails. Incorporation of these connectors at all spacecraft interfaces requiring interruption and restoration of signal/power circuits will increase total spacecraft weight by approximately 45 lb and increase recurring unit cost by $15 thousand. Non-recurring cost associated with these connectors will be less than $20 thousand. There is an additional five lb weight penalty for EOS-D because of an added solar array.

It is estimated that the added wiring and related components necessary to provide the hardwire electrical power and control interfaces between EOS modules and the Orbiter to satisfy Requirement 3 can be incorporated with less than a 10 lb weight impact. The associated cost impact will be insignificant if the requirements are incorporated into the initial EPS design efforts.

Requirement 4 imposes a design change imposed by Orbiter design constraints to disconnect the EOS negative power bus from EOS structure while it is drawing Orbiter power. Since this requirement is common to all Orbiter payloads, it should be implemented with a standard design approach for all payloads. Although it does present design problems, this segmented bus concept, similar to that utilized in the Apollo Lunar Module design has been tentatively selected to achieve the necessary Shuttle compatability; its impact is considered to be within the 10 lb penalty for additional wire runs cited in Table 4-4. A second approach would be to provide isolated payload power from the Orbiter. This approach may be required in any event, to provide battery charge control from Orbiter power. The ultimate solution to the grounding constraint, including refinement of specific requirements and development of an acceptable design, is considered to be a subject for further study.

4.1.3 ATTITUDE CONTROL

Table 4-5 reflects the ACS design changes associated with the Shuttle compatibility requirements identified in subsection 3.2.2. It is apparent that, other than the mechanics of physically exchanging the ACS module to satisfy Requirements 3 and 4, there are no changes in ACS functional design necessary to achieve compatibility.

Table 4-3 Electrical Power Design Changes (Sheet 1 of 2)

FUNCTIONAL ELEMENT: BASIC SPACECRAFT

DISCIPLINE	EOS MISSION						SHUTTLE MODE			REMARKS
	A	B	C	D	E	F	DELIVER	RETRIEVE	RESUPPLY	
ELECTRICAL POWER	X	X	X	X	X	X	1. Prolonged Orbiter Stay No Change. Use Orbiter supplied power.			
							2. Orbiter/EOS Connection No Change. Use EOS/ground umbilical connectors relocated at EOS aft bulkhead.	2. Orbiter/EOS Connection Format		In baseline FSS, the Orbiter/EOS umbilical interface is located in the positioning platform (i.e. at the aft end of the S/C).
							3. Orbiter Power Routing No Change. Use baseline external power distribution network.		3. Orbiter Power Routing Add additional power distribution network to EOS harness, external to Power Module.	For Resupply, assume that power must be available to S/C while EPS module is removed (e.g. critical equipment htr. pwr.). If power is not required, there would be no change to baseline design.
							4. Negative Bus Isolation Provide EOS special negative bus with provision for isolating from Single Point Ground.			Design approach should be common with all Shuttle payloads.
								5. Survival Power No Change. Reduced pwr demands enable baseline design to meet reqmts.		
								6. Static Discharge No Change. Shuttle RMS will contain appropriate provisions.		Assume that RMS will be configured to satisfy discharge functional requirement common to all Shuttle retrieval payloads, not just EOS.
								7. Solar Array Retract (See Struct/Mech, subsection 4.1.4)		

T6-28(1)

Table 4-3 Electrical Power Design Changes (Sheet 2 of 2)

FUNCTIONAL ELEMENT: BASIC SPACECRAFT

DISCIPLINE	EOS MISSION						SHUTTLE MODE			REMARKS
	A	B	C	D	E	F	DELIVER	RETRIEVE	RESUPPLY	
ELECTRICAL POWER (Cont'd.)	X	X	X	X	X	X			8. Solar Array Circuits Use self-aligning, blind-mate connectors.	
									9. Power Module Circuits Use self-aligning, blind-mate connectors	
									10. S/C Module Circuits Use self-aligning, blind-mate connectors.	
									11. Solar Array Replacement (See Struct/Mech. Sub-section 4.1.4)	
									12. Power Module Replacement (See Struct/Mech. Sub-section 4.1.4)	
									13. Power Enable No Change. Baseline design includes adequate cmd capability.	
									14. Module Power Control No Change. Baseline design includes adequate cmd capability.	
									15. Alternate Pwr Dist See Change 3	

T6-28(2)

Table 4-4 Electrical Power Impact Assessment

CHANGE	MISSION						DELIVER			RETRIEVE			RESUPPLY		
							WT	COST ($K)		WT	COST ($K)		WT	COST ($K)	
	A	B	C	D	E	F	(lb)	NON-RECUR	RECUR	(lb)	NON-RECUR	RECUR	(lb)	NON-RECUR	RECUR
• Self-align, blind mate connectors	X	X	X	 X	X	X							45 49	20 20	15 16
• Add'l. Wire Runs	X	X	X	X	X	X	10	Insig.	Insig.	10	Insig.	Insig.	10	Insig.	Insig.
• Negative bus isolation	X	X	X	X	X	X	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
TOTAL	X	X	X	 X	X	X	10 10	Insig. Insig.	Insig. Insig.	10 10	Insig. Insig.	Insig. Insig.	55 59	20 20	15 16

Note:
(1) Included in Additional wire run impact

T6-29

The ACS baseline design includes a safe mode, similar to that of OAO, to accommodate real-time mission maintenance and management. This mode utilizes a coarse run sensor acting through an analog processor in the ACS electronics assembly to inertia wheels, magnetic torquers, and/or OAS/RCS thrusters to effect vehicle attitude control, thereby providing an inherent back-up capability to satisfy Shuttle compatibility requirements. The coarse sun sensor is capable of achieving the $\pm 1^{o}$/sec attitude limits necessary for Orbiter manipulator acquisition.

Since, for this analysis, implementation of structural attachments and circuit connectors are addressed under Structure/Mechanisms and EPS, respectively, there is no ACS design impact attributable to Shuttle compatibility.

One area which is considered worthy of additional study is the effect on EOS attitude stability during the terminal phases of capture. As the Orbiter closes with the EOS to within reach of PDRM, the Orbiter upward firing RCS thrusters will be required for braking. Referring to Fig. 3-1, it is possible that the thruster exhaust plumes will impinge upon the spacecraft, imparting disturbing torques. While the reach of the manip-

Table 4-5 Attitude Control Design Changes

FUNCTIONAL ELEMENT: BASIC SPACECRAFT

DISCIPLINE	EOS MISSION						SHUTTLE MODE			REMARKS
	A	B	C	D	E	F	DELIVER	RETRIEVE	RESUPPLY	
ATTITUDE CONTROL	X	X	X	X	X	X	1. Back-up Capability No Change. Baseline design provides inherent back-up.	1. Back-up Capability No Change. Capability is inherent in baseline design.		
								2. Back-up Mode Stability No Change. Capability is inherent in baseline design.		
									3. Module Attachment (See Struct/Mech, subsection 4.1.4)	
									4. Circuit Interfaces (See EPS, subsection 4.1.2)	

T6-30

ulator (slightly in excess of 45 ft) appears adequate to alleviate any impingement problem, this is contingent upon the capture sequence and position, and the total envelope of plume expansion. In addition, this analysis should consider the potential disturbances imparted as the manipulator effector locks on to the spacecraft.

4.1.4 STRUCTURE/MECHANISMS

The structural and mechanical design changes resulting from Shuttle compatibility requirements, compiled in Table 4-6 and 4-7, fall into four distinct groupings:

- Reaction to Shuttle induced environment (Change 1)
- Interfacing with the FSS (Changes 2 through 5)
- Retraction of deployed appendages (Change 6)
- Replacement of spacecraft modules/assemblies (Change 7).

The acoustic and load environments induced by Shuttle (Subsections 3.7.1 and 3.7.2) do differ from these induced by conventional launch vehicles. The Shuttle acoustic environment evidences a 3 dB increase in sound pressure level at 1000 Hz and 2000 Hz octave band center frequencies. Although this is a significant increment, the resonant frequencies of structural components historically fall below 1000 Hz. Consequently, it is not anticipated that the Shuttle acoustic environment will produce any significant change in EOS and FSS structural design. Similarly, at the present level of EOS and FSS structural design, no significant penalties can be identified for the increased lateral load factors imposed by Shuttle. Accordingly, pending additional analyses, no significant change in structural or mechanical design appears necessary to achieve compatibility with the Shuttle induced environment.

It will be necessary, however, to demonstrate EOS-Shuttle safety-of-flight by verifying the ability of EOS secondary structure to withstand Shuttle crash loads. This requirement can be accommodated by demonstrating static load design qualification with an acceleration test using an EOS full mass representation, including all primary and secondary structure. Since static load qualification by acceleration was included in the basic EOS test program, there is no cost impact associated with Shuttle level qualification.

Currently, the FSS Retention Cradle is configured to interface with a full-circumference transition ring at the EOS upper bulkhead. A full ring design would add 81 lb to spacecraft of the 3000-lb class (e.g., EOS-A and EOS-B) and 117 lb to 4000 +lb-class spacecraft (e.g., EOS-C). The Grumman design approach utilizes six discrete attach fittings, one at each structural longeron intersection with the upper bulkhead. Table 4-7

Table 4-6 Structure/Mechanisms Design Changes

FUNCTIONAL ELEMENT: BASIC SPACECRAFT

DISCIPLINE	EOS MISSION A	B	C	D	E	F	SHUTTLE MODE DELIVER	RETRIEVE	RESUPPLY	REMARKS
STRUCTURE/MECHANISMS	X	X	X	X	X	X	1. Shuttle Induced Environment Verify secondary structure for crash loads.			Present estimates indicate minimal changes required for Shuttle compatibility. Additional detailed analysis is required for verification. Structural qualification needs crash load demo.
	X	X	X	X	X		2. FSS Cradle Attachment Add attach fittings at selected points on upper EOS bulkhead.			Baseline S/C-launch vehicle interface is at lower EOS bulkhead.
	X	X	X	X	X	X	3. Posit. Platform/Tug Connect Add 3 passive docking probes to lower EOS bulkhead.			The probe arrangement is identical for FSS and Tug. There are differences in supporting structure.
	X	X	X	X	X		4. PDRM Attach Fitting Add a passive attach fitting at S/C C.G. location.			
							5. Emergency Release No Change			Assuming this to be common to all Shuttle payloads, it is assumed that the Shuttle/FSS will contain the appropriate provisions.
	X	X	X	X	X	X		6. Appendage Retract a. Solar Array: Add mechanisms and drive units for folding panels, retracting boom, and latching in stowed position. b. TDRS Antenna: Add mechanisms and drive units for furling the antenna, retracting the supporting truss, and latching in stowed position. c. Steerable Antennas: Add mechanisms and drive units for retracting and latching in stowed position.		
									7. Module Replacement a. Add latch mechanisms to individual modules/assemblies. b. Add tracks and latch rollers to supporting structure.	Latch design offers lower loads and simpler mechanisms for MMS operations.

4-16

Table 4-7 Structure/Mechanisms Impact Assessment (Sheet 1 of 2)

CHANGE	MISSION						DELIVER			RETRIEVE			RESUPPLY		
							WT	COST ($K)		WT	COST ($K)		WT	COST ($K)	
	A	B	C	D	E	F	(lb)	NON-RECUR	RECUR	(lb)	NON-RECUR	RECUR	(lb)	NON-RECUR	RECUR
FSS INTERFACE: ADD	X	X	X	X	X										
• Cradle Attach Fittings							14	78	16	14	78	16	14	78	16
• Positioning Platform Probes							9	50	10	9	50	10	9	50	10
• PDRM Attach Fitting							4	22	4	4	22	4	4	22	4
TUG INTERFACE: ADD						X									
• Tug Attach Probes							24	133	4	24	133	4	24	133	4
APPENDAGE RETRACT: ADD															
• TDRS Antenna	X	X	X	X	X					3	352	213	3	450	272
- Ant Refold Mech															
- Truss Retract Mech															
- Stow Latch Mech															
• Solar Array	X	X	X		X	X				1	186	36	1	231	45
				X						2	205	54	2	252	66
- Panel Refold Mech															
- Boom Retract Mech															
- Stow Latch Mech															
• Steerable Antenna	X	X	X	X	X	X				1	64	22	1	116	40
- Re-entry Restraint Device															
• Deployable Experiments				X						9	GFE	GFE	9	GFE	GFE
- Re-entry Restraint Device					X					6	GFE	GFE	6	GFE	GFE
						X				4	GFE	GFE	4	GFE	GFE
REPLACE MODULES: Add															
• Latches/Pins															
- Basic S/C	X	X	X		X	X							38	270	95
				X									45	320	112
- Instruments	X	X											39	115	105
			X										53	156	143
				X									58	171	156
					X								77	227	207
						X							40	118	108

T6-32(1)

Table 4-7 Structure/Mechanisms Impact Assessment (Sheet 2 of 2)

CHANGE	MISSION A	B	C	D	E	F	DELIVER WT (lb)	COST ($K) NON-RECUR	RECUR	RETRIEVE WT (lb)	COST ($K) NON-RECUR	RECUR	RESUPPLY WT (lb)	COST ($K) NON-RECUR	RECUR
o Rollers/Tracks															
- Basic S/C	X	X	X		X	X							14	100	35
				X									16	114	40
- Instruments	X	X											10	45	40
			X	X									15	68	60
					X								20	90	80
						X							11	50	44
TOTAL	X	X					27	150	30	32	752	301	133	1477	662
			X				27	150	30	32	752	301	152	1541	720
				X			27	150	30	42	707	297	176	1525	736
					X		27	150	30	38	688	279	187	1518	764
						X	24	133	4	30	319	40	133	902	331

T6-32(2)

shows that this approach is significantly lighter, incurring a penalty of only 14 lb to the current baseline design.

Interfacing with the FSS Positioning Platform necessitates the addition of three passive docking probes to the EOS lower bulkhead, configured as specified in References 2 (Drawing 3066-29). The installation of these probes entails a penalty of only 9 lb, and a minimal cost impact as reflected in Table 4-7. The Space Tug can utilize a similar arrangement to effect P/L deploy, retrieve, and, presumably, resupply. Three structurally reinforced, passive docking probes on the EOS-F lower bulkhead will fulfill these functions, as well as providing primary structural attachment to the Tug during Orbiter ascent and descent. Because of the structural reinforcement, the EOS-F penalty is heavier by 24 lb. If the Positioning Platform is deleted for Deliver and Retrieve Shuttle utilization modes (an approach which is considered worth further consideration since it will reduce EOS-chargeable payload weight by approximately 1400 lb), the probes can be eliminated from all EOS concepts except F.

A standard PDRM attach fitting has been configured for all EOS concepts, consisting of a simple pedestal with sufficient structural rigidity to hold the spacecraft rigid in all axes. To meet the requirement for longitudinal alignment with the spacecraft center of gravity, the fitting is appropriately positioned on a rail at the side of the spacecraft, spanning the one-foot range of anticipated center of gravity locations. This approach adds four lb to baseline vehicle weight.

No design change has been identified for emergency release provisions associated with Requirement 5. As stated in subsection 3.2.4, implementation of this requirement appears most logical in the FSS.

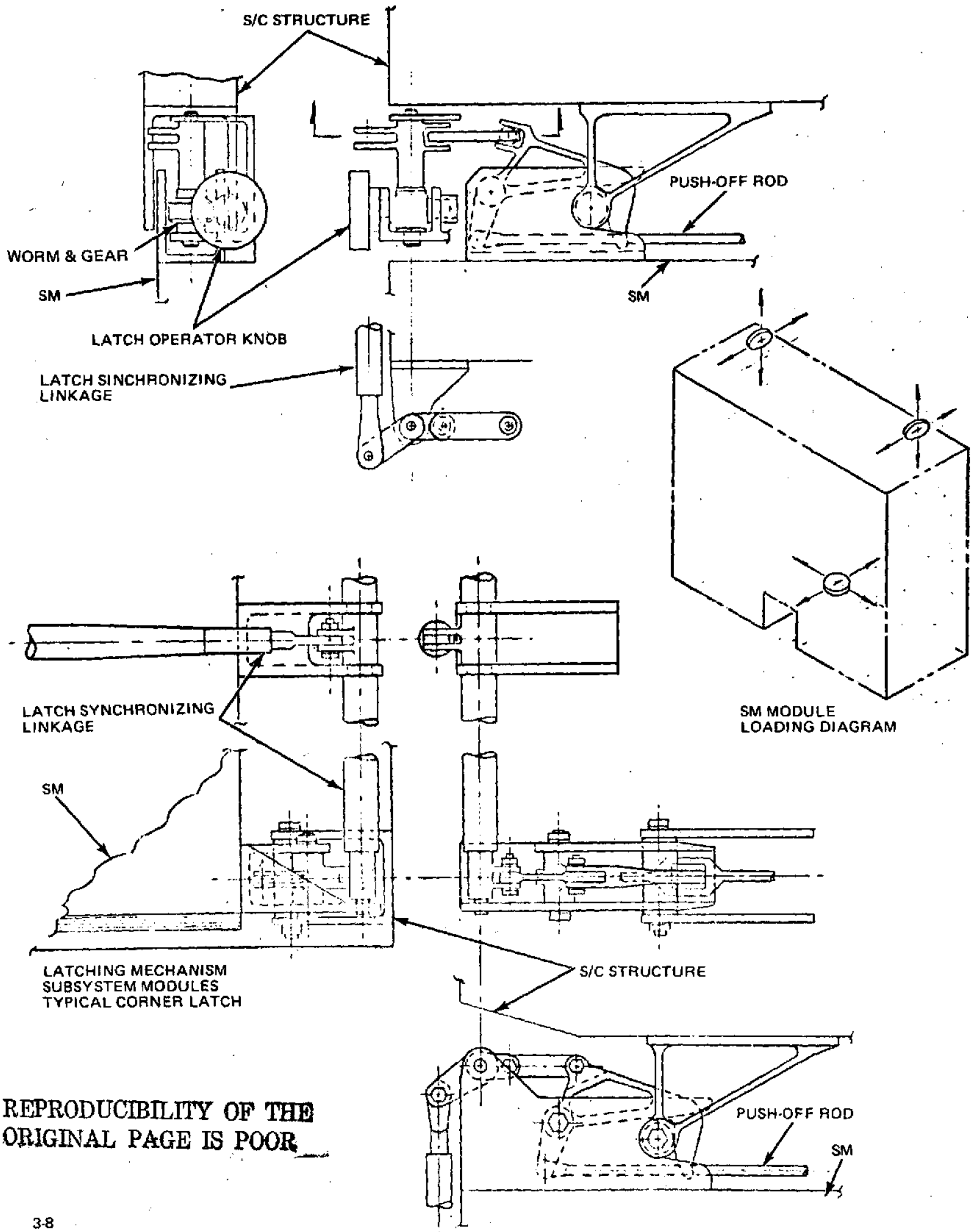
Due to the standardized FSS definition used as a point-of-departure for this study, there is a constant penalty of 27 lb for $150 thousand non-recurring/$30 thousand recurring for FSS interfaces for all Shuttle utilization modes. For EOS-F, the only interface is with Tug, with a corresponding lesser impact of 14 lb and $133 thousand non-recurring/ $4 thousand recurring.

Retracting spacecraft appendages entails adding appropriate mechanisms and drives to basic deployment provisions. With the current level of definition for these appendages, it is difficult to accurately determine associated design impact. Contingent upon further definition, preliminary indications are that the necessary impacts will be minimal.

As shown in Table 4-7, the most significant impact on baseline design arises from the need to mechanize module replacement for Resupply. Furthermore, the impact is most sensitive to mission concept, reflecting the varying complement of instruments mission-to-mission. The proposed Grumman mechanization entails adding latches and pins to each replaceable module, and corresponding tracks and rollers to adjacent structure. The latching mechanism, depicted in Fig. 4-1, differs from the SPMS baseline approach in that there is only a single latch operator. A worm gear set provides motive power, resulting in extremely low forces (< 10 lb) for module exchange. The latching mechanisms were more fully discussed in Reference 1 (Appendix D). Because of a common implementation approach, the mechanization of all Observatory latches (i.e., Basic Spacecraft plus Instrument/Mission Peculiar Equipment) has been considered in this discipline and is reflected in the accompanying tables.

4.1.5 THERMAL CONTROL

Thermal subsystem changes attributed to Shuttle utilization are due mainly to differences in the thermal environment and Shuttle mission requirements. Shuttle induced



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6-52

Fig. 4-1 Latching Mechanism Subsystem Modules – Typical Central Latch thermal environments are summarized in subsection 3.7 and mission requirements affecting thermal control are described in subsection 3.2.5.

4.1.5.1 SHUTTLE MISSION ANALYSIS

A review of the Shuttle reference mission timeline (Reference 6) reveals a substantial difference in time required for EOS deployment for a Shuttle launch compared with a conventional launch. The Shuttle delivery mission has a 24-hour on-orbit contingency period prior to EOS deployment with payload bay doors open for Shuttle cooling purposes. During this time, it is assumed there are no attitude constraints. In contrast, an EOS delivered into orbit by a conventional launch vehicle is assumed immediately stabilized and earth pointing. The major thermal study emphasis has been addressed to this point, and the effects of Shuttle environment on the subsystem modules have been examined.

Shuttle retrieval and/or resupply missions require survival mode capability. This mode implies operating the spacecraft in a minimum power dissipation condition for extended periods, during which time non-operating equipment temperatures are permitted to fall to survival limits to minimize heater power. Spacecraft attitude constraints are not assumed, although solar array orientation is obviously required.

EOS Module replacement during a resupply mission also has thermal design implications. Thermal integrity of both module and spacecraft during the module replacement activity requires the addition of insulation blankets, thermal coatings, and possibly heaters in locations not required for the missions without resupply.

4.1.5.2 SUBSYSTEM MODULE TRANSIENT ANALYSIS

- Survival Mode Study

Transient analysis of the subsystem modules was performed to determine whether survival temperature limits are exceeded during a 24-hour hold with zero equipment power dissipation. A simple two node transient model of each module (four nodes for the EPS module) was therefore evaluated. Radiative couplings between each module heat sink and skin were the previously cited design values for the conventional launch vehicle EOS land resources mission. Environmental heat fluxes based on a range of Shuttle/EOS attitude were treated as parameters. Figures 4-2, 4-3, 4-4, and 4-5, respectively, show the transient temperature response of the battery, EPS module, CDH module, and ACS module during a 24-hour attitude hold for the extremes of absorbed external heat flux. Examination of these curves reveals the minimum survival temperature limit of all

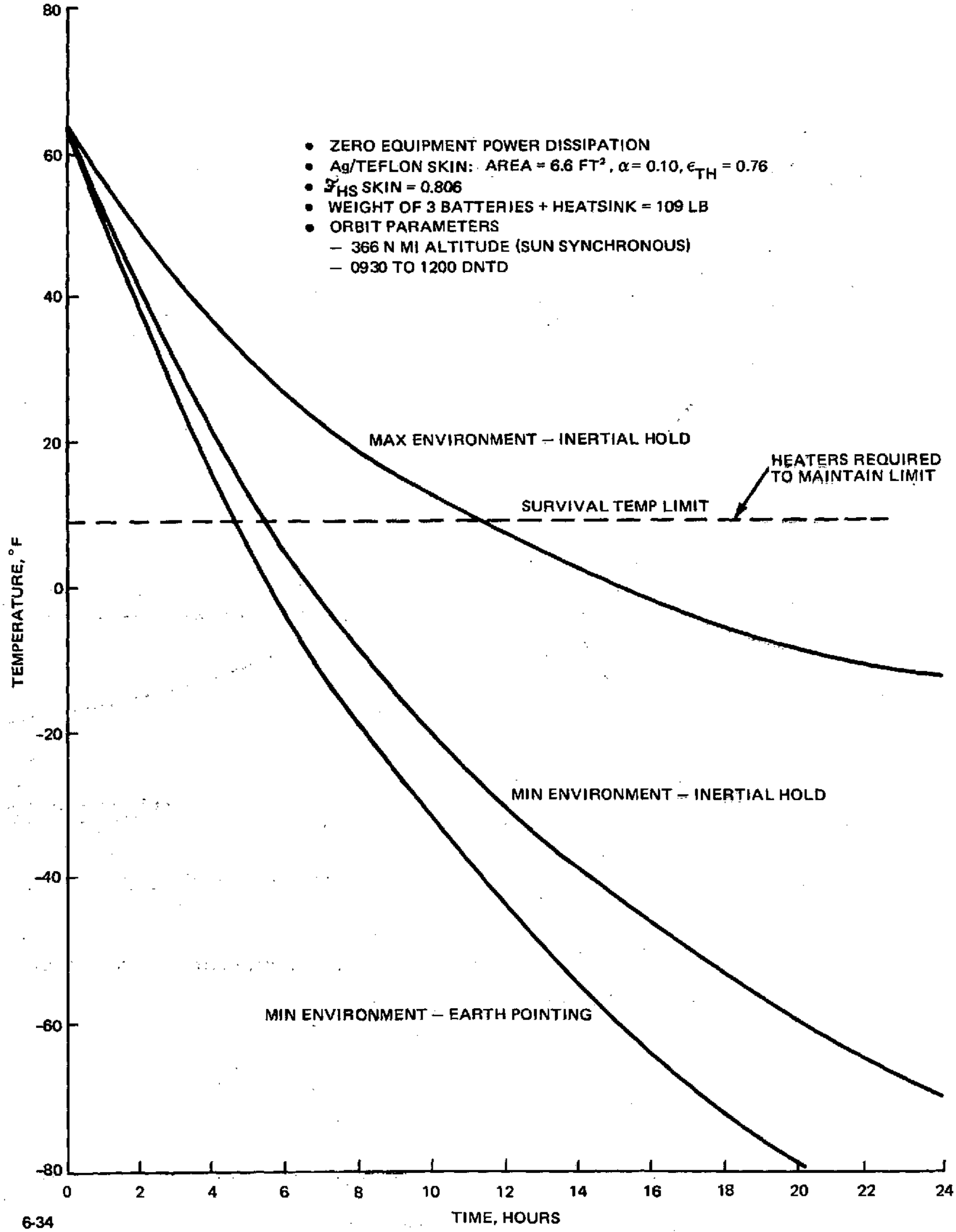


Fig. 4-2 Worst Case Launch Analysis – EPS Module Battery Heatsink Temperature

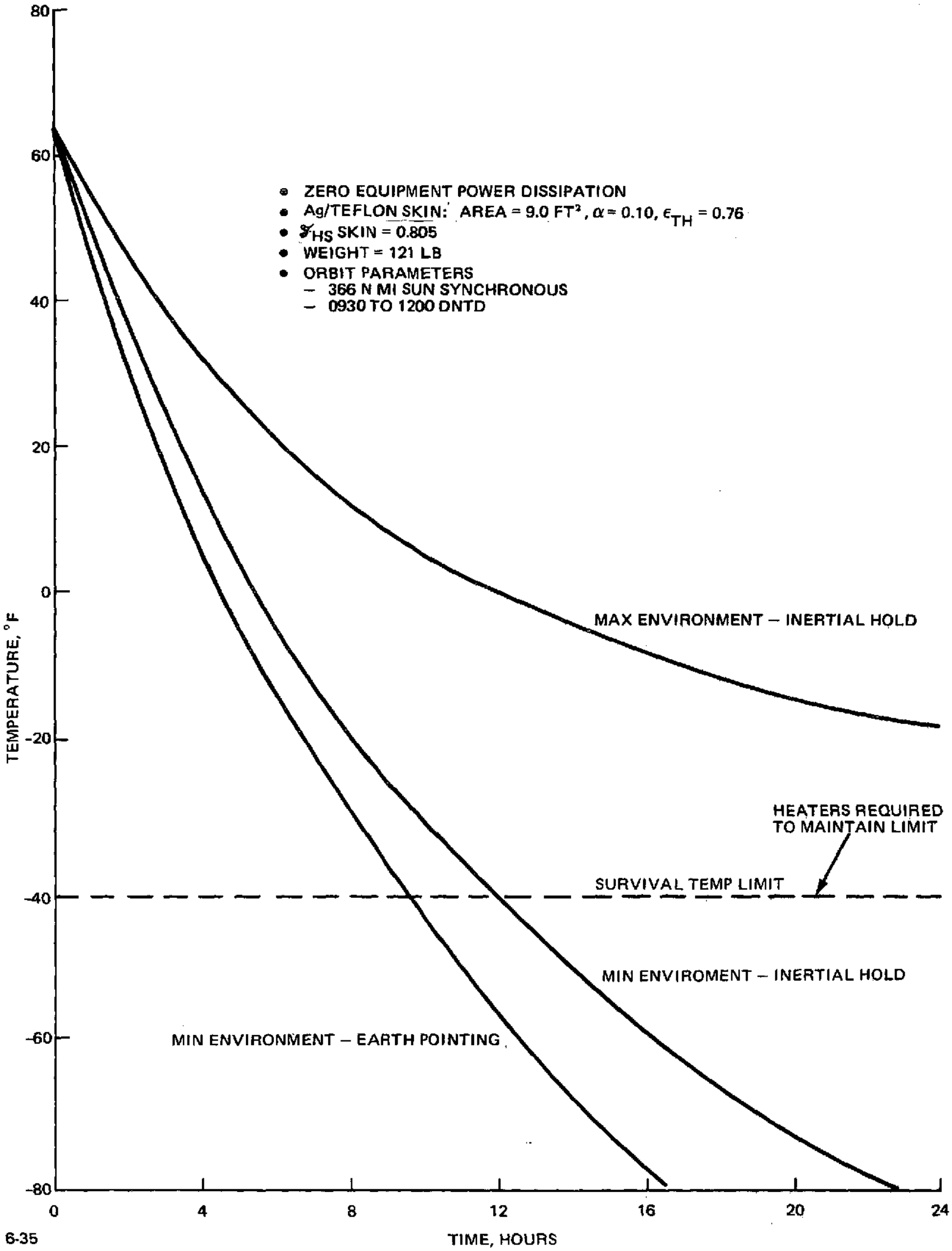


Fig. 4-3 Worst Case Launch Analysis – EPS Module Heatsink Temperature

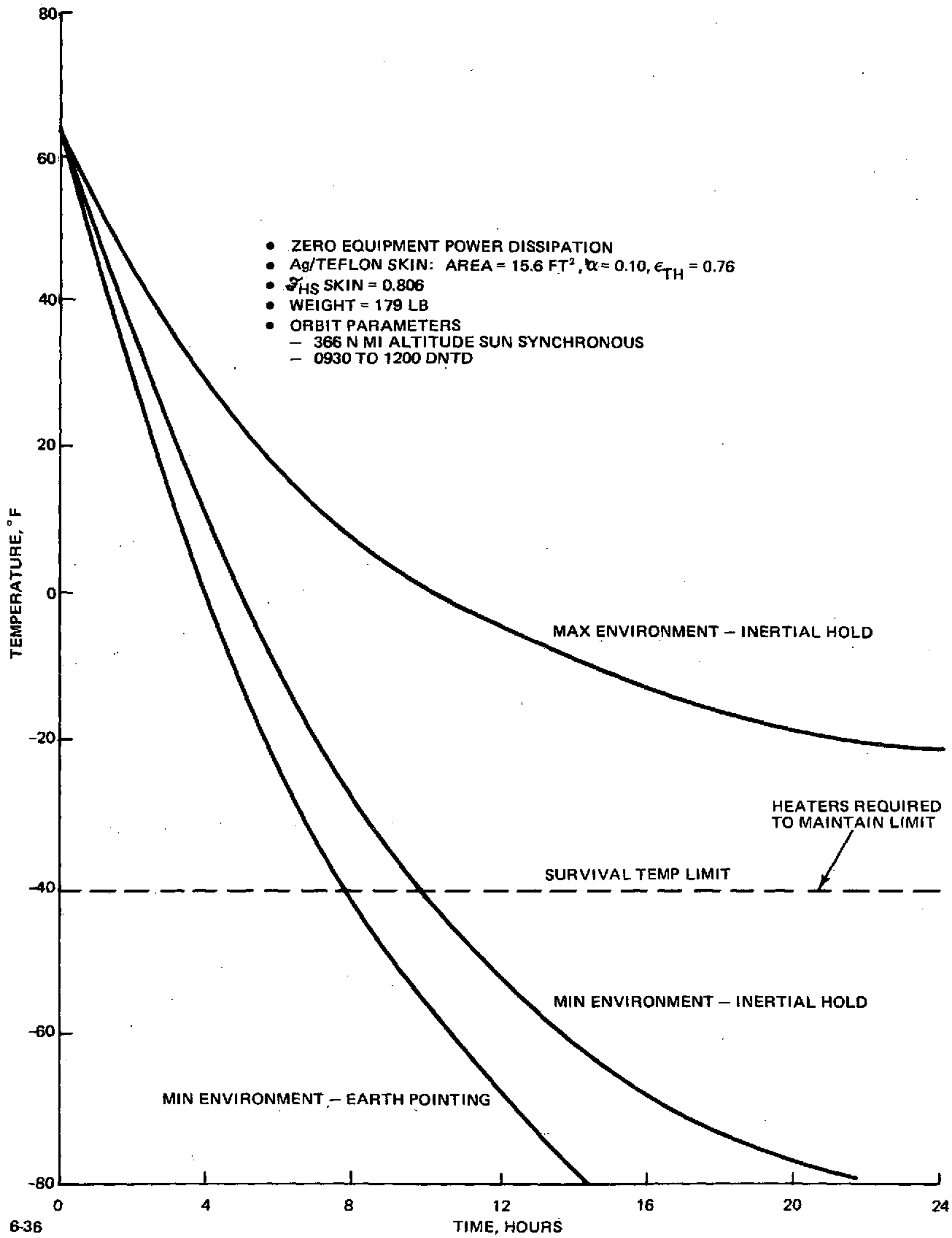


Fig. 4-4 Worst Case Launch Analysis – CDH Module Heatsink Temperature

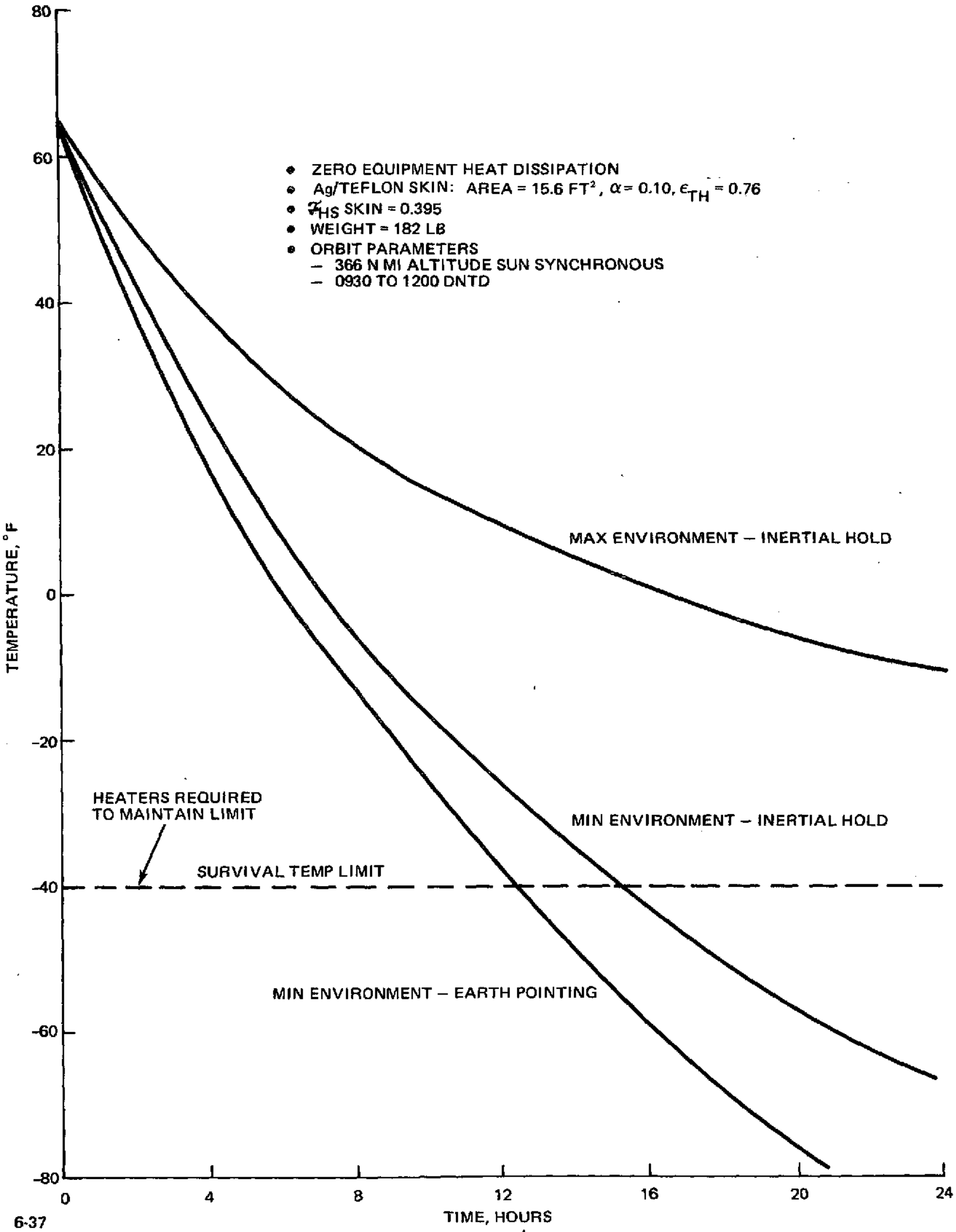


Fig. 4-5 Worst Case Launch Analysis – ACS Module Heatsink Temperature

modules is exceeded in the 24-hour period whenever minimum environmental heat fluxes are encountered. This established the requirement for heater power during survival mode operation.

It is assumed that the EOS equipment will be powered-up, requiring normal operating temperature limits, during spacecraft launch by Shuttle and during module transport for on-orbit resupply operations. During EOS retrieval, however, or during return of exchanged modules following resupply, survival temperatures must be maintained for all equipment.

- Entry Mode Study

A "worst case" entry analysis was performed using the previously described transient module of the subsystem modules. The assumed modes of heat transfer between the EOS and Shuttle during entry were:

- Free (natural) convection to payload bay air
- Radiation to the payload bay walls

Boundary conditions assumed for the analysis were 200^{o}F payload bay wall and air temperatures. Both boundary temperatures were assumed constant during the 1.2-hour period from the start of entry at 400,000 ft altitude until the start of ground cooling 0.5 hour after touchdown. A free convection film coefficient of 1.0 BTU/hr/ft^{2o}F was assumed constant during the time period.

Analysis results have been influenced by some of the simplifying assumptions. Wall and air temperature are not constant, but vary during entry, reaching a peak value of 200^{o}F. The convective heat transfer coefficient is not constant but varies as the pressure increases from zero to one atmosphere. Both of these conditions result in conservative estimates. The assumed free convection mode of heat transfer is optimistic since air motion over the spacecraft module during repressurization could result in forced convection heat transfer coefficients greater than the assumed value.

The results of the study are shown in Fig. 4-6, in which heat sink temperature is plotted against time for the subsystem modules. These results, considering the conservatism of the analysis, indicate that the only apparent thermal problem during entry is that the battery module temperature exceeds its 120^{o}F survival limit. This may or may not be a problem depending on battery re-use requirements. The analytical uncertainties encountered in formulating the entry analysis point out the need for better definition of

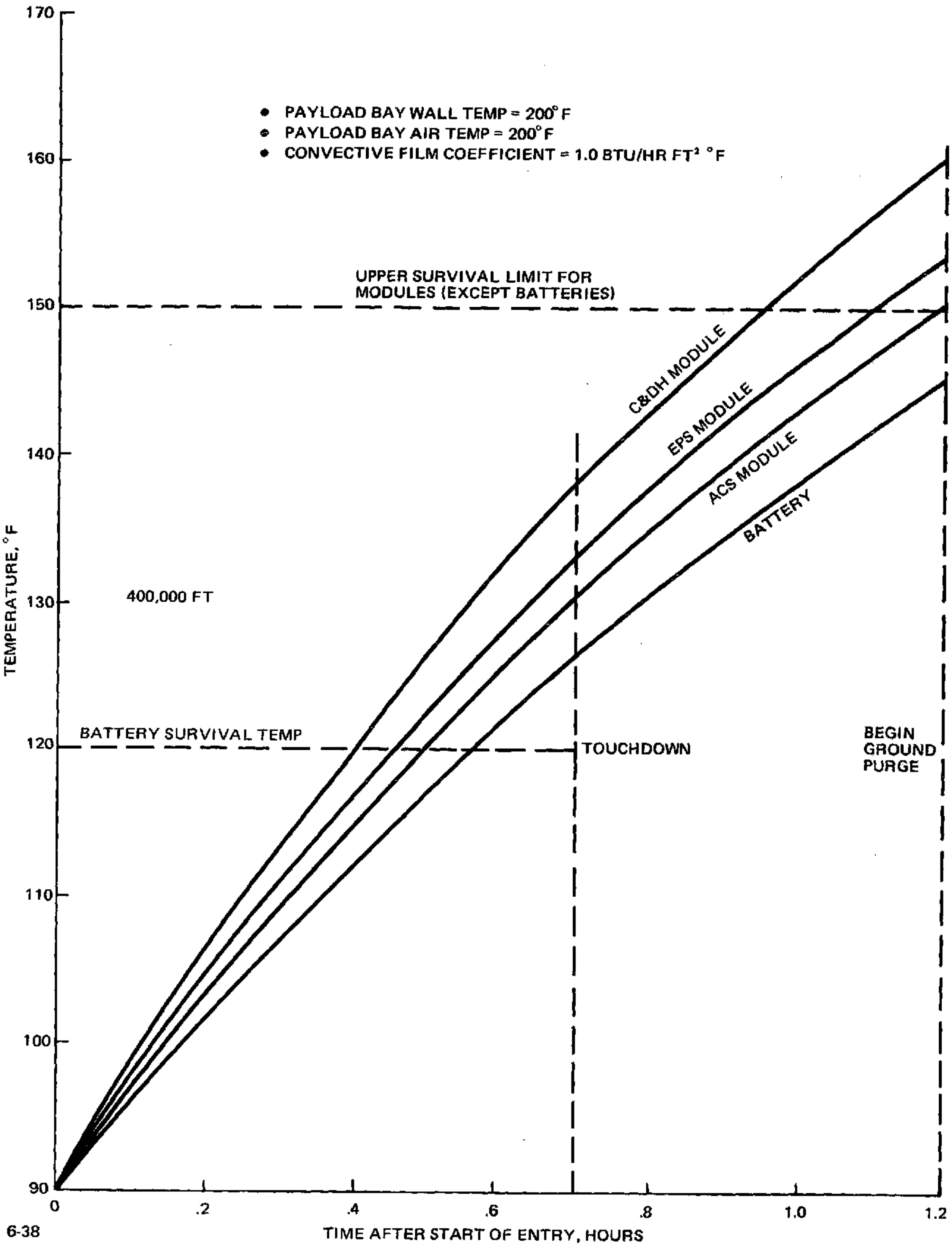


Fig. 4-6 Shuttle Utilization Mission – Module Transient Temperature during Entry

thermal boundary conditions during entry, particularly in the free convection vs forced convection regimes. It is assumed that future Shuttle ICD's will contain this type of information, since convective heat transfer between the EOS modules and the payload bay air should dominate over radiative heat transfer to the payload bay walls during entry and post-landing mission phases.

4.1.5.3 DESIGN CHANGES

The necessary thermal design changes and associated impacts to satisfy the Shuttle compatibility requirements developed in subsection 3.2.5 are defined in Tables 4-8 and 4-9, respectively. As previously stated, only the batteries are expected to exceed their upper survival limit temperature during re-entry, but it has been assumed that batteries will not be re-used. Hence, no change has been identified relative to the P/L bay environment. The remaining changes entail additional thermostats and insulation blankets

The required changes to a typical module heater control circuit to implement the powered-down survival mode requirement (Requirement 2) are shown schematically in Fig. 4-7.

In normal operation, the relay is enabled and the heater duty cycle is controlled by the thermostat set at the minimum operating temperature. During powered-down survival mode operation, the relay is disabled and temperature control is transferred to the survival temperature thermostats. The duty cycle of the heaters, and, therefore, power demands, is substantially reduced to provide survival temperature operation. If recovery from a survival mode is required, the relay is enabled and the module heaters operate continuously until the module warms to the minimum operating temperature, at which time the heaters duty cycle to maintain this temperature. This concept achieves maximum economy by using the heaters provided for the on-orbit operating mode for all three mode of operation (i.e., operating temperature control, survival temperature control, and recovery from survival).

Additional factors which may influence the heater circuit designs include:

- Basic spacecraft operating temperature heaters may not be in suitable locations for survival temperature control. This would require revised heater circuit layouts
- Survival heater circuits (lower wattage) may not be compatible with on-orbit heater circuits (higher wattage). This would require additional heater circuits
- Specific temperature requirements at Shuttle pickup points (module or vehicle) may require the use of additional heater circuits at these locations

Table 4-8 Thermal Design Changes

FUNCTIONAL ELEMENT: BASIC SPACECRAFT

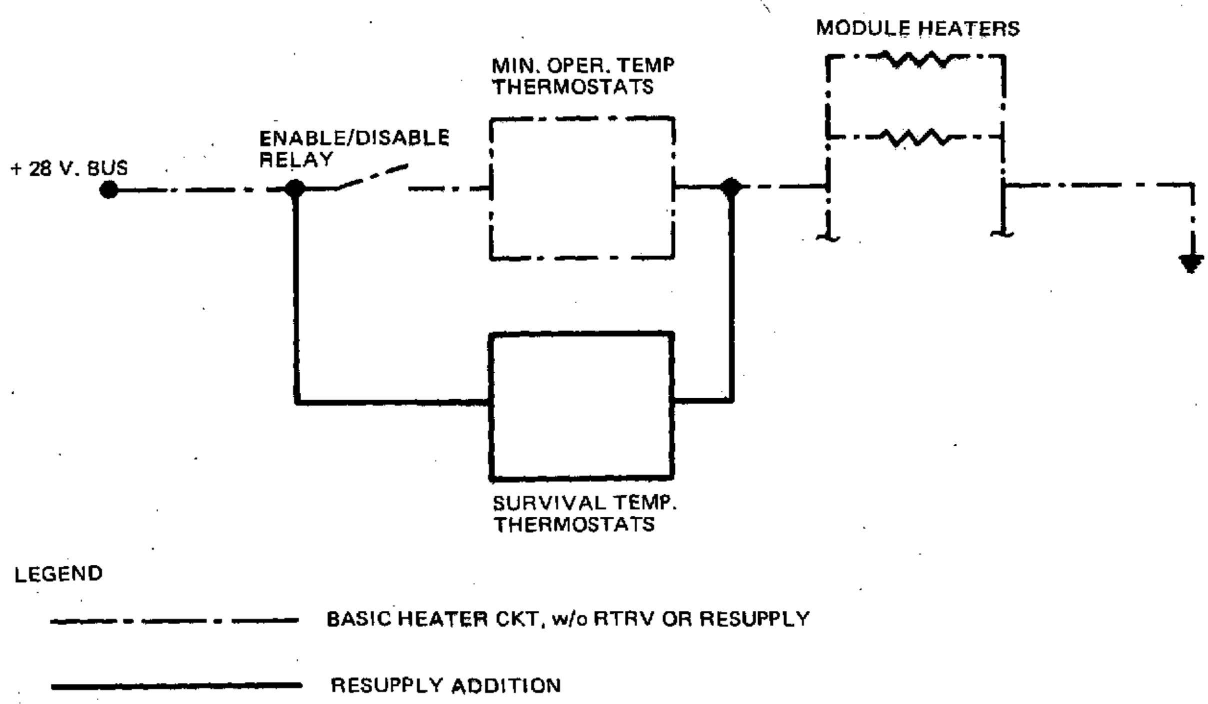
DISCIPLINE	EOS MISSION						SHUTTLE MODE			REMARKS
	A	B	C	D	E	F	DELIVER	RETRIEVE	RESUPPLY	
THERMAL	X	X	X	X	X	X	1. P/L Bay No Change.			In general, thermal inertia of S/C modules is adequate to maintain internal equipment temperatures within non-operating survival limits.
								2. Survival Mode Temp Add low temp thermostats to each heater circuit to maintain survival temp.		
									3. Module Stowage Same as Change 2.	Assumes that appropriate power/signal circuits are inherent in the module stowage magazine (MM) design and heater control will be provided by survival mode thermostats (see Item 2).
									4. Thermal Balance Add insulation blankets to structure to provide thermal closure while modules are removed.	

T6-33

Table 4-9 Thermal Impact Assessment

CHANGE	MISSION						DELIVER			RETRIEVE			RESUPPLY		
							WT	COST ($K)		WT	COST ($K)		WT	COST ($K)	
	A	B	C	D	E	F	(lb)	NON-RECUR	RECUR	(lb)	NON-RECUR	RECUR	(lb)	NON-RECUR	RECUR
• Low Temp Thermostats	X	X	X	X	X	X				0.4	7	4.7	0.4	7	4.7
• Additional Insulation Blankets													18	13	13.7
TOTAL							0	0	0	0.4	7	4.7	18.4	20	18.4

T6-34



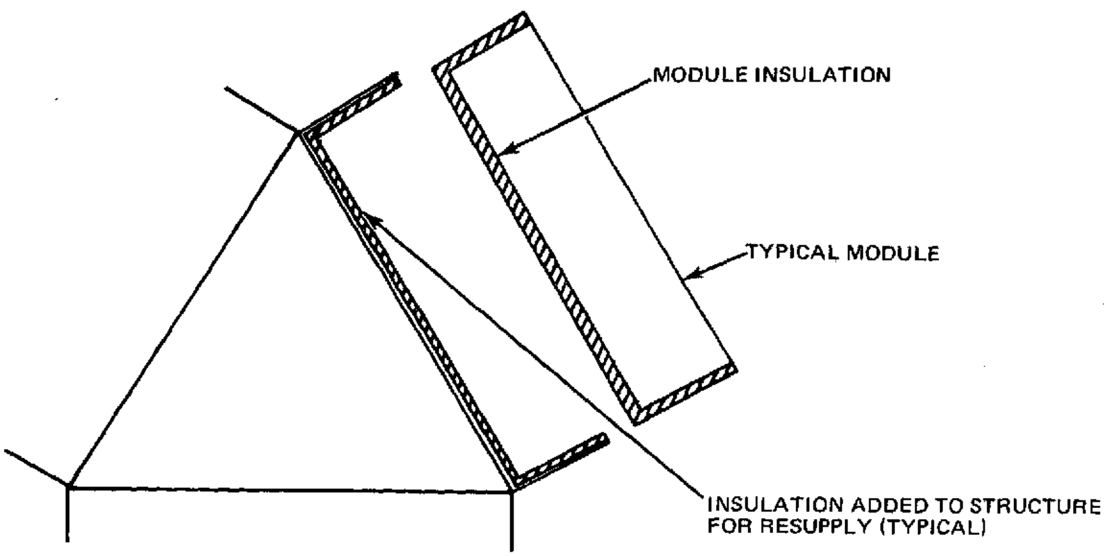
6-53

Fig. 4-7 Survival Mode Temperature Control

- If it is determined that it is not acceptable, during resupply, to permit new modules to go below operating temperature limits (in a non-operating mode), then additional circuitry would be required to elevate module temperatures prior to the resupply activity.

The required changes to the spacecraft thermal insulation for the Shuttle resupply mission for a typical subsystem module are shown in Fig. 4-8.

The added structure insulation insures that adverse thermal heat losses or gains do not occur during the module replacement activity due to exposure of bare structure to space. A similar insulation blanket is required at the interface between the module structure and propulsion module.



6-54 **Fig. 4-8 Typical Additional Insulation Installation**

4.1.6 PROPULSION

The propulsion design changes, and resultant weight/cost impacts, necessary to comply with the Shuttle compatibility requirements derived in Subsection 3.2.6 are compiled in Tables 4-10 and 4-11, respectively. Impacts on all EOS concepts except EOS-C and -E are minimal, about 3 lb and $33 thousand non-recurring, because of the inherent capabilities of the baseline design. Significant impacts result for EOS-E in all Shuttle modes because of the need for an OTS to achieve and return from mission orbit. EOS-C realizes a negative impact since the OTS required for circularization when delivered by a conventional launch vehicle is not needed for Shuttle operations.

Table 4-10 Propulsion Design Changes

FUNCTIONAL ELEMENT: BASIC SPACECRAFT

DISCIPLINE	EOS MISSION						SHUTTLE MODE			REMARKS
	A	B	C	D	E	F	DELIVER	RETRIEVE	RESUPPLY	
PROPULSION - Orbit Adjust - Reaction Control - Orbit Transfer	X	X	X	X	X	X	1. Pressure Relief a. Add GN_2 pressure relief valve and burst disk assembly to propellant storage. b. Add GN_2 pressure vent valves to propellant storage			See Figure 4.1.6-1
							2. Fail Safe Thruster Opn No Change			Fail safe op'n is inherent in basic S/C design
							3. Crash Load Prop. Retention Modify tank and supporting structure to withstand increase in lateral loads from 2.0 to +2.0, - 4.5 g's			a. Only Z-axis loads exceed conventional launch vehicle environment(see subsection 3.7.2) b. Necessary design conditions factored into initial s/c design will result in indiscernable weight/cost impacts.
					X		4. Orbit Transfer a. Off-load modified Star 17 SRM to raise apogee from 168 to 450 n mi. b. Add off-loaded modified Star 17 SRM to circularize at 450 n mi.	4. Orbit Transfer Same plus: a. Add off-loaded modified Star 17 SRM to lower perigee from 450 to 168 n mi. b. Add off-loaded modified Star 17 SRM to circularize at 168 n mi. c. Modify propulsion module to accommodate 4 SRM's.		a. Shuttle parking orbit of 168 n mi allows use of same SRM as for conventional launch with off-loading. b. If the Shuttle employs an elliptical orbit with a 450 n mi apogee, one SRM can be eliminated from Dlvr and two from Rtrv. and Resupply.
						X	4. Orbit Transfer No Change			Integral kick-stage is impractical. Assume Space Tug availability.
									5. Structural Attachment No change to Propulsion design	Attachment mechanisms are covered in Struct/Mech, subsection 4.1.4
									6. Supply/Power Circuits No change	Circuit connectors are covered EPS, subsection 4.1.2

T6-35

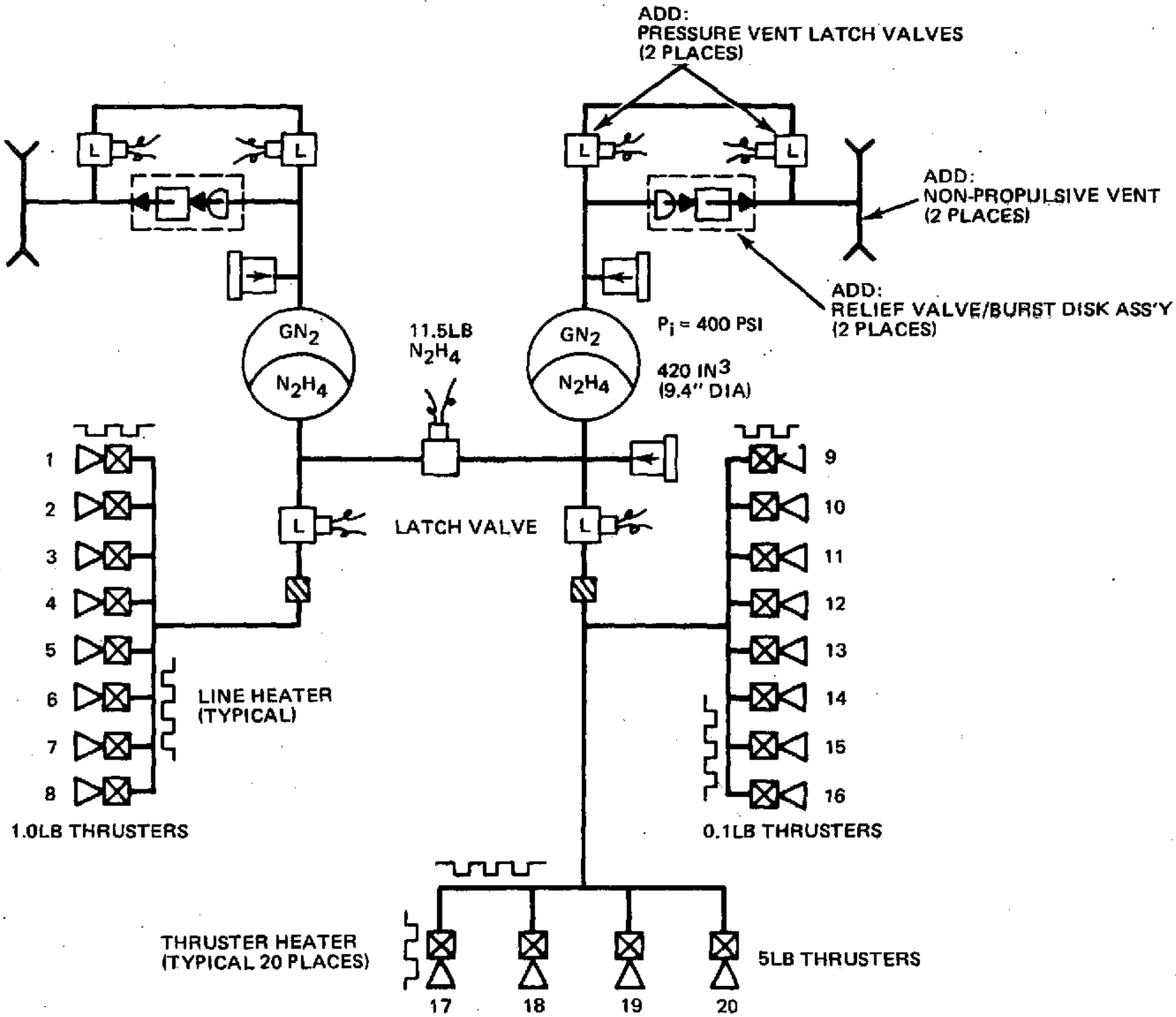
Table 4-11 Propulsion Impact Assessment

CHANGE	MISSION						DELIVER			RETRIEVE			RESUPPLY		
							WT	COST ($K)		WT	COST ($K)		WT	COST ($K)	
	A	B	C	D	E	F	(lb)	NON-RECUR	RECUR	(lb)	NON-RECUR	RECUR	(lb)	NON-RECUR	RECUR
Pressure Relief	X	X	X	X	X	X	2	33	5.4	2	33	5.4	2	33	5.4
Pressure Vent	X	X	X	X	X	X	1.5	0	3.5	1.5	0	3.5	1.5	0	3.5
Orbit Transfer					X										
- SRM's							177	100	115	524	100	230	524	100	230
- Structural Support							25	50	13	74	148	37	74	148	37
- RCS Prop (TVC)							3	-	-	7	-	-	2	-	-
Orbit Transfer			X												
- SRM's							-256		-115	-256		-115	-256		-115
- Structural Support							- 37		- 18	- 37		- 18	- 37		- 18
- RCS Prop (TVC)							- 4		-	- 4		-	- 4		-
TOTAL	X	X		X		X	4	33	8.9	4	33	8.9	4	33	8.9
			X				-293	33	-124	-293	33	-124	-293	33	-124
					X		209	183	-137	609	281	276	609	281	276

T6-36

A relief valve has been added to each OA/RCS propellant tank (see Fig. 4-9) to provide an automatic pressure relief capability for such contingency situations as propellant temperature exceeding 120°F and causing an over-pressure condition. A non-propulsive vent external to the OA/RCS module is provided to assure that the Observatory is not disturbed if the GN_2 is relieved during free flight. The same vent assembly will exhaust the GN_2 into the Orbiter cargo bay if an overpressure condition occurs while the EOS is still within the Shuttle. A dedicated umbilical panel and overboard venting system is not considered necessary since only inert GN_2 is vented; the propellant is retained by a diaphragm. The GN_2 can be carried outboard of the Orbiter through the existing cargo bay vent ports.

In addition, a set of latching solenoid valves has been added to each propellant tank (see Fig. 4-9) to enable reduction of tank pressure to a safe level prior to Orbiter descent in the event of a mission abort in the Deliver mode and EOS return in the Retrieve or Resupply modes. Grumman's Space Tug System Study established that a pressure level of 20 psi meets the safety requirements of manned flight while assuring that the propellant tank



6-40

Fig. 4-9 OA/RCS Schematic

will not implode due to cargo bay ambient pressure build-up during entry. The non-propulsive vent described in conjunction with the relief valve will also be utilized here. Here, too, a dedicated umbilical and overboard venting system is not required.

Figure 4-9 shows that the OA/RCS baseline includes latch valves upstream of the individual thruster valves. With these latch valves closed, a viable operational procedure when operating near or contained in the Orbiter, there is inherent dual protection against inadvertant thruster firing.

When the EOS mission orbit is beyond the inherent capabilities of the Orbiter, a kick stage must be added to the Propulsion module. Based on the performance assessment of subsection 5.2, EOS-E and -F are beyond Shuttle capabilities in all utilization modes reflected in Requirement 4.

EOS-F is an equatorial geosynchronous mission. The development of an integral EOS kickstage to support these orbital characteristics will be equivalent to developing an Orbit-to-Orbit Shuttle (OOS) or Space Tug in terms of performance and guidance capabilities. In light of the planned development of OOS and Tug in time frames compatible with EOS utilization of Shuttle, it has been assumed that they will be available to provide the necessary performance augmentation, and therefore, no OTS implementation is anticipated for EOS-F.

The 450 n mi mission orbit of EOS-E necessitates an OTS for all Shuttle utilization modes. Baseline EOS-E deployment is accomplished via a Titan IIIB, requiring an EOS OTS, comprised of a single SRM, for circularization. The SRM selected was a modified Star 17 motor. For Shuttle utilization, individual SRM's are required for orbit transfer and circularization. Hence, Deliver entails two SRM's, and Retrieve and Resupply four SRM's. If the baseline design SRM (i.e., a modified Star 17) is utilized, the resultant Shuttle parking orbit is approximately 140 n mi, somewhat below the optimum Shuttle operating orbit derived from previous NASA studies. In lieu of specifying a new-development SRM, which would entail significant cost, variants of the baseline modified Star 17 motor were investigated. Off-loading of 10% results in an $I_t \approx 47,800$ lb-sec, yielding a Shuttle parking orbit of 168 n mi, which, although below the 200 n mi altitude baselined for this study, is totally acceptable for Shuttle operations. Off-loading SRM's by 10% is well within the current state-of-art. Accordingly, the off-loaded, modified Star 17 has been assumed for the Shuttle compatible EOS-E to exploit the economic advantages over new development SRM's.

EOS-E can be accommodated using an OOS or Tug. If this approach is adopted, the OTS can be eliminated entirely, but relative costs may not be competitive and Tug length requirements may impact installation.

4.1.7 ON-BOARD SOFTWARE

The Shuttle compatibility requirements developed in Subsection 3.2.7 encompasses two software-related functions:

- Output of spacecraft status data for safety-of-flight monitoring
- Output of spacecraft status data for mission suitability assurance.

Both of these functions are inherent in the baseline EOS concept onboard software in terms of the telemetry downlist which provides the status of all systems, and indicator words which summarize the results of automated spacecraft checkout routines (OBC). The implications of Shuttle compatibility entail formulation of the Orbiter mission specialist station to accept the EOS telemetry output as a data source and loading the EOS available computer core with the appropriate test programs. Based on the current level of EOS and Shuttle definition, no impact can be identified against either implication. The Shuttle does have available computer memory dedicated to payload support which can be utilized to implement the processing of the EOS data stream. The necessary EOS test programs need be no different than those utilized for pre-flight mission readiness verification and in-flight initial checkout of the baseline EOS. Nominal POCC contact message implementation provides the necessary input capability.

4.2 INSTRUMENT/MISSION PECULIAR EQUIPMENT

The design changes necessary to meet the Shuttle compatibility requirements defined in Subsection 3.3 are listed in Table 4-12. As indicated, there are no changes to the functional design of any equipment. Where changes are necessary in physical characteristics (i.e., Changes 3 to 6), they are common to Basic Spacecraft implementations and have been addressed in the appropriate disciplines as referenced. Requirements 2 and 7, which could impact spacecraft design, can be accommodated with operational procedures.

Table 4-12 (Change 1) shows that definition of spacecraft design is not sufficiently advanced to permit an accurate assessment of the impact of the Shuttle environment. Based on the acoustic and loads environments defined in Subsection 3.7, however, no significant changes are expected, and if those changes which are necessary are factored into initial designs, the resultant impact on equipment weight and cost will be virtually zero.

Table 4-12 Instrument/Mission Peculiar Equipment Design Changes

FUNCTIONAL ELEMENT: Instrument/Mission Peculiar Equipment

DISCIPLINE	EOS MISSION						SHUTTLE MODE			REMARKS
	A	B	C	D	E	F	DELIVER	RETRIEVE	RESUPPLY	
Inst/Mission Peculiar Equip	X	X	X				1. Shuttle Environment No Change. Environment is not sufficiently different to indicate any design changes at current level of design def'n.			
							2. RCS Plume Impingement No Change to Instrument Design			Inhibiting Orbiter upward firing jets will minimize potential contamination
								3. Survival Add low-temperature thermostats to maintain non-operating temperatures		Temp control is covered in Basic Spacecraft, Thermal Control, subsection 4.1.5
								4. Appendage Retract No Change to functional design		Retraction mechanisms are covered in Basic Spacecraft, Struct/Mech., subsection 4.1.4
									5. Structural Attachment No Change to functional design	Attachment mechanisms are covered in Basic Spacecraft Struct/Mech., subsection 4.1.4
									6. Signal/Power Circuits No Change to functional design	Circuit connectors are covered in Basic Spacecraft, EPS, subsection 4.1.2
									7. Alignment No Change. Use in-flight calibrations	

T6-37

Instrument baselines currently include movable covers on almost all contamination-sensitive surfaces to provide protection during conventional launch and various situations anticipated during the conduct of the mission. Never-the-less, direct impingement from Orbiter RCS plumes would increase the probability of Instrument performance degradations due to condensate and particulate contamination. As noted in Change 2 of Table 4-12, this condition can be avoided simply by inhibiting those Orbiter upward-firing jets whose plume patterns infringe upon the EOS during mated and near-in operations. This issue has been previously recognized by the FSS contractor (Reference 7). An alternate solution, though highly undesirable, is to incorporate sealable movable covers on all sensitive surfaces, sufficient to withstand the effects of direct impingement. Due to the complex design problems associated with such an approach, it has been assumed that the operational restriction of jet firing is acceptable to Orbiter operations.

Instrument-spacecraft alignment errors which may result from on-orbit module replacement (Requirement 7) are not expected to be significantly different than those arising from the stresses of powered ascent, whether induced by Shuttle or a conventional launch vehicle. In the baseline concept, alignment errors will be determined and calibrated out in flight through use of a combination of ephemeris data, ground control points, and spacecraft attitude control. This same approach is considered acceptable for the Shuttle operations.

4.3 FLIGHT SUPPORT SYSTEM

The FSS is currently under development. Due to the design variations among the participating EOS Study contractors, it has not been possible to conduct detailed assessments of the implications of the changes resulting from the Grumman approach to EOS design. In general, this section identifies the changes which could be made in the FSS concept to better meet the needs of each of the three candidate Shuttle utilization modes. Impact estimates for complete assemblies have been extracted from Reference 2. The basic intent is to identify areas of future study, either by the FSS developer or EOS study contractors, to optimize interface design.

4.3.1 PAYLOAD RETENTION AND POSITIO [illegible] IG

To date, generic FSS baselines have be[illegible] leveloped and costed for two classes of EOS, a heavy Titan class (4000 lb plus) and a [illegible] hter Delta class (about 3000 lb). Within the limits of current design definition, the current FSS baseline (Titan class) defined in Reference 2 will meet the full range of EOS-A through EOS-E physical characteristics called out in Requirement 1. Table 4-13 shows that no basic changes are deemed

Table 4-13 Payload Retention and Positioning Design Changes

FUNCTIONAL ELEMENT: FLIGHT SUPPORT SYSTEM

DISCIPLINE	EOS MISSION						SHUTTLE MODE			REMARKS
	A	B	C	D	E	F	DELIVER	RETRIEVE	RESUPPLY	
PAYLOAD RETENTION AND POSITIONING	X	X	X	X	X		1. Structural Support No Change. Titan class FSS will meet necessary range.			Additional study necessary to accommodate two EOS S/C.
						X	2. EOS-F Support No Change. FSS now intended to support Tug.			
	X	X	X	X	X		3. Emergency Release No immediate change.			Requirement has been previously identified. Implimentation is part of refining design details
							4. Structural Attachement No Change. Annular clamp arrangement is compatible with discrete attach points.			Additional attach point forward of cradle to provide ± Z load compensation is potential requirement
							5. Docking Interface Incorporate Delta-class interface arrangement for Titan-class EOS.			
							6. Indexing Delete EOS rotation mechanism		6. Retain Current concept	

T6-38

necessary for a single EOS mission approach. The baseline FSS, however, is not compatible with multiple spacecraft delivery or retrieval as currently conceived. Because of the interaction between the Retention Cradle and Positioning Platform, it appears that a pair of these components is necessary for each EOS carried. This seems to be an undue penalty ($\approx$ 2000 lb) and means should be explored that will eliminate this need.

EOS-F does not enter into consideration as an impact to FSS design. The Space Tug will impose a unique set of support requirements upon the Orbiter, as yet undefined, which will preclude any application of the FSS as currently conceived.

From an EOS standpoint, the most effective mating with the Orbiter for structural support is via discrete attach points located on the upper bulkhead rather than a continuous, circumferential ring. At present, the EOS design incorporates six individual pick-up points, one at each intersection of the structural longerons and the upper bulkhead. Due to the distribution of these points around the periphery of the spacecraft (see Fig. 4-10), the configuration is, in essence, a segmented ring which appears compatible with the current Retention Cradle clamp arrangement. The introduction of the discrete point attachment concept suggests that a trusswork support assembly could be viewed as a viable alternative to the cradle concept. It should be noted that there are indications that, regardless of the configuration of the Retention Cradle (or truss), an additional snubber may become necessary in a more forward location to accept the $\pm$Z loads resulting from the cantilevered support approach. This is particularly applicable to those EOS concepts entailing lengthy installations forward of the upper bulkhead (e.g., EOS-C).

The area offering the most significant reduction in FSS weight is the Positioning Platform. For Deliver and Retrieve, it appears viable to dispense with the platform entirely. If the PDRM can safely maneuver the spacecraft directly to and from the cradle, the platform can be deleted, reducing EOS- chargeable payload weight by approximately 1400 lb and cost by $1.2 million (non-recurring plus first flight unit). The Positioning Platform is the single most weighty and costly item in the PRPS.

4.3.2 PAYLOAD DEPLOYMENT AND RETRIEVAL

The PDRM is a general purpose device intended to interface with the full range of Shuttle payloads. There are no characteristics unique to EOS which will influence its design.

As previously discussed in Subsections 3.4.2 and 4.3.1, the potential for using the PDRM to effect EOS deployment and retrieval without employing the Positioning Platform should be explored.

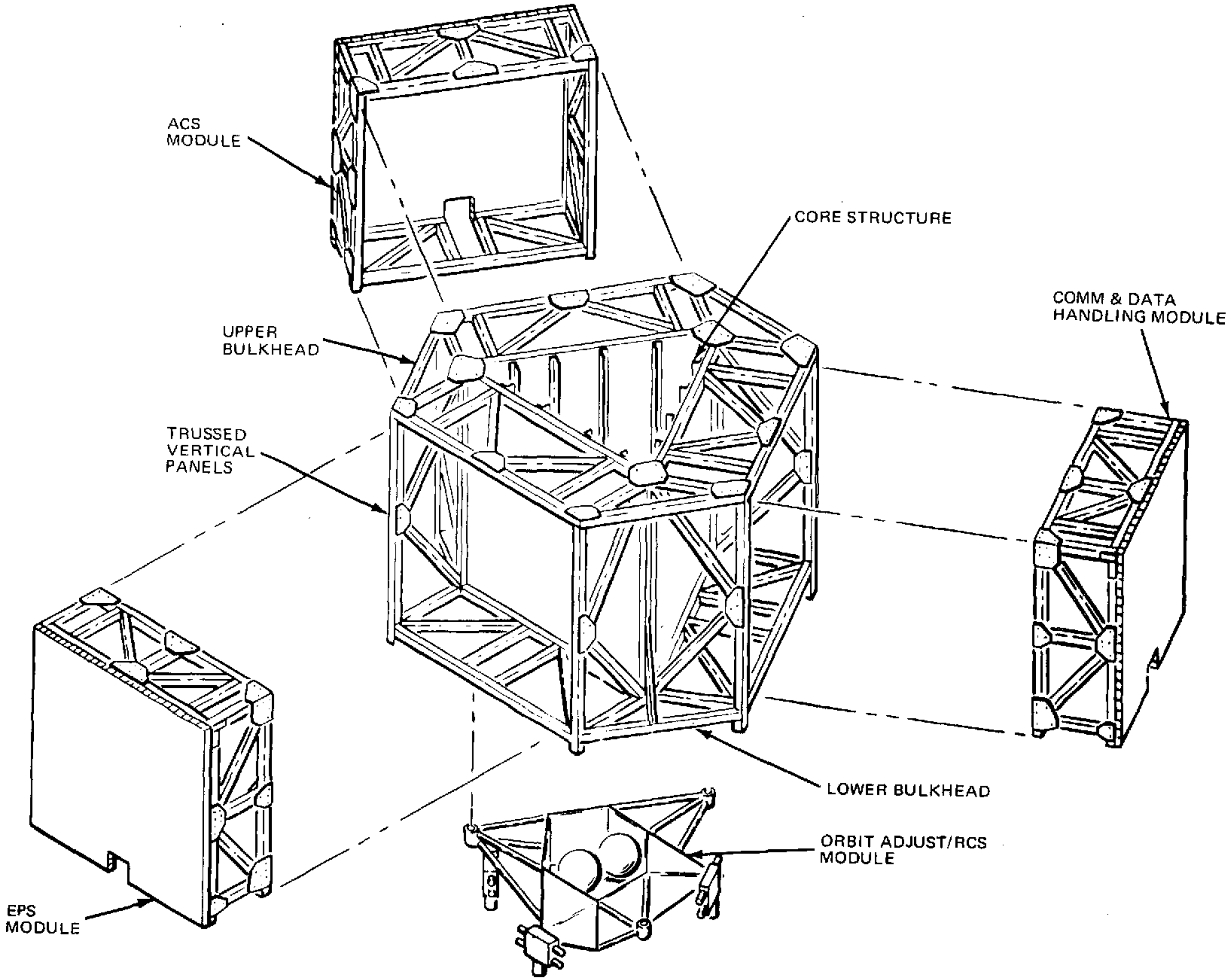


Fig. 4-10 EOS Basic Spacecraft – Exploded View

In addition, with the incorporation of the Grumman module latching mechanism for Resupply, the required module exchange forces have been reduced to a level within the reach of PDRM capability ($\approx$ 10 lb). It is suggested that additional study be undertaken to determine the potential for using the PDRM to effect module exchange in lieu of the SPMS, considering such factors as tip forces, accuracy, stability, and speed.

4.3.3 PAYLOAD RESUPPLY

Specific design changes associated with the requirements defined in Subsection 3.4.3. have not been delineated in this study. The requirements are sufficiently explicit in themselves to indicate the necessary changes and the available level of SPMS definition does not lend itself to detailed impact assessment.

It has been assumed that the Module Magazine (MM) will contain the appropriate wiring and connectors to accommodate necessary power and signal circuits to the replacement modules in stowage in response to Requirements 3 and 4. In any event, even if not currently included, the design impact of incorporating these provisions will be minimal.

The most significant effect of the Grumman EOS design approach is the single-operator latch mechanization for module replacement. This approach yields a significantly simpler operation in the removal and replacement of spacecraft modules and requires effector forces in the order of 10 lb. It would appear that these two factors could result in a simpler mechanization of the term: l device and a lighter construction approach for the entire mechanism.

4.3.4 ANCILLARY ORBITER SUP RT

Currently defined payload su rt provisions are adequate for EOS purposes. Specific software and console design have not been addressed at the current level of EOS definition.

4.4 PRE/POST FLIGHT OPERATIONS

The impact on the design and cost of logistics and support elements which make up pre/post-flight operations has been evaluated based on the concept that the POCC crew will be utilized to provide the support to these efforts.

4.4.1 GSE

All GSE becomes part of the POCC after the last deliverable EOS spacecraft. The POCC will be responsible for the maintenance and operation of such equipment thereafter.

Any modification required to the GSE for Shuttle compatibility must be completed prior to POCC acceptance. Table 4-14 lists only those GSE items from Table 3-15 that either require modification or are new end-items not in the EOS/Delta inventory. Table 4-15 summarizes the associated costs as well as the costs associated with each of the following areas.

4.4.2 MANAGEMENT

The management of logistics and support for EOS is provided by the POCC team.

4.4.3 TRANSPORTATION/HANDLING

It is assumed that, for an alternate-site landing, the EOS modules are removed from the SPMS and returned to the prime site independent of the SPMS shipment. The module handling and transportation equipment exists and that for the SPMS is provided by the SPMS fabrication. The module equipment is maintained by the POCC crew.

4.4.4 DATA MANAGEMENT

The initial EOS data base is turned over to POCC management. This includes all vehicle and GSE data.

4.4.5 PUBLICATIONS

Maintenance manuals for EOS flight equipment and GSE will be maintained by POCC.

4.4.6 PERSONNEL/TRAINING

POCC personnel will be provided with training in all aspects of EOS operation and maintenance as well as the operation and maintenance of the GSE.

4.4.7 SPARES/INVENTORY

Spares for the GSE are estimated at 25 percent of the overall GSE procurement parts cost. These are turned over to the POCC. Spares for the EOS have been estimated elsewhere.

4.4.8 TOOLS

POCC assumes control of the existing EOS tools.

4.4.9 FACILITIES

The maintenance and launch preparation facilities are provided and maintained by the launch center.

Table 4-14 Pre/Post-Flight Operations Design Changes

FUNCTIONAL ELEMENT: PRE/POST FLIGHT OPERATIONS

DISCIPLINE	EOS MISSION						SHUTTLE MODE			REMARKS
	A	B	C	D	E	F	DELIVER	RETRIEVE	RESUPPLY	
GROUND SUPPORT EQUIPMENT (Ref. Table 3-15)	X	X	X	X	X	X	1. Test Integration Station Modify front end to accept downlink and uplink to orbiter comm.			
							8. Interface Adapter Set 9. Hoist Bar & Sling Set Modify to permit installation of EOS horizontally into orbiter FSS.			
							15. EOS-Shuttle Comm. Interface Cable New End Item			
							16. Shuttle Umbilical Simulator New end item equivalent in complexity to Titan umbilical simulator			16. Possibility that minor mod. to Delta unit would suffice.
							17. Stage Motor Installation Fixture Modify Existing Fixture			
								18. Module Deployment Fixture New end item similar in complexity to solar array fixture.		

T6-39

Table 4-15 Pre/Post-Flight Operations Impact Assessment

CHANGE	MISSION A	B	C	D	E	F	DELIVER WT (lb)	DELIVER COST ($K) NON-RECUR	DELIVER COST ($K) RECUR	RETRIEVE WT (lb)	RETRIEVE COST ($K) NON-RECUR	RETRIEVE COST ($K) RECUR	RESUPPLY WT (lb)	RESUPPLY COST ($K) NON-RECUR	RESUPPLY COST ($K) RECUR
1. GROUND SUPPORT EQUIPMENT (1.7.4)															
• Interface Adapt. Set (1.7.4.2)	X	X	X	X	X	X		12.5			12.5			12.5	
• Shuttle Comm. Interface Cable (1.7.4.1)	X	X	X	X	X	X		2.7			2.7			2.7	
• Shuttle Umbilical Simulator (1.7.4.1)	X	X	X	X	X	X		30.0			30.0			30.0	
• Module Deployment Fixture (1.7.4.2)	X	X	X	X	X	X					51.0			51.0	
2. SPARES/INVENTORY (1.7.5.1)	X	X	X	X	X	X					100			100	
TOTAL	X	X	X	X	X	X		45.2			96.2			96.2	

T6-40

4.5 MISSION OPERATIONS

There are no design changes associated with the implementation of the Shuttle compatibility Requirements 1-4 defined in Subsection 3.6. The only impacts envisioned to support these requirements fall into two areas:

- Additional manpower to support additional mission planning efforts
- Additional communications links, voice and data, among NASA/GSFC, NASA/JSC, and, potentially, NASA/MSFC.

Manpower costs are estimated within the context of subsection 4.6 as part of the incremental total program cost. There is no need for additional POCC hardware since it has been structured around general purpose consoles which are adaptable for any mission operations function. While additional manpower is required to accommodate the mission planning activities, based on OAO experience, mission execution and mission analysis functions can be accomplished by the baseline complement of POCC personnel.

The necessary voice and data communications links already exist and can be enabled upon request by NASCOM. Thus, no impact is associated with Requirements 3 and 4.

4.6 DESIGN COST IMPACT ASSESSMENT

The total Recurring and Non-Recurring EOS-B cost impact associated with each Shuttle utilization mode have been identified as a function of Work Breakdown Structure (WBS) element and are listed in Table 4-16. In summary, the total costs (Non-Recurring) for each mode are:

Mode	Observatory	FSS	SPMS
Deliver (Deploy Only)	$0.41 million	$4.9 million	-
Retrieve (Deploy/Retrieve)	$2.18 million	$4.9 million	-
Resupply (Deploy/Retrieve/ Resupply)	$4.40 million	$4.9 million	$10.0 million

Table 4-16 EOS-Shuttle Compatibility Cost Impact Assessment (EOS-B, $K)

COST AREA	DEPLOY		DEPLOY/RETRIEVE		DEPLOY/RETRIEVE/ RESUPPLY	
	NR	R	NR	R	NR	R
PROGRAM MANAGEMENT – NASA (1.1)						
PROGRAM MANAGEMENT – CONTRACTOR (1.7.1)	23	23	111	91	185	90
SYS. ENGINEERING & INTEGRATION (1.7.2)	100	20	200	40	300	100
RELIABILITY & QUALITY ASSURANCE ( )	80	40	100	40	160	40
INTEGRATION & TEST (1.7.3.14)						
DEVELOPMENT TEST (1.7.7)	-0-		50		516	
ENVIRONMENTAL TEST (1.7.3.14)						
GSE S/C (1.7.4)	44		44		44	
GSE MISSION						
STRUCTURE (1.7.3.5)	62	30	150	30	521	160
HARNESS/SIG CONDITIONER (1.7.3)						
POWER (1.7.3.2)	34	22	34	30	76	49
SOLAR ARRAY (DRIVE) (1.7.3.7)	-0-	-0-	186	36	231	36
COMMUNICATIONS & DATA HANDLING (1.7.3.1)	90	373	90	373	90	373
ATTITUDE CONTROL SUBSYSTEM (1.7.3.3)						
REACTION CONTROL SUBSYSTEM (1.7.3.10)	33	5	33	9	39	9
AOP SOFTWARE (1.7.3.4)						
WBVTR (1.7.3.6)						
TM (1.3.1.1)						
MSS (1.3.2.5)						
DCS (1.3.1.3)						
TM DATA HANDLING (1.7.3.6)						
MSS DATA HANDLING (1.7.3.6)						
INSTRUMENT DATA HANDLING ( )						
W. B. COMMUNICATIONS (1.7.3.6)						
ORBIT TRANSFER SYSTEM (1.7.3.11)						
INSTRUMENT SUPPORT STRUCTURE (1.7.3.6)	-0-	-0-	416	235	620	380
ORBIT ADJUST SYSTEM (1.7.3.9)	70	35	70	35	70	35
NETWORK MODIFICATIONS (1.2.6.2) (1.4.1.6)						
CONTROL CENTER (1.4.1.4)						
CENTRAL DATA PROCESSING (1.2.1, 2, 3, 4, 7) (1.2.7.1, 3, 4, 5, 6)						
NETWORK OPERATIONS (1.4.1.1)						
CONTROL CENTER OPERATIONS (1.4.1.2, 3.5 & 7)	-0-		128		200	
DATA PROCESSING OPERATIONS (1.2.8) (1.2.10.2)						
DATA PROCESSING EXPENDABLES (1.2.9)						
LOW COST GROUND STATIONS (1.2.5 & 1.2.7.2)						
LOW COST GND. STATION OPS. (1.2.10.1)						
FOLLOW-ON INSTRUMENTS (1.3.1.2, 1.3.2.1, 2, 3, 4, & 6)						
LAUNCH SYSTEM (1.5)						
LOGISTICS SUPPORT (1.7.5)						
FACILITIES (1.7.6)						
SHUTTLE MANIPULATOR & STOWAGE SYS. (1.6)					10000	2500
FSS	4900	2100	4900	2100	4900	2100
CHANGEOVER TO LPS						
TOTALS	5313	2643	7079	3010	19296	5863

T6-41

When the costs of achieving EOS-B Observatory compatibility with the Shuttle are added to the 10-year program costs from the Shuttle utilization study (Fig. 6-7), the conclusion that Resupply is the most cost-effective approach is unaltered. As shown in Fig. 4-11, the net result is that Resupply becomes more beneficial than Retrieve at approximately one year and more beneficial than Deploy at 2.75 years, the Mean Mission Duration (MMD) of the spacecraft. This early benefit is even more prominent when considering a heavier and more costly instrument complement represented by EOS-C, as shown in Fig. 4-12. If the full non-recurring cost of developing the SPMS is added to Resupply, Retrieve becomes the most attractive approach throughout the 10-year program for EOS-B and for programs up to approximately 5.5 years for EOS-C type spacecraft. These cost comparisons are based on the cost makeup summarized in Table 4-17.

Costing Groundrules and Assumptions

The costs shown in Table 4-16 reflect both the labor and procurement costs of incorporating Shuttle compatibility requirements into the EOS-B (LRM) system for each of the three potential Shuttle utilization modes (i.e., Deliver, Retrieve, and Resupply).

Design costs against the EOS program WBS elements include items such as redundancy provisions, Shuttle safety-of-flight considerations (e.g., propellant tank relief valves and C&W mechanization), appendage retraction devices, spacecraft module replacement latches, and Shuttle FSS interface features.

Test and Integration, and operational costs include preparation of an EOS spacecraft for a Shuttle demonstration flight, additional development tests, Shuttle-unique GSE, phasing the EOS into the Launch Processing System, operational type maintenance manuals, and additional mission planning efforts. The Shuttle demonstration flight is considered necessary only for the Resupply mode since payload deploy and retrieve are not considered unique to EOS. It has been assumed that the qualification spacecraft can be updated for Shuttle flight status to serve as the demo model; the costs of this updating are included in development test for the Resupply option.

Shuttle transportation costs were not included in the design cost impact assessment (Table 4-16) since they are dependent upon the number of flights and transportation cost tariff structure. They are included in the Shuttle utilization analysis, Section 6.

The Shuttle Flight Support System (FSS) and Special Purpose Manipulator System (SPMS) non-recurring and recurring costs have been included for completeness since they are currently being developed for support of the EOS program. This type of equipment,

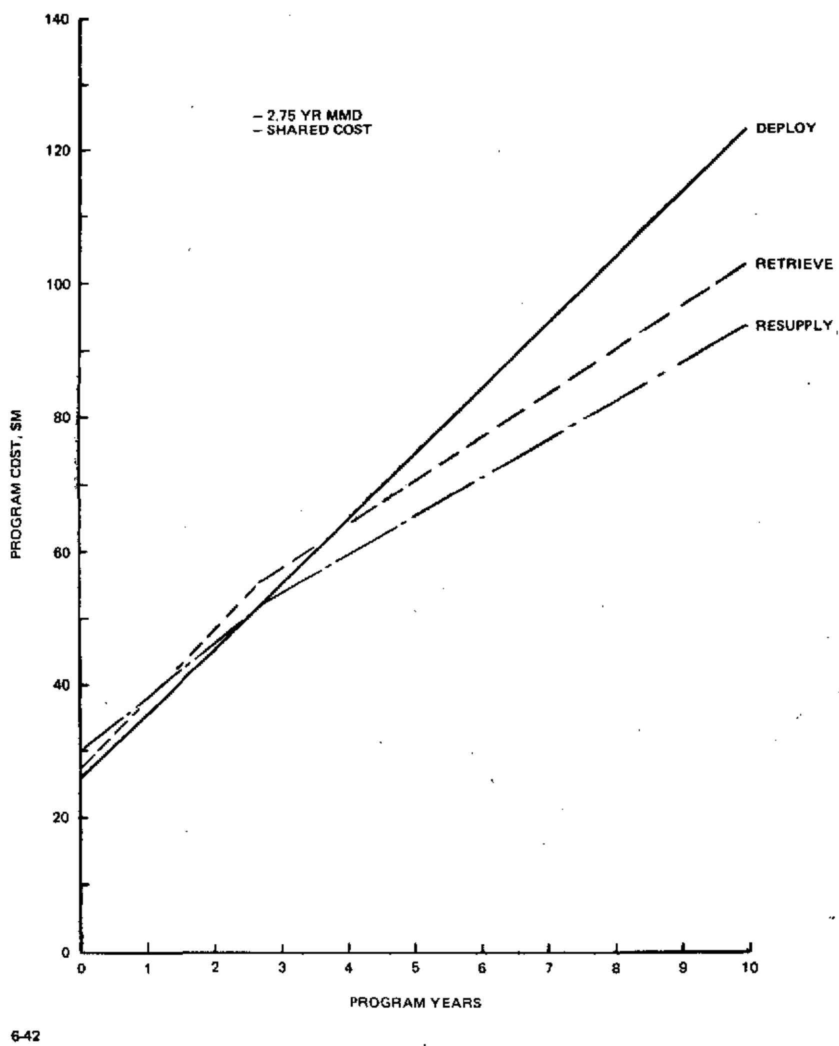


Fig. 4-11 Total Cost, EOS-B

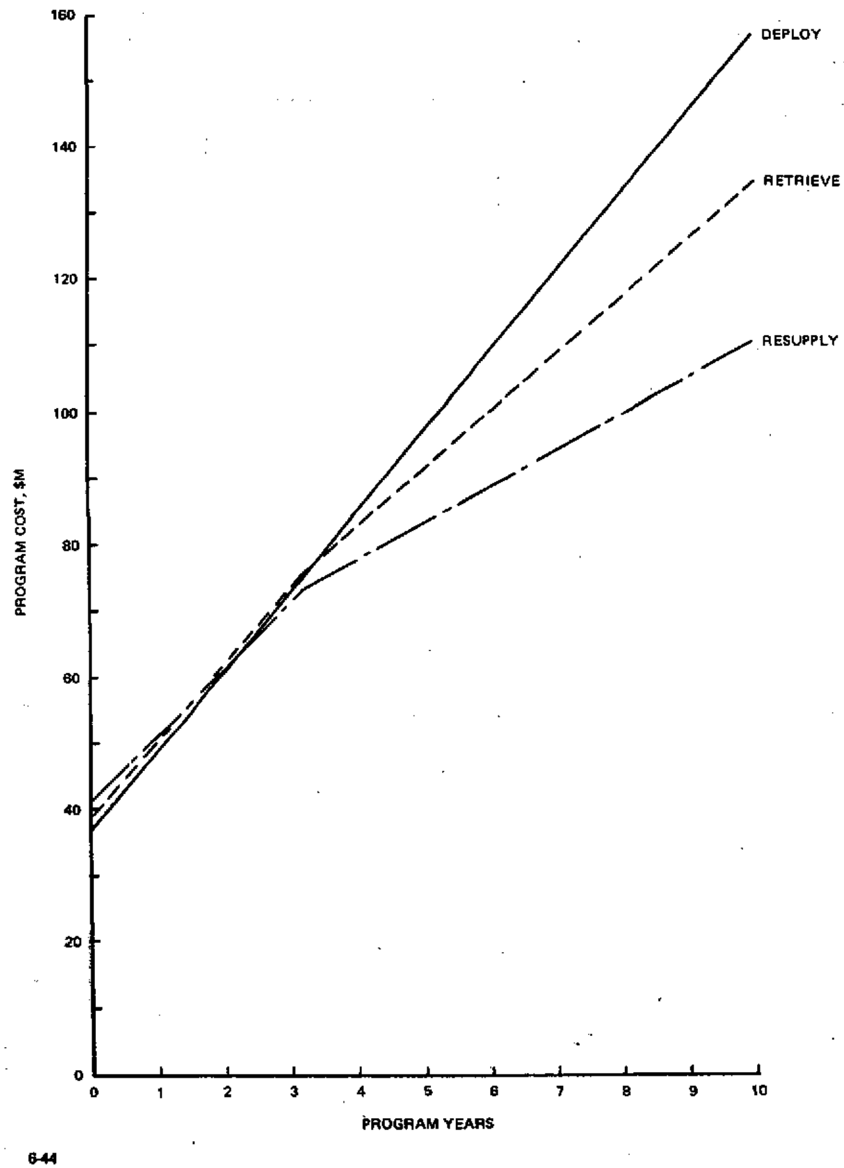


Fig. 4-12 Total Cost, EOS-C

however, is applicable to the majority of all Shuttle payloads, not just EOS, and their costs would normally be amortized across all users, significantly reducing the amount charged to the EOS.

Table 4-17 Program Cost Makeup

INCLUDED	NOT INCLUDED
• INITIAL OBSERVATORY • REPLACEMENT OBSERVATORIES - DELIVER ONLY • LOGISTICS - SPARE S/C (RTRV) - SPARE MODULES (RESUPPLY) • REFURBISHMENT • SHUTTLE TRANSPORTATION - PROPORTIONAL RATE • SHUTTLE COMPATIBILITY IMPACT	• BASELINE PROGRAM DEVELOPMENT • GROUND DATA SYSTEM • FLIGHT SUPPORT SYSTEM • MODULE EXCHANGE SYSTEM • MISSION OPERATIONS

T6-42

5 - MISSION SUITABILITY

5.1 PAYLOAD CHARACTERISTICS SUMMARY

A Shuttle payload model for the EOS missions was created for use as a base for further Shuttle utilization studies. This model includes those Shuttle-compatible spacecraft which have launch weights within the Shuttle payload capability.

The complete matrix of EOS missions and Shuttle operational modes (i.e., Deploy, Retrieve, and Resupply) was investigated and the weight of the total Shuttle payload determined for each case. EOS-A, -B, and -C were also investigated for dual spacecraft missions involving the deployment, retrieval, or resupply of two spacecraft on the same mission.

The spacecraft weights which apply to the Shuttle EOS Mission Model are shown in Tables 5-1, 5-2, and 5-3. As noted previously, these weights include the Shuttle compatibility design changes discussed in Section 4. The most significant changes included are:

	Weight (lb)
• Deploy	
- Positioning Table, and the Payload Deployment & Retrieval Mechanism	27
- Fail-safe redundancy in the CDH module for Shuttle crew safety	24
• Retrieve	
- Retraction and retention in the stowed position of deployable assemblies (e.g., Solar Array, TDRSS Antenna, and certain Instruments)	5 to 15
• Resupply	
- Addition of latch mechanisms and blind-mate electrical connectors to in-flight replaceable modules and assemblies	150

In addition, it will be noted that mission E requires kick stages for all Shuttle modes for single spacecraft missions. All three spacecraft investigated for dual spacecraft missions require kick stages for deploy, retrieve, and resupply. Utilizing kick stages enables the Shuttle to deliver the spacecraft to a parking orbit of lower altitude than the mission orbit. The EOS kick stage provides the necessary impulse to raise the spacecraft altitude to mission altitude and, at some later date, to lower the spacecraft to the Shuttle parking orbit for retrieval or resupply. A nominal Shuttle parking orbit of 200 n mi has been selected for all missions except EOS-E. The EOS-E requires four SRM's for any Shuttle mission to provide for a roundtrip between the Shuttle parking orbit and the 450 n mi mission altitude. The parking orbit used in this case was 168 n mi, since it allowed the use of the same basic

Table 5-1 Shuttle Payload Summary — Deploy/Retrieve Mission

FUNCTION	WEIGHT, LB						
	EOS-A BASELINE	EOS-A RESUPPLY	EOS-B	EOS-C	EOS-D SEASAT-B	EOS-E TIROS-O	EOS-F SEOS
• BASIC STRUCTURE	388	440	440	460	450	440	477
• ELECTRICAL POWER	169	169	169	201	201	169	169
• ELECTRICAL HARNESS	45	90	90	90	94	90	90
• SOLAR ARRAY & DRIVE	195	195	195	279	279	195	135
• ATTITUDE CONTROL	161	161	161	306	161	161	167
• RCS (HYDRAZINE)	40	40	40	40	40	40	54
• COMM & DATA HANDLING	146	146	146	146	146	146	137
• THERMAL CONTROL	62	80	80	80	140	80	155
SPACECRAFT, LB	*1206*	*1321*	*1321*	*1602*	*1511*	*1321*	*1384*
• MISSION PECULIAR	(338)	(391)	(399)	(687)	(395)	(1259)	(329)
– ORBIT/ADJUST/TRANSFER	27	27	27	43	27	886	27(2)
– INSTRUMENT SUPPORT	136	189	189	445	235	198	214
– TDRSS COMMUNICATION	87	87	87	87	87	87	–
– WB COMM & DATA HNDLG	88	88	96	112	46	88	88
• INSTRUMENTS	560	560	800	1700	706	770	2300
• CONTINGENCY	202	222	222	322	246	240	212
OBSERVATORY, LB	*2306*	*2494*	*2742*	*4311*	*2858*	*3590*	*4225*
• FLIGHT SUPPORT SYSTEM	2528	2528	2528	2528	2528	2528	200(1)
SHUTTLE PAYLOAD, LB	*4834*	*5022*	*5270*	*6839*	*5386*	*6118*	*4425*

NOTES: (1) FLIGHT SUPPORT SYSTEM FOR EOS-F CONSISTS OF EOS/TUG ADAPTER; PAYLOAD WEIGHT IS USED FOR COMPARISON TO TUG PERFORMANCE.
(2) KICK STAGES FOR 168 N MI PARKING ORBIT; FOR 200 N MI PARKING ORBIT SUBTRACT 100 LB.

TI-20
T6-43

Table 5-2 Shuttle Payload Summary — Resupply Mission

FLIGHT REPLACEABLE MODULES	WEIGHT, LB					
	EOS-A RESUPPLY	EOS-B	EOS-C	EOS-D SEASAT-B	EOS-E TIROS-O	EOS-F SEOS
• ELECTRICAL POWER	256	256	288	288	256	256
• SOLAR ARRAY & DRIVE	207	207	291	292	207	147
• ATTITUDE CONTROL	241	241	386	241	241	247
• RCS/ORBIT ADJUST/TRANSFER	111	111	127	111	970 (2)	125
• COMM & DATA HNDLG	229	229	229	229	229	220
SPACECRAFT MODULES, LB	*1044*	*1044*	*1321*	*1161*	*1903*	*995*
• INSTRUMENT MISSION PECULIAR BOX	123	131	147	81	123	123
• KU-BAND ANTENNA (TDRSS)	96	96	96	96	96	–
• X-BAND ANTENNA (2)	27	27	27	27	27	27
IMP MODULES, LB	*246*	*254*	*270*	*204*	*246*	*150*
• MULTI-SPECTRAL SCANNER	167	–	–	–	–	–
• THEMATIC MAPPER	407	407	407	–	–	–
• HRPI	–	407	814	–	–	–
• SYNTHETIC APERTURE RADAR	–	–	507	–	–	–
• SEASAT-B (5 MODULES)	–	–	–	750	–	–
• TIROS-O (8 MODULES)	–	–	–	–	832	–
• SEOS (3 MODULES)	–	–	–	–	–	2328
INSTRUMENT MODULES, LB	*574*	*814*	*1728*	*750*	*832*	*2328*
• TOTAL RESUPPLY	1864	2112	3319	2115	2981	3473
• FLIGHT SUPPORT SYSTEM	6035	6035	6035	6035	6035	550 (1)
• CONTINGENCY	146	146	170	160	162	114
SHUTTLE PAYLOAD, LB	*8045*	*8293*	*9524*	*8310*	*9178*	*4137*

NOTES: (1) FLIGHT SUPPORT SYSTEM FOR EOS IS EOS/TUG ADAPTER AND MODULE MANIPULATOR AND STOWAGE SYSTEM. PAYLOAD WEIGHT IS FOR COMPARISON TO TUG PERFORMANCE.
(2) KICK STAGE FOR 168-N MI PARKING ORBIT; FOR 200-N MI PARKING ORBIT SUBTRACT 100 LB.

TI-21
T6-44

Table 5-3 Shuttle Payload Summary - Dual Spacecraft Missions

CONFIGURATION	WEIGHT, LB			
	EOS-A (BASELINE)	EOS-A (RESUPPLY)	EOS-B	EOS-C
DEPLOY MISSION				
• SPACECRAFT WEIGHT - SINGLE	2,306	2,494	2,742	4,311
• ADD KICK STAGE PENALTY	396	426	561	931
SPACECRAFT WEIGHT - DUAL	*2,702*	*2,920*	*3,303*	*5,242*
• TOTAL SPACECRAFT WEIGHT - DUAL	5,404	5,840	6,606	10,484
• TOTAL FLIGHT SUPPORT SYSTEM	5,413	5,413	5,413	5,413
ORBITER PAYLOAD - DUAL DEPLOY	*10,817*	*11,253*	*12,019*	*15,897*
RESUPPLY MISSION				
• SPARES WEIGHT - SINGLE	–	2,004	2,252	3,494
• ADD KICK STAGE PENALTY	–	453	588	974
SPARES WEIGHT - DUAL	–	*2,457*	*2,840*	*4,468*
• TOTAL SPARES WEIGHT - DUAL	–	4,914	5,680	8,936
• TOTAL FLIGHT SUPPORT SYSTEM	–	11,116	11,116	11,116
ORBITER PAYLOAD - DUAL RESUPPLY		*16,030*	*16,796*	*20,052*

T1-22
6T-45

SRM (with propellant offloading) for the Titan IIIB-launched spacecraft and the Shuttle-launched spacecraft. The weight of SRM's required for the various missions requiring the use of a Shuttle parking orbit are shown in Table 5-4.

Table 5-4 Solid Rocket Motor (SRM) Weights for EOS Mission Model

• LAUNCH VEHICLE – EOS MISSION o MODE	SRM WEIGHT, LB			
	ASCENT		DESCENT	
	TRANSFER	CIRC	TRANSFER	CIRC
• TITAN III B (SSB)/NUS				
– EOS-C (1 S/C) DEPLOY	–	256	–	–
– EOS-E (1 S/C) DEPLOY	–	205	177 (1)	170 (1)
• SPACE SHUTTLE				
– CIRCULAR ORBIT				
o EOS-E (1 S/C) DEP/RES	196 (1)	186 (1)	177 (1)	170 (1)
o EOS-E (1 S/C) DEP/RES	172	163	155	150
o EOS-A (2 S/C) DEP/RES	97	93	90	88
o EOS-B (2 S/C) DEP/RES	127	124	118	116
o EOS-C (2 S/C) DEP/RES	211	203	197	193
– ELLIPTICAL ORBIT				
o EOS-A (2 S/C) DEP/RES	–	154	146	–
o EOS-B (2 S/C) DEP/RES	–	190	181	–
o EOS-C (2 S/C) DEP/RES	–	335	319	–

NOTES:
(1) SRM WEIGHTS SHOWN HERE FOR EOS-E ARE FOR 168 N MI PARKING ORBIT.
(2) UNLESS OTHERWISE NOTED, SRM WEIGHTS ARE FOR 200 N MI PARKING ORBIT.
(3) TOTAL KICK STAGE PENALTIES, INCLUDING SRM, STRUCTURE, TVC PROPELLANT AND PROPULSION ARE 16% GREATER THAN SRM WEIGHTS.
(4) FOR DUAL MISSIONS, SRM WEIGHTS PER SPACECRAFT (S/C) ARE SHOWN.

T1-26
6T-46

A major component of the Shuttle payload weight is the Shuttle Flight Support System, which is described in subsection 3.4. The Flight Support System consists of two major groups:

- Payload Retention and Positioning System (PRPS)
- Special Purpose Manipulator System (SPMS)

In addition to these, there is a set of Load Reaction Plates for each support installation.

For Deploy/Retrieve missions, only the PRPS is required. The weight breakdown of the PRPS installation is shown in Table 5-5. Note that the Orbiter weight includes a 495 lb allowance for payload support, which is used to partially offset the PRPS weight. Similarly, one Payload Deployment and Retrieval Manipulator (PDRM) is included in the Orbiter weight, but if a second PDRM is required, the weight must be included as part of the payload.

Table 5-5 Flight Support System Weight for Single Spacecraft Deploy/Retrieve

ITEM	WEIGHT, LB
• PAYLOAD RETENTION & POSITIONING SYSTEM	(2367)
– RETENTION CRADLE (RETENTION MECH)	624
– POSITIONING PLATFORM (DEPLOYMENT/DOCKING MECH)	1433
– DATA MGMT, ELECTRICAL, THERMAL	310
• LOAD RETENTION PLATES	(656)
– RETENTION CRADLE	328
– POSITIONING PLATFORM	328
• LESS: PAYLOAD RETENTION ALLOWANCE	495
• TOTAL	2528
NOTE: PAYLOAD DEPLOYMENT AND RETRIEVAL MECHANISM (PDRM) WEIGHT OF 730 LB IS INCLUDED IN THE ORBITER WEIGHT. IF A SECOND PDRM IS REQUIRED, THE WEIGHT IS CHARGED TO THE PAYLOAD.	

T1-23
6T-47

For Resupply missions, both the PRPS and the SPMS are required: the SPMS to store and handle the EOS spares complement; and the PRPS to provide for retrieval of the serviced Observatory in the event it does not check out following resupply, to provide spacecraft retention and indexing during resupply, and to provide structural support for the SPMS. The Flight Support System weight breakdown applicable to the Resupply mission is shown in Table 5-6.

The weight of the FSS required to handle the second spacecraft in a Dual Deploy/Retrieve or a Dual Resupply mission is shown in Table 5-7. For dual resupply missions, contingency retrieval is provided for only one spacecraft.

Table 5-6 Flight Support System Weight for Single Spacecraft Resupply

ITEM	WEIGHT, LB
• PAYLOAD RETENTION & POSITIONING SYSTEM	(2542)
– RETENTION FRAME (UNIQUE ASSY. FIXTURE)	175
– RETENTION CRADLE (RETENTION MECH)	624
– POSITIONING PLATFORM (DEPLOYMENT/DOCKING MECH)	1433
– DATA MGMT, ELECTRICAL THERMAL	310
• SPECIAL PURPOSE MANIPULATOR SYSTEM	(2840)
– MODULE EXCHANGE MECHANISM	1265
– MODULE MAGAZINE	1160
– MODULE MAGAZINE SUPPORT STRUCTURE	415
• LOAD REACTION PLATES	(1148)
– RETENTION FRAME	164
– RETENTION CRADLE	328
– POSITIONING PLATFORM	328
– SPECIAL PURPOSE MANIPULATOR	328
• LESS: PAYLOAD RETENTION ALLOWANCE	495
• TOTAL	6035

T-124
T6-48

Table 5-7 Dual Spacecraft Flight Support System

ITEM	DEPLOY – RETRIEVE, LB	RESUPPLY MISSION, LB
• SPECIAL PURPOSE MANIPULATOR SYSTEM	(–)	(2,840)
– MODULE EXCHANGE MECHANISM	–	1,265
– MODULE MAGAZINE	–	1,160
– MODULE MAGAZINE SUPPORT	–	415
• P/L RETENTION & POSITIONING SYSTEM	(2,229)	(1,585)
– RETENTION FRAME	–	–
– RETENTION CRADLE	624	–
– POSITIONING PLATFORM	1,433	1,433
– ELECTRICAL & THERMAL	172	152
• LOAD REACTION PLATES	656	(656)
– RETENTION FRAME	–	–
– RETENTION CRADLE	328	–
– POSITIONING PLATFORM	328	328
– SPMS	–	328
• FLIGHT SUPPORT SYSTEM NO. 2	2,885	5,081
• FLIGHT SUPPORT SYSTEM NO. 1	2,528	6,035
• TOTAL ORBITER FSS	5,413	11,116

NOTE: RESUPPLY MISSION PROVIDES FOR CONTINGENCY RETRIEVAL OF ONE OF THE TWO SERVICED SPACECRAFT IN THE EVENT THAT IT MUST BE RETURNED TO EARTH FOR REPAIR.

T1-25
6T-49

The FSS should be of primary interest in future Shuttle Utilization studies, since, in terms of Shuttle launch performance, the FSS weight is of equal magnitude and importance to the spacecraft weight. Therefore, the spacecraft and the FSS should be studied as a system, so that favorable tradeoffs can be made to reduce the overall payload weight. Alternate support concepts, taking advantage of the discrete EOS/FSS cradle interface points, should be explored. In addition, a complete downward resizing of the FSS to match the diameter of a triangular cross-section EOS configuration (84 in.) should be considered.

5.2 CONVENTIONAL LAUNCH VEHICLE AND SHUTTLE PERFORMANCE

5.2.1 CONVENTIONAL LAUNCH VEHICLE

Initial deployment of the EOS class of satellites can be accomplished using four types of conventional launch vehicles. Table 3-1 summarizes (for EOS missions A through F) the EOS mission orbit, launch vehicle and maximum deployment capability, and approximate launch date for each mission.

The Delta 2910, Delta 3910, and TITAN IIIB (SSB) are used to deliver EOS satellites which have sun-synchronous and polar mission orbits. The performance of each of these launch vehicles is shown in Fig. 5-1 for sun-synchronous orbits (EOS missions A, B, C & E) and Fig. 5-2 for the polar mission (EOS-D). Each figure also illustrates the projected weight of each satellite in comparison to launch vehicle capability. Figure 5-3 presents the same parameters for the TITAN IIIC7 launch vehicle which is used for the EOS-F mission to geosynchronous equatorial (19,323 n mi altitude, 0^{o} inclination) orbit. The TITAN IIIC7, which has a Transtage as an upper stage, places the EOS-F into the geosynchronous transfer ellipse. Since the Transtage has propellant remaining after it performs the transfer ellipse maneuvers, it is retained to perform the circularization maneuver at apogee (19,323 n mi).

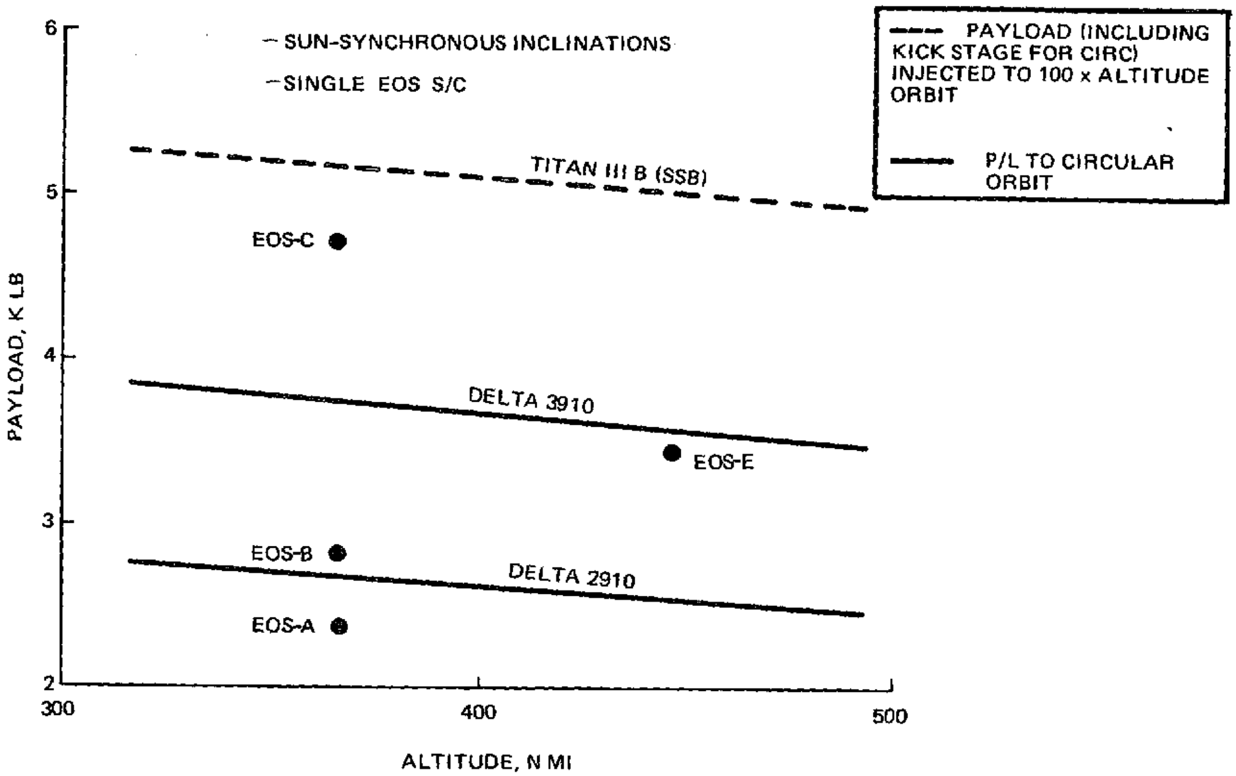


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Fig. 5-1 Conventional Launch Vehicle Capability

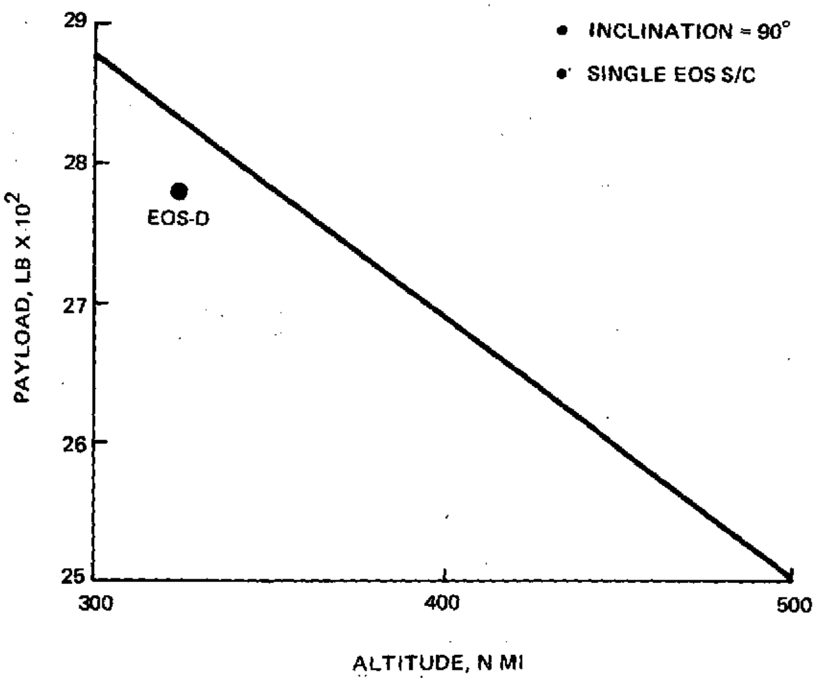
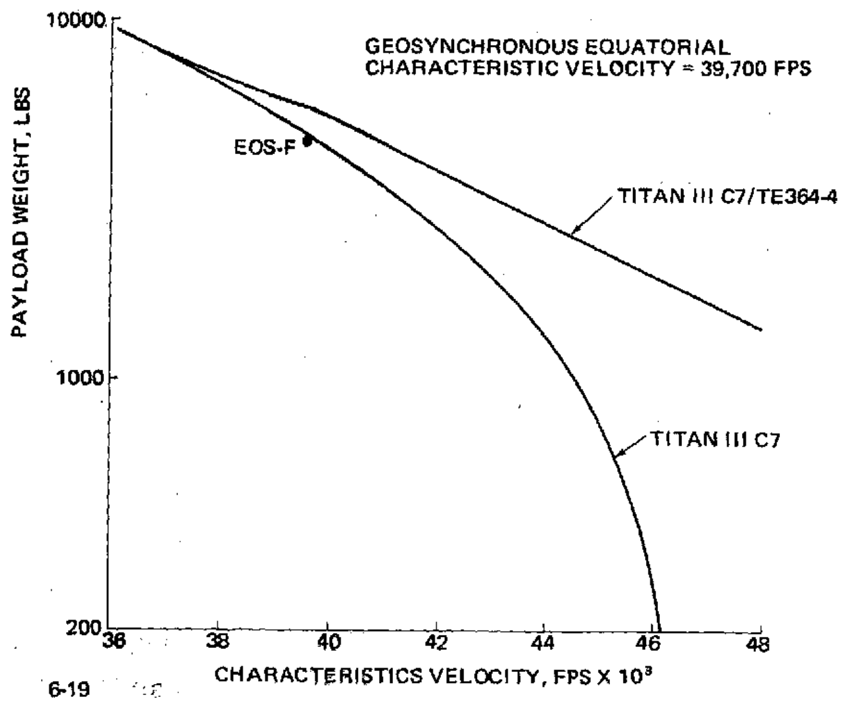


Fig. 5-2 Delta 2910 Capability to Polar Orbits



6-19

Fig. 5-3 Titan III C7 Payload Weight Vs Characteristics Velocity – ETR Launch

5.2.2 SHUTTLE

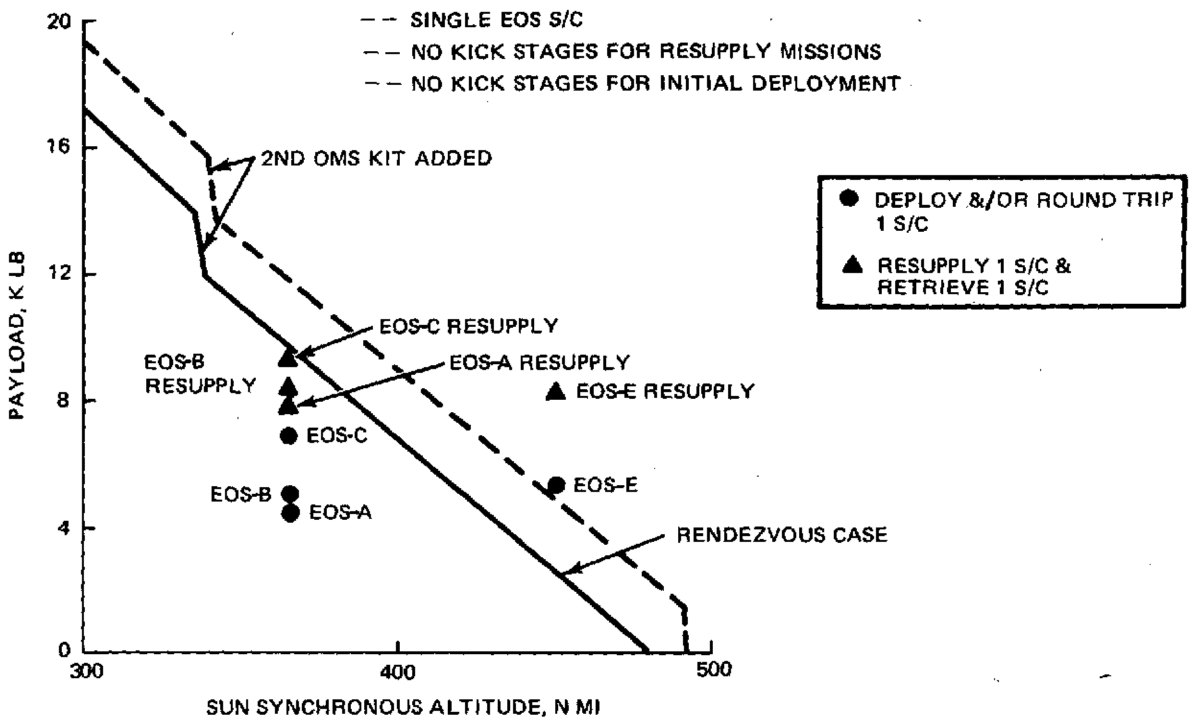
5.2.2.1 UNAUGMENTED SINGLE DEPLOYMENT AND RESUPPLY USING SHUTTLE

After the initial launch of EOS Spacecraft by conventional launch vehicles, the Shuttle can be used to deploy additional vehicles (Deploy), replace vehicles (Deploy-Retrieve-Round-Trip), and to resupply or service them. Figure 5-4 presents the Shuttle payload capability to sun-synchronous altitudes and inclinations, and compares the payload requirements of the EOS-A, -B, -C, and -E missions to Shuttle capability. Deployment into the mission orbits without using kick stages can be accomplished for the EOS-A, -B, and -C missions. Resupply of these vehicles has been considered and the payload requirements for a resupply (and possible retrieval) mission are also presented in Fig. 5-4. EOA-A, -B, and -C can be resupplied directly by the Shuttle in their mission orbits. Resupply of EOS-E in its sun-synchronous mission orbit is beyond the Shuttle's capability and provisions must be mode for resupply (or servicing) in a lower orbit. EOS-E cannot be deployed directly into its 450 n mi mission orbit by the Shuttle and requires the assistance of kick stages to get into the mission orbit, and later, kick stages to return to the Shuttle for servicing. Deployment and resupply of EOS-E will be discussed in more detail in subsection 5.2.2.2.

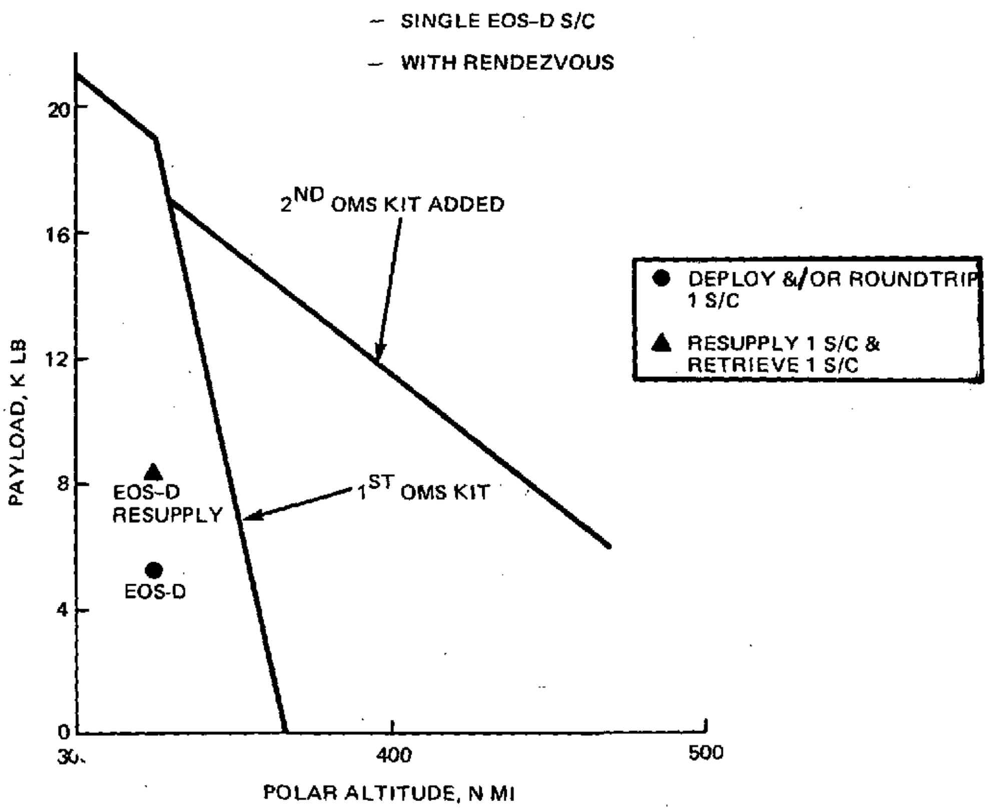
Figure 5-5 illustrates that EOS-D can be deployed and resupplied in its mission orbit of 324 n mi at 90° inclination. In this case, the Shuttle capability with one OMS kit aboard far exceeds the EOS-D requirement and allows room for payload growth without affecting delivery or resupply capability.

5.2.2.2 AUGMENTED SINGLE DEPLOYMENT AND RESUPPLY USING THE SHUTTLE

The EOS-F mission orbit requirements far exceed the unassisted Shuttle capability and require the use of a Shuttle/OOS or Shuttle/Tug to reach its geosynchronous equatorial mission orbit. The Orbit-to-Orbit Shuttle (OOS) is envisioned as an adaptation of an existing stage and is scheduled to become operational in 1979 and remain so until 1983, when a newly developed Tug is scheduled to become operational. Figure 5-6 shows the EOS-F performance requirement (4200 lb and 14,000 fps) and the deploy capability of an OOS (a derivative of the Transtage) operating in several modes from the Shuttle (160 n mi parking orbit). If the OOS is to be recovered, it will release EOS-F in a 160 x 19,323 n mi orbit and a kick stage must be used to circularize the EOS-F at geosynchronous altitude.



6-20 **Fig. 5-4 Shuttle Payload Capability to Sun-Synchronous Altitudes**



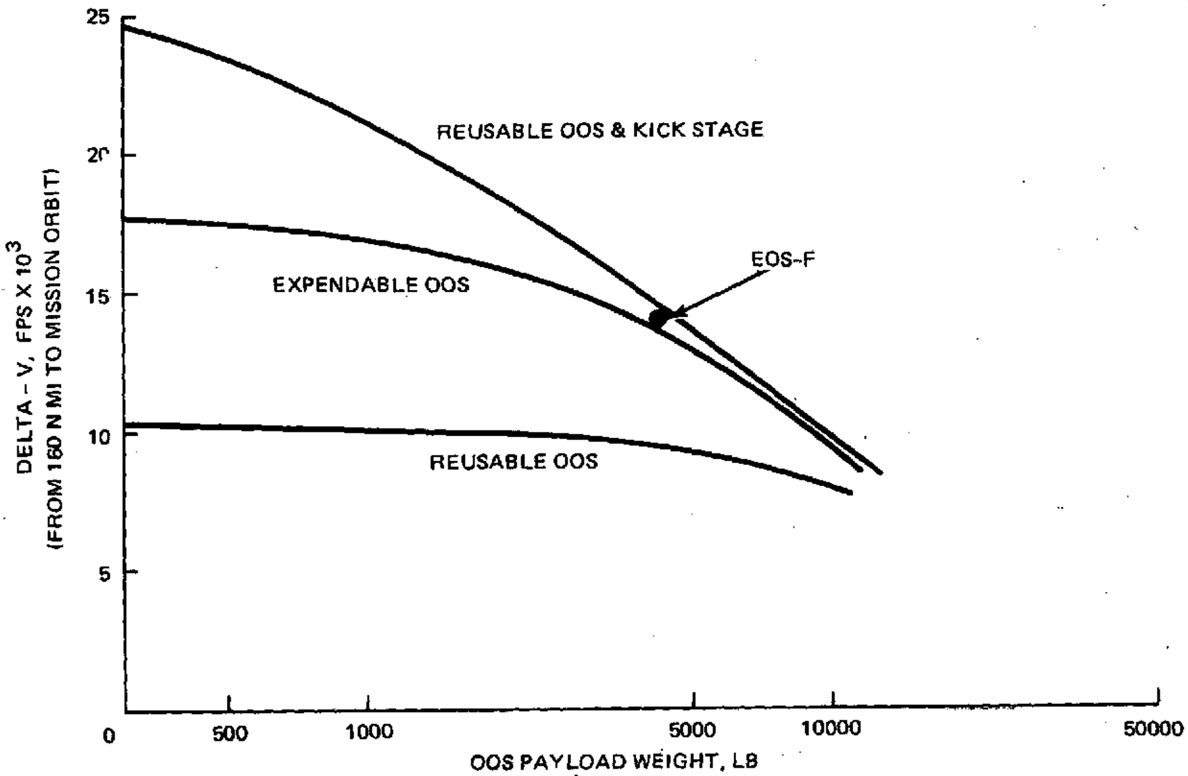
6-21 **Fig. 5-5 Shuttle Capability to Polar Orbits**

The Shuttle-carried resupply weight for EOS-F is approximately 4000 lb, comprised of the FSS, SPMS, and EOS replacement modules. This would be considered a roundtrip payload on an OOS or Tug since modules which are brought to the EOS would be exchanged for units of equal weight. The capability of the OOS falls short of this resupply requirement, and thus, resupply or retrieval can only be considered when the full capability Tug becomes operational in 1983. Figure 5-7 shows that resupply of the EOS-F in geosynchronous equatorial orbit (delta-V=14000 fps) is beyond the capability of even the full capability Tug. An alternative (not considering cost) would be to retrieve the EOS-F with the Tug and return it to earth for refurbishment. The figure shows that the Tug does have the capability to deploy, or retrieve, the EOS-F on separate Shuttle flights.

In summary, the Shuttle, in conjunction with either an OOS or a Tug, can deploy the EOS-F vehicle. Shuttle-based resupply using either the OOS or Tug, is not possible in the geosynchronous mission orbit. Resupply of EOS-F using a Tug-mounted resupply system cannot be accomplished unless the combined weight of the resupply system and replacement EOS modules is kept below 2700 lb. Retrieval of the vehicle is possible using the Tug.

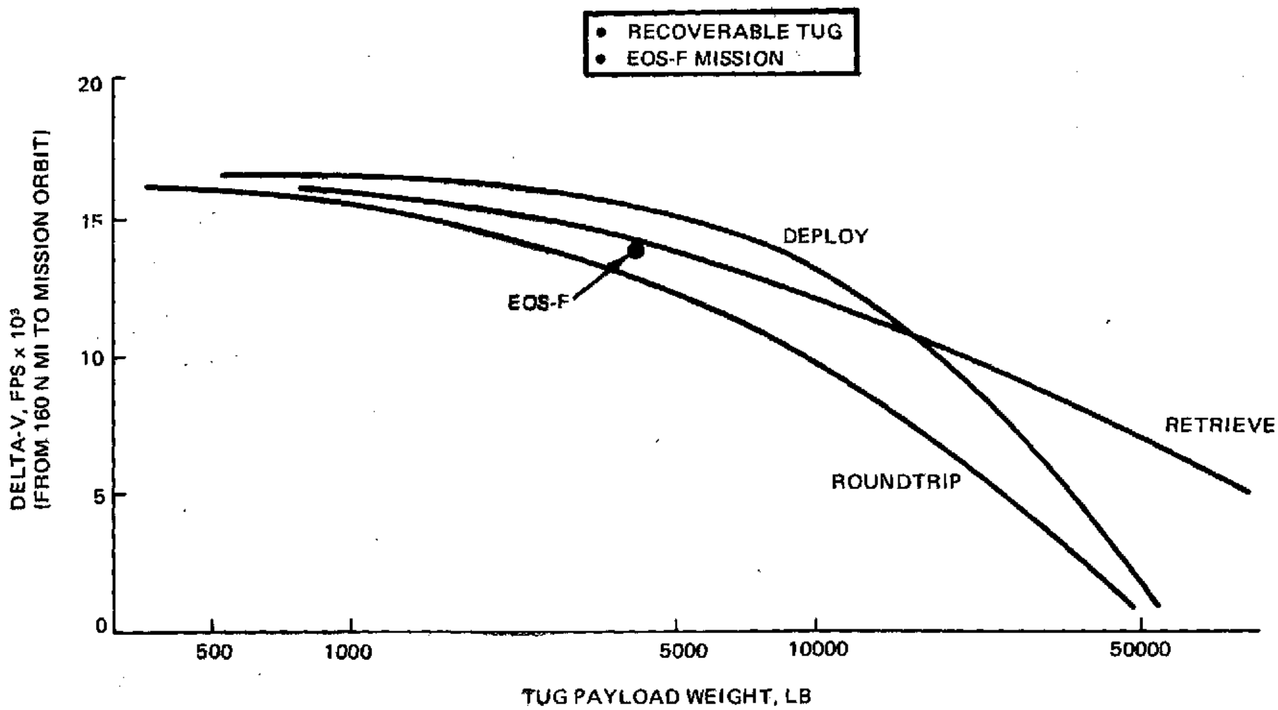
As mentioned earlier, the EOS-E deployment and resupply missions cannot be accomplished without augmenting the Shuttle's capability (refer to Fig. 5-4). In order to plan for the resupply of EOS-E, the payload must be outfitted with a four-SRM kick stage and deployed by the Shuttle at a 200 n mi circular orbit. The kick stage would then be used to attain the 450 n mi mission orbit. When resupply is required, the kick stage would de-orbit EOS-E by lowering perigee to 200 n mi; after coating to perigee, the last SRM would circularize the vehicle at 200 n mi, the Shuttle parking orbit altitude for this case. After EOS-E has been serviced in the low altitude Shuttle orbit, it would be equipped with a four-SRM kick stage, two SRM's for ascent to its original mission orbit, and two for return to the Shuttle for resupply or service. Although resupply or service of the satellite could be performed in the elliptical orbit, preliminary analyses performed by NASA (JSC) indicated that circular orbit servicing is preferable (see References 8, 9, and 10).

Figure 5-8 indicates that the initial deployment of EOS-E to 200 n mi, and later, resupply in a 200 n mi circular orbit can be accomplished by the Shuttle with integral OMS tankage only.



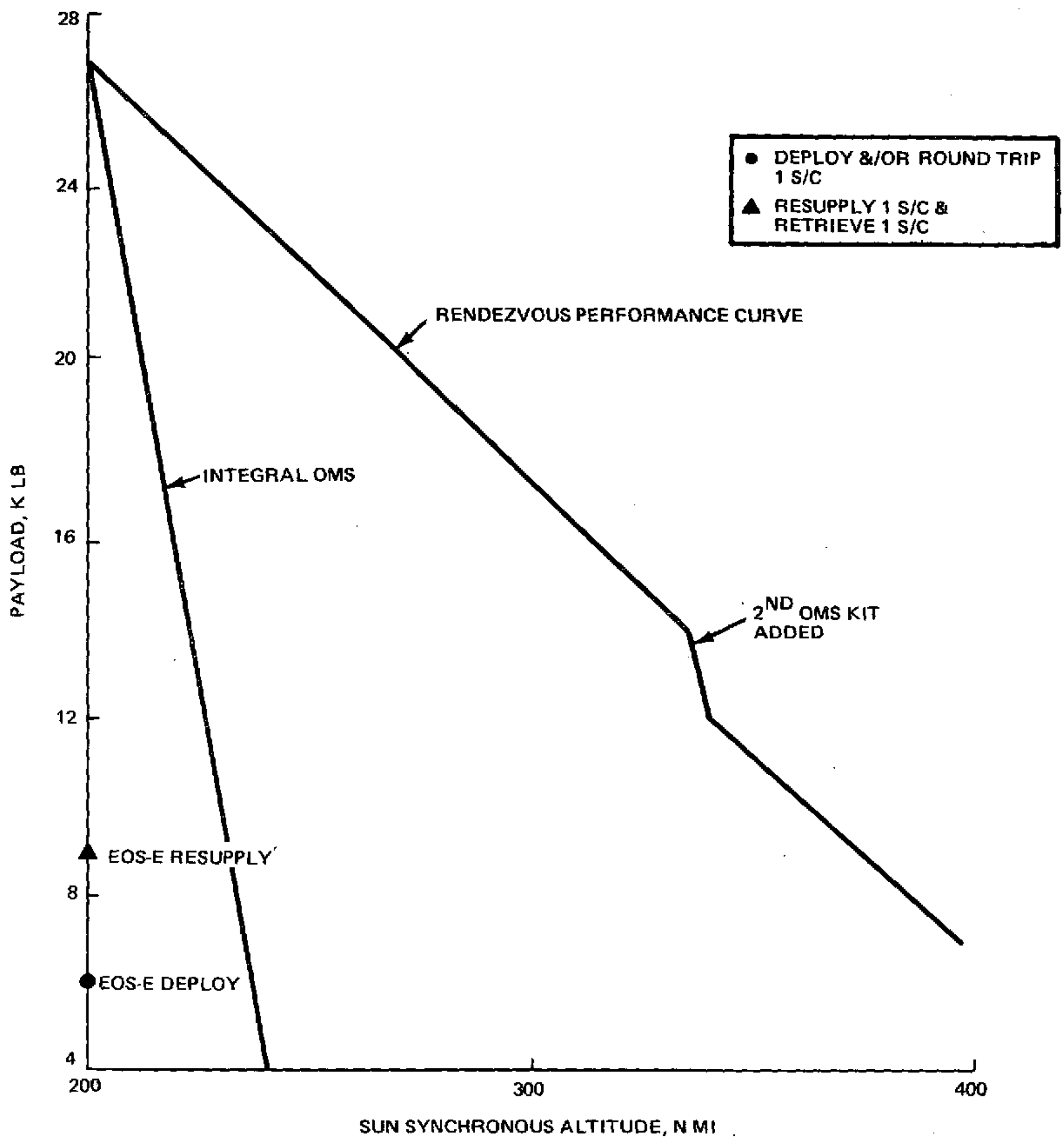
6-22

Fig. 5-6 Shuttle/OOS (Transtage) Deploy Performance from 160 Nautical Miles



6-23

Fig. 5-7 Shuttle/Cryogenic Tug Performance from 160 Nautical Miles



6-24 **Fig. 5-8 Shuttle Performance to Sun-Synchronous Altitudes, EOS-E Deployment – Resupply**

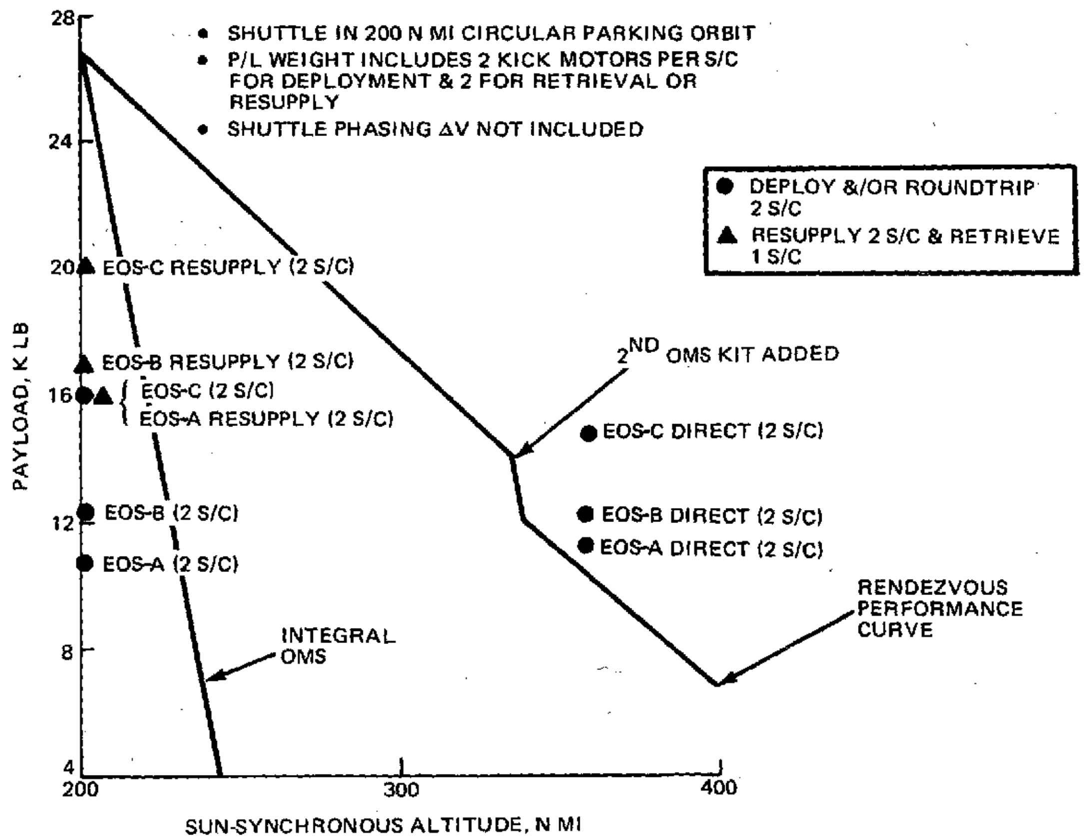
5.2.2.3 DUAL EOS DEPLOYMENT USING THE SHUTTLE

5.2.2.3.1 CIRCULAR ORBIT DEPLOYMENT AND RESUPPLY

Dual deployment of EOS-A, -B, and -C spacecraft to a 200 n mi orbit (SRM to mission orbit) has been analyzed and determined to be within the Shuttle integral OMS capability. Figure 5-9 presents the Shuttle payload capability and payload requirements of EOS dual launches. Dual deployment directly into the mission orbits is beyond the Shuttle's capability; deployment into elliptical orbits with apogee at the mission orbit altitude is feasible and will be discussed later.

Each EOS spacecraft deployed at 200 n mi would have a four-SRM kick stage with the following purposes:

- SRM #1 - Initiate transfer from 200 n mi circular to mission orbit
- SRM #2 - Circularizes EOS at mission altitude
- SRM #3 - Initiates transfer from mission orbit to 200 n mi orbit for service or resupply
- SRM #4 - Circularizes EOS at 200 n mi for service or resupply.



6-25

Fig. 5-9 Shuttle Capability to Sun-Synchronous Altitudes

After the first EOS kick stage transfer maneuver at 200 n mi, the Shuttle coasts to set-up the proper phasing between vehicles. Figure 5-10 presents phasing delta-V and phase time characteristics for various phasing angles between vehicles, in a 366 n mi, mission orbit. The Shuttle can remain in its 200 n mi parking orbit and phase with the first deployed EOS without the expenditure of OMS phasing delta-V. This phasing results from the difference in the period (and the corresponding angular velocity) of the Shuttle and the deployed EOS vehicle. The Shuttle can also lower its perigee, thereby increasing the mean differential angular motion, and make up the required phasing angle in a shorter time. Reference to Fig. 5-10 will indicate that the phasing time saved by doing so is not worth the expenditure of the additional delta-V required, and that the gross phasing should be performed in the 200 n mi parking orbit.

Resupply of the EOS-A, -B, and -C vehicles would take place in the 200 n mi Shuttle parking orbit; the payload requirements for the resupply are well within the Shuttle's integral OMS capability (Fig. 5-9). The payload requirements include the return of one EOS spacecraft to the ground.

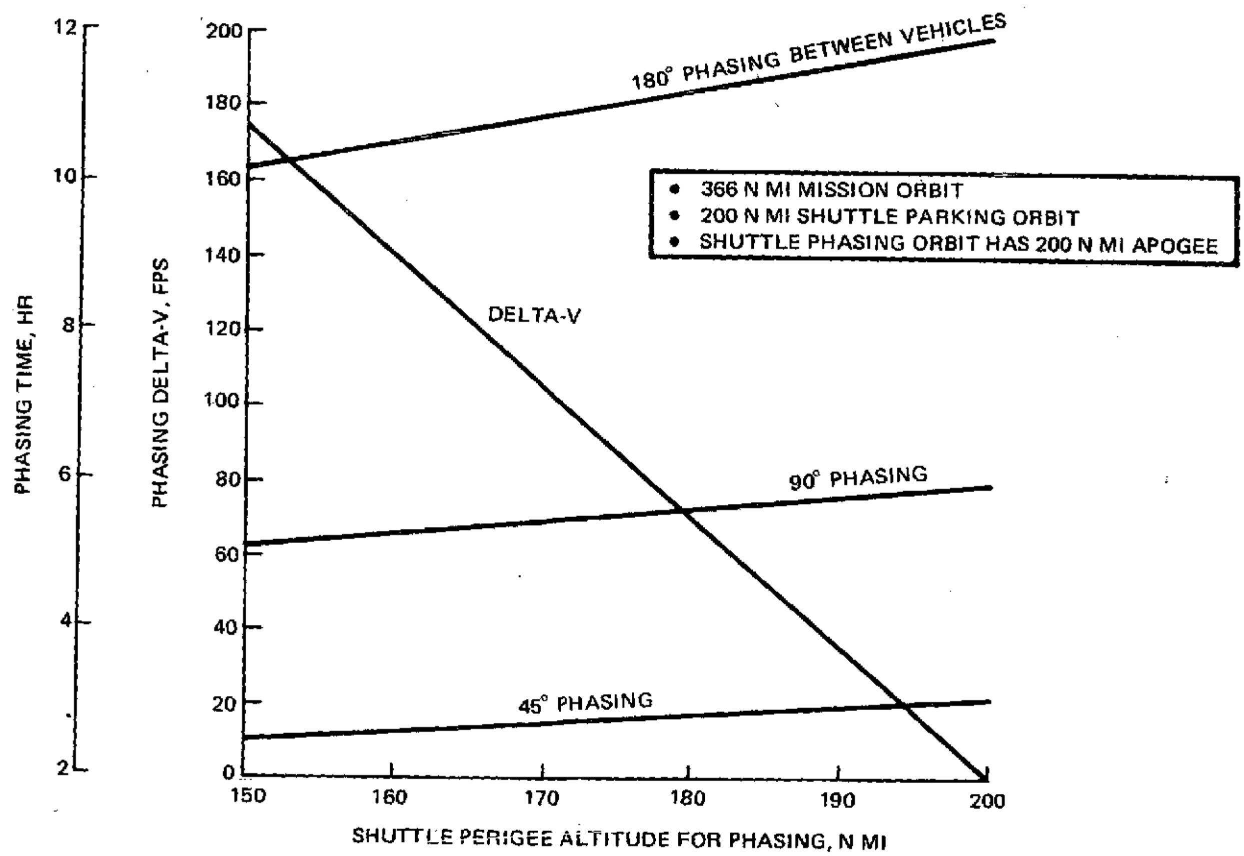


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Fig. 5-10 Shuttle Phasing Characteristics for Dual EOS Deployment

An alternative approach entails a mission scenario in which the two Observatories are delivered (or retrieved) from mission orbit by using Orbit Transfer System SRM's to accommodate a 200 n mi Shuttle parking orbit, but Resupply is accomplished by the Shuttle in mission orbit. Such an approach, with the Orbiter at EOS mission altitude, however, cannot take advantage of the natural phasing inherent with the Orbiter in a lower parking orbit. Accordingly, the Orbiter must expend delta-V to achieve the necessary phasing between Observatories with a corresponding reduction in available payload capability. As shown in Fig. 5-11, the penalty for phasing is extremely sensitive to the time available for phasing. If, for example, only two days phasing time is allotted for 180° phasing, the Orbiter will expend approximately 582 fps, reducing payload capability by over 11,500 lb. This penalty is well beyond the 9700 lb Orbiter capability to the 366.1 n mi mission orbit reflected in Fig. 5-9. By extending phasing time to four days, the delta-V penalty is reduced to 280 fps and the Orbiter can still accommodate a 4100 lb payload. This capability is still inadequate for the baseline FSS assumed for dual Resupply (11,116 lb) plus replacement modules (1400 and 3400 lb for

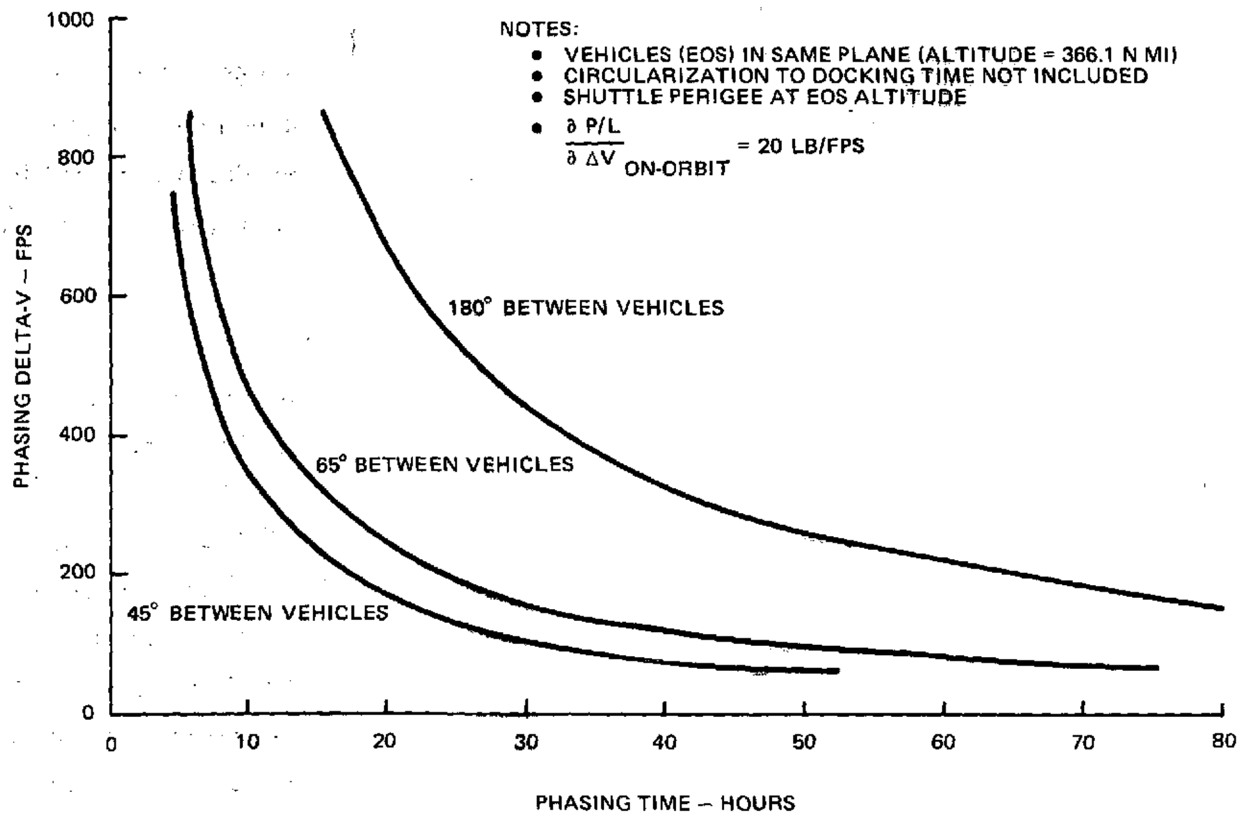

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Fig. 5-11 Shuttle On-Orbit Phasing Characteristics

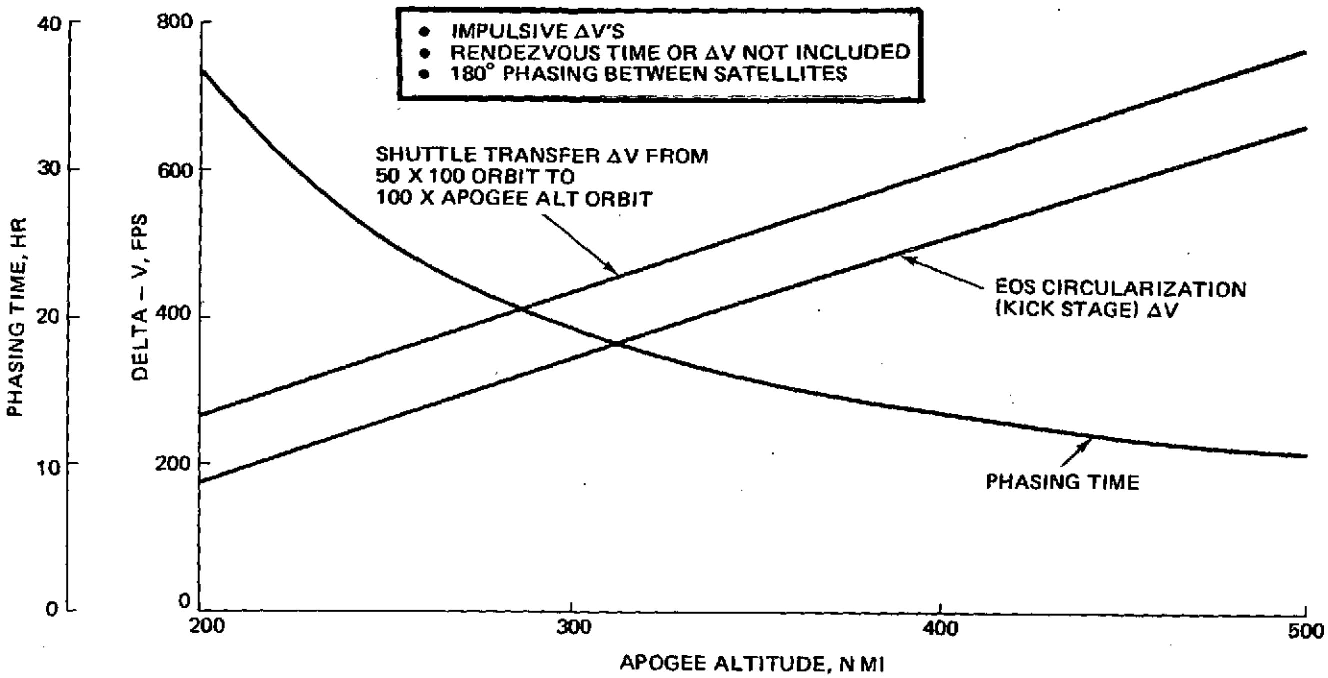

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Fig. 5-12 Phasing and Circularization Characteristics of Multiple EOS Deployments using the Shuttle Elliptical Orbits

EOS-B and -C, respectively). If, however, a recently projected FSS weight (including MEM and MM) of 1900 lb is applied, 2200 lb is available for replacement modules, adequate for a moderate level of resupply. The combination of lower FSS weight and fewer replacement modules, then, makes dual-Observatory Resupply via direct Shuttle ascent a viable alternative.

5.2.2.3.2 ELLIPTIC ORBIT DEPLOYMENT AND RESUPPLY

A typical dual EOS elliptical orbit deployment scenario would begin by Shuttle launch into a 50 x 100 n mi orbit at perigee, followed by a coast to 100 n mi, at which point an OMS maneuver would produce an apogee at the mission orbit altitude and a perigee at 100 n mi. While in the elliptical transfer orbit, the EOS satellite would be separated; at apogee the EOS circularizes with a kick stage as the Shuttle coasts in the elliptic transfer orbit. Coasting in the elliptic transfer orbit will result in phasing between EOS deployments. Figure 5-12 presents the time that the Shuttle must coast after deploying the first EOS spacecraft to attain 180 degrees separation between the first and second EOS. The data is presented for various Shuttle apogee (mission orbit) altitudes. In addition, the delta-V that the EOS needs to circularize at the mission orbit altitude from the Shuttle transfer orbit is presented. Also presented is the impulsive delta-V that the OMS must supply to get the Shuttle from the 50 x 100 n mi insertion orbit onto the transfer orbit.

Figure 5-13 presents the Shuttle capability to elliptic transfer orbits of various apogee altitude in comparison to the payload requirements of the EOS-A, -B, and -C dual deployment missions, and the EOS-B and -C resupply missions. All of these deployment and resupply missions are within the Shuttle's capability operating on the integral OMS tankage.

Resupply of the dual EOS by the Shuttle can be performed in the elliptic transfer orbit, but the analyses documented in Reference 9 suggest that the circular orbit approach provides "significant advantages over the elliptic orbit in terms of the mission planning cycle".

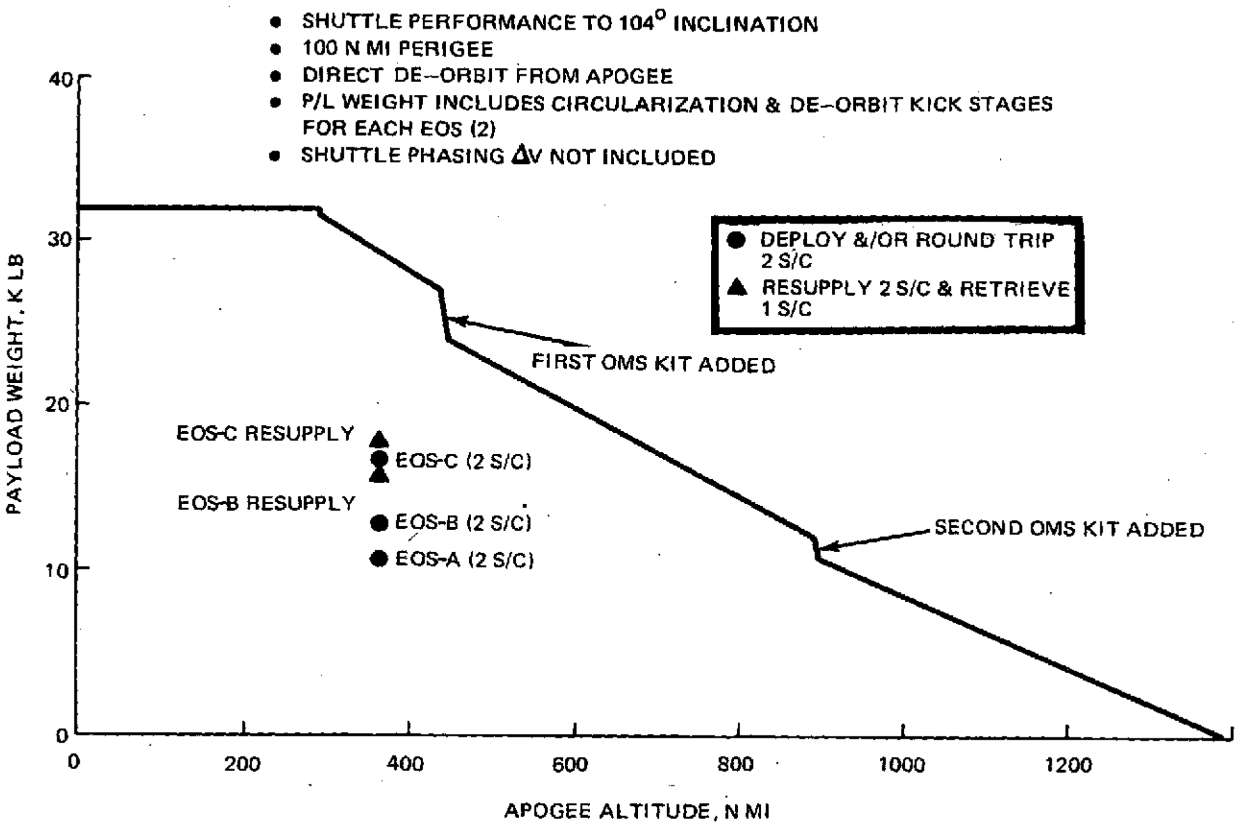

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Fig. 5-13 Shuttle Payload Weight vs Elliptical Orbital Altitude, WTR

5.3 INSTALLATION COMPATIBILITY

There are two factors to be addressed in determining the compatibility of EOS installations with Shuttle constraints, dimensions and mass characteristics including center of gravity location. Figure 5-14 summarizes the volumes available for payload installation in both Shuttle and the currently assigned conventional launch vehicle shrouds. Figures 5-15, 5-16, and 5-17 depict the allowable Shuttle center of gravity envelope in all three vehicle axes.

5.3.1 DIMENSIONAL COMPATIBILITY

The range of EOS dimensions has been assessed relative to available Shuttle payload bay volume. All concepts as currently conceived can be accommodated as indicated on Table 5-8. The following analysis selected the worst case conditions to verify that no conflicts exist.

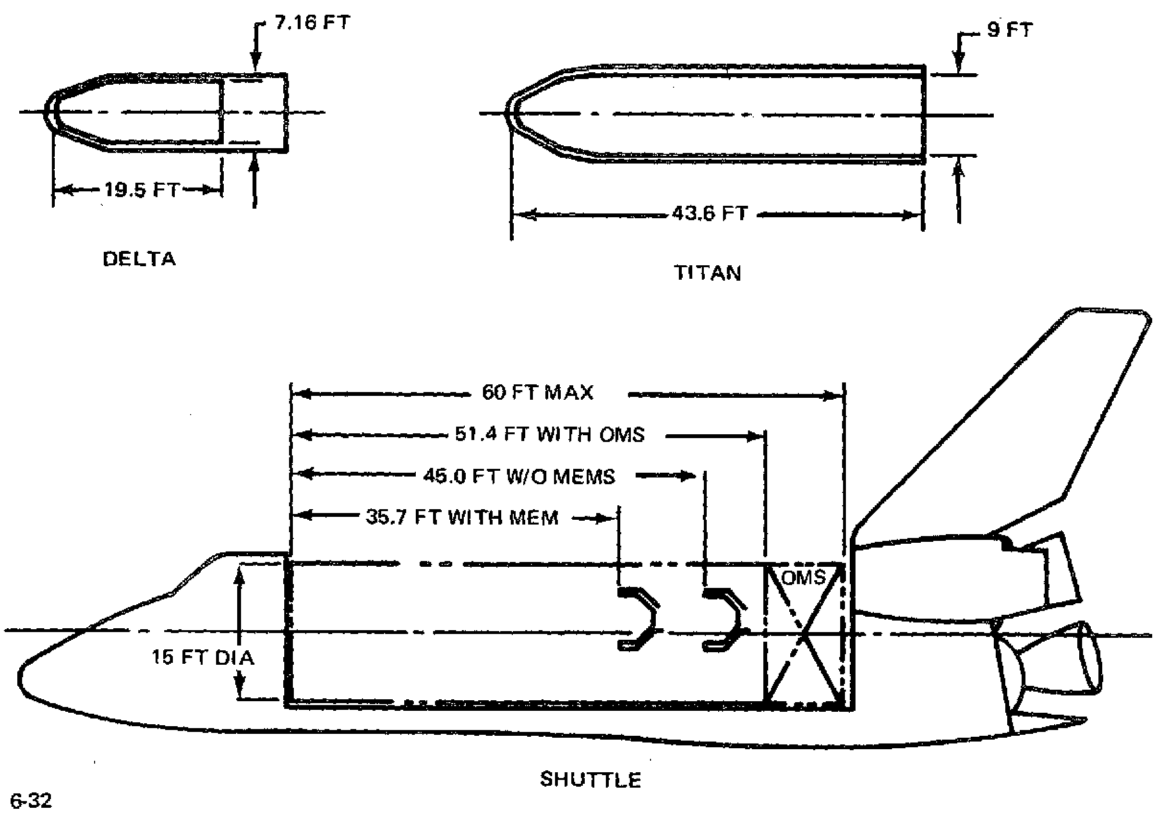
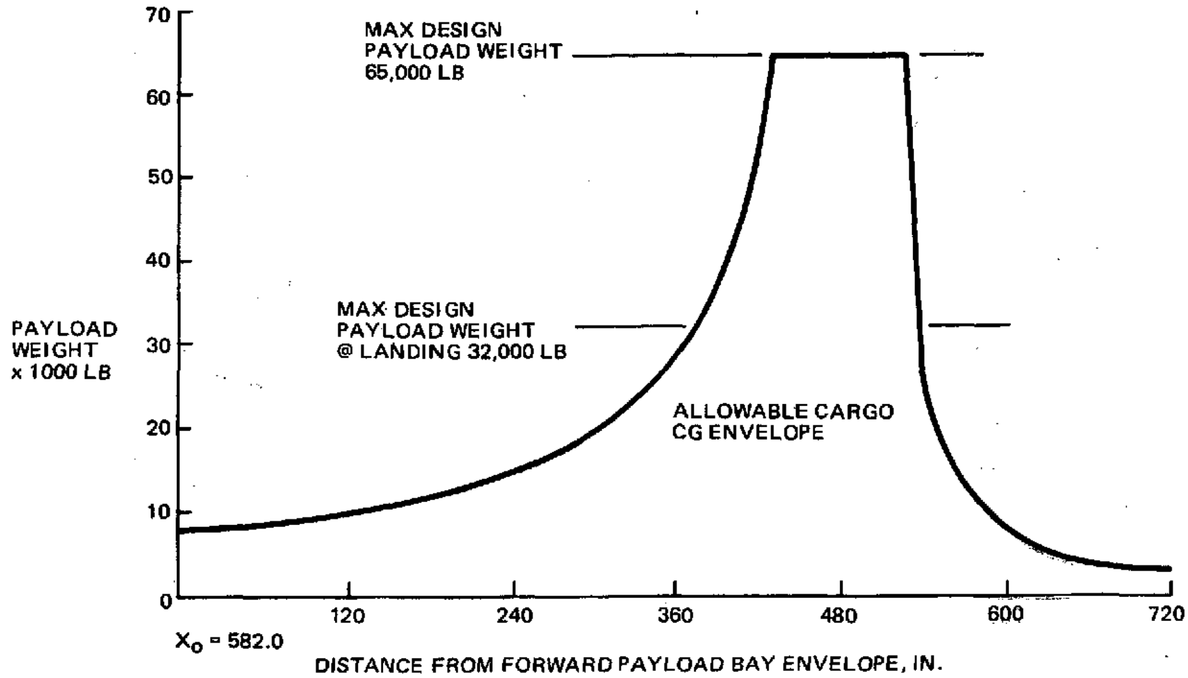
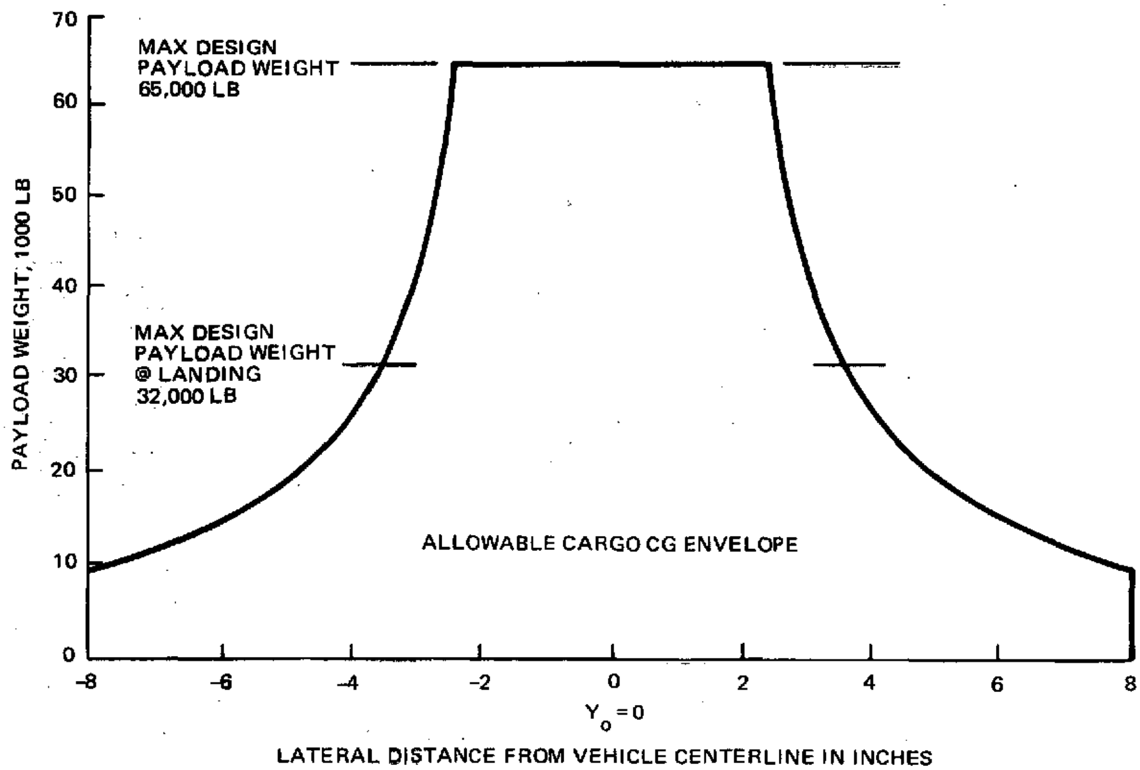


Fig. 5-14 Available Payload Volume



6-29 Fig. 5-15 Cargo CG Limits (Along X-Axis)



6-31 Fig. 5-16 Cargo CG Limits (Along Y-Axis)

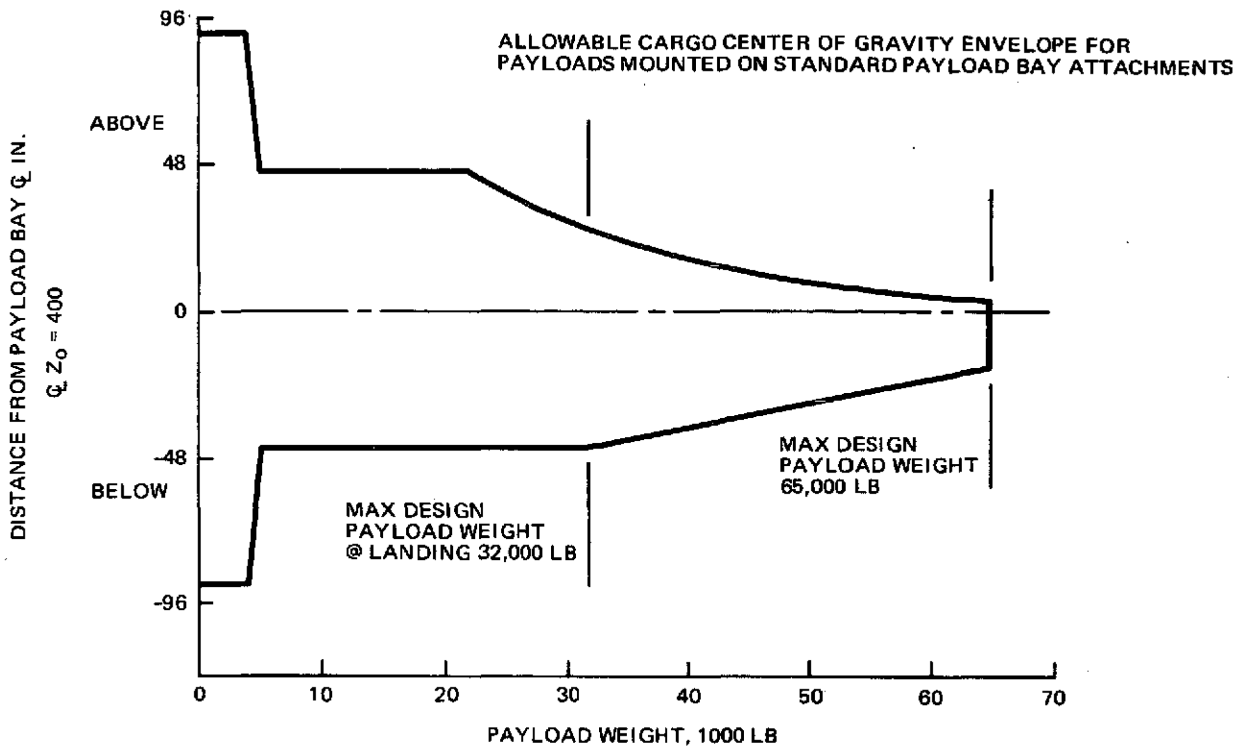


Fig. 5-17 Cargo CG Limits (Along Z-Axis)

Table 5-8 Shuttle Dimensional Compatibility

CONFIGURATION	DELIVER		RETRIEVE		RESUPPLY	
	SINGLE S/C	DUAL S/C	SINGLE S/C	DUAL S/C	SINGLE S/C	DUAL S/C
EOS-A (MSS, TM)	YES	YES	YES	YES	YES	YES
EOS-B (HRPI, TM)	YES	YES	YES	YES	YES	YES
EOS-C (HRPI, 2TM, SAR)	YES	NO	YES	NO	YES	YES
EOS-D (SEASAT B)	YES	X	YES	X	YES	X
EOS-E (TIROS N)	YES	X	YES	X	YES	X
EOS-F (SEOS)	YES	X	YES	X	YES	X

T6-50

Figure 5-18 illustrates a multiple Observatory Shuttle deploy and retrieve installation. The Observatory shown is for an EOS-D (SEASAT-A) mission and represents the largest of the A, B, D & E mission Observatories. The 60 ft x 15 ft diameter allowable Shuttle payload envelope provides sufficient volume for two Observatories, with the required FSS Retention Cradles and Positioning Platforms mounted forward of the OMS kit.

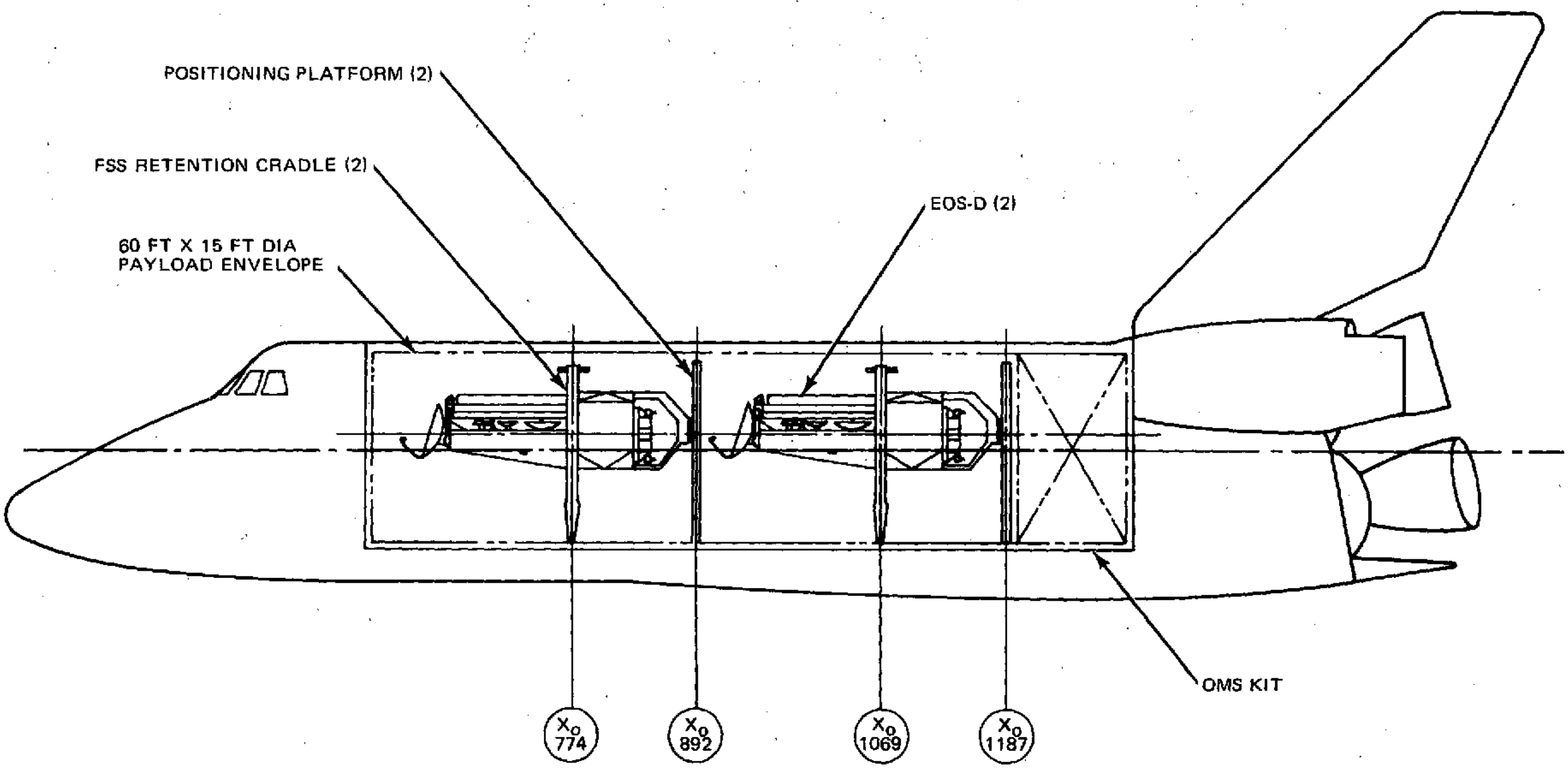


Fig. 5-18 EOS-D (SEASAT A) – Shuttle Multi-Observatory Launch/Retrieve

A reduction in weight, cost and complexity may be possible by eliminating the Positioning Platform and utilizing only the PDRM and Retention Cradle for deploy and retrieve.

Figure 5-19 illustrates a single Observatory resupply configuration, with the Observatory stowed for a contingency return. The Observatory shown is EOS-C, the longest of all Observatories used for Missions A through E. The allowable payload envelope provides adequate volume to arrange the FSS components, SPMS and OMS kit required for resupply. When Missions A, B, D, and E Observatories are installed in the same arrangement, payload volume remains which may be utilized for shared missions or the relocation of the Observatory in the bay in the event the payload centers of gravity fall outside of allowable envelope. This installation encompasses all Shuttle single Observatory deploy or retrieve missions by removal of the SPMS components shown.

Figure 5-20 shows a multiple Observatory resupply installation with single contingency retrieval capability. The SEASAT-A Observatory is shown as the representative vehicle since it is the longest of the Mission A, B, D, and E Observatories. As shown, two complete SPMS complements have been assumed for resupply of two Observatories because of the necessary proximity of the Module Magazine to the Module Exchange Mechanism. In addition to supporting resupply, the FSS Retention Cradle and Positioning Platform accommodate retrieval and return of one non-space-repairable Observatory.

Figure 5-21 shows a Shuttle launch configuration of a SEOS mission Observatory (EOS-F). As shown, the allowable payload envelope provides sufficient volume to house the $33\frac{1}{2}$ ft Cyro Tug required for the Observatory to achieve geosynchronous orbit and a 6.6 ft Tug/Observatory adapter.

5.3.2 MASS CHARACTERISTICS COMPATIBILITY

A detailed analysis was performed on the configurations depicted in subsection 5.3.1 in addition to EOS-A, -B, and -C to determine the combined longitudinal center of gravity (X_0) of the spacecraft (or spares complement for resupply missions) and the Flight Support System (FSS) and OMS kits required for each configuration. These centers of gravity are plotted in terms of their distance from the forward end of the Shuttle payload bay envelope vs the total payload weight in Figs. 5-22 thru 5-26. The same figure has the allowable payload weight vs center of gravity envelope superimposed so that a direct evaluation of center of gravity acceptability is shown. The figures demonstrate that the center of gravity is within limits for each of the EOS configurations.

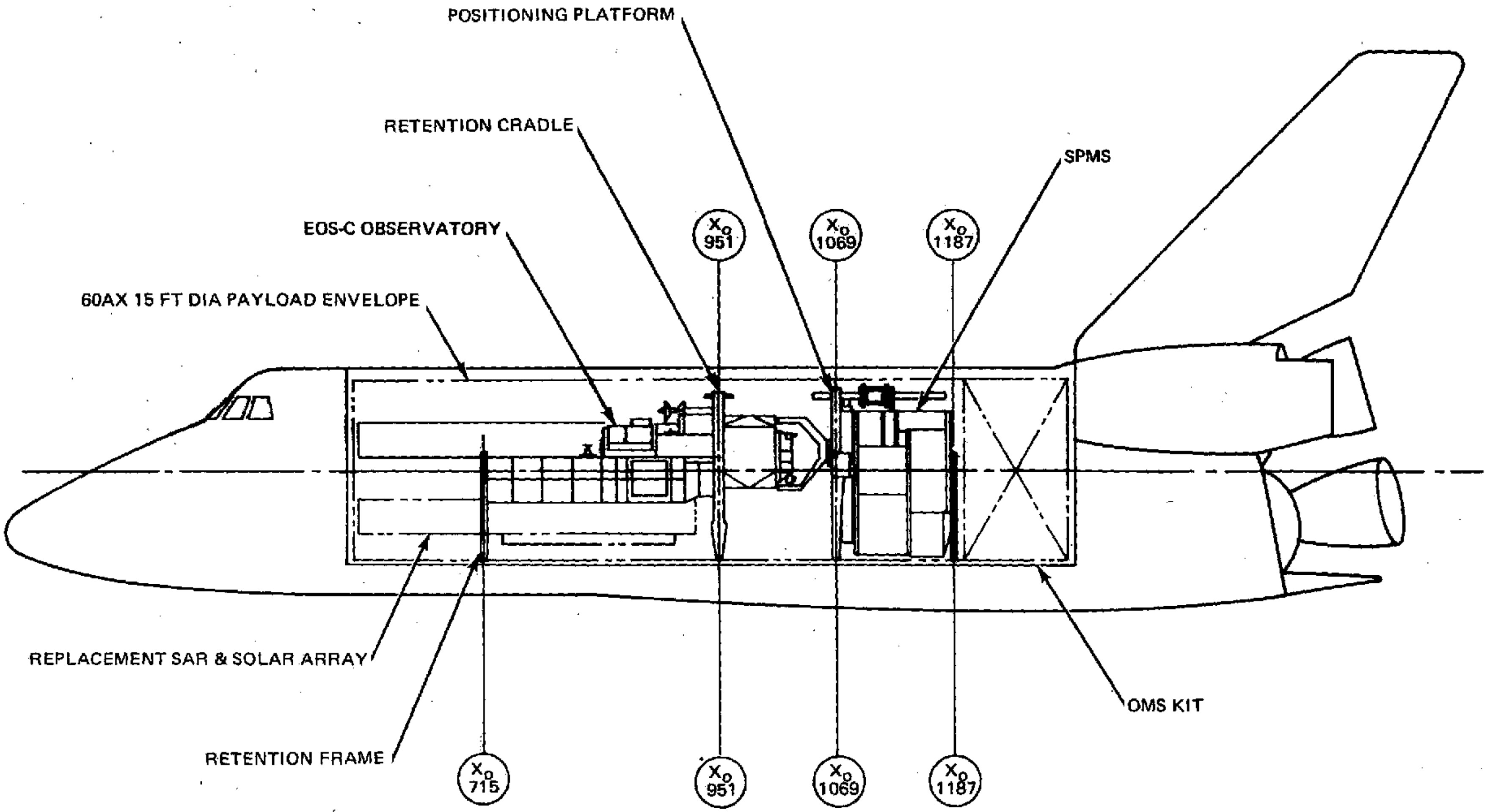


Fig. 5-19 Shuttle Single Observatory Resupply

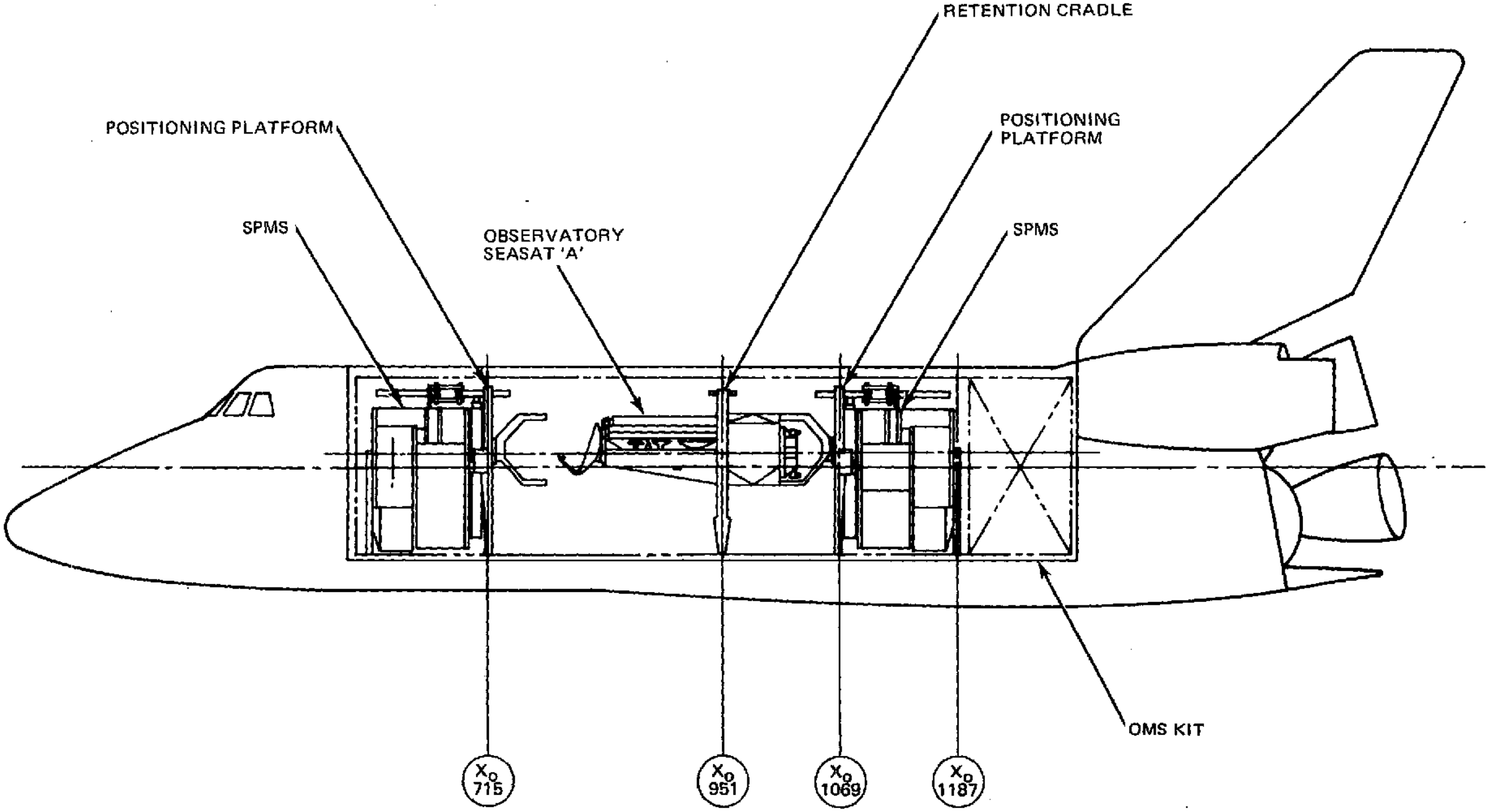


Fig. 5-20 Multi-Observatory Resupply

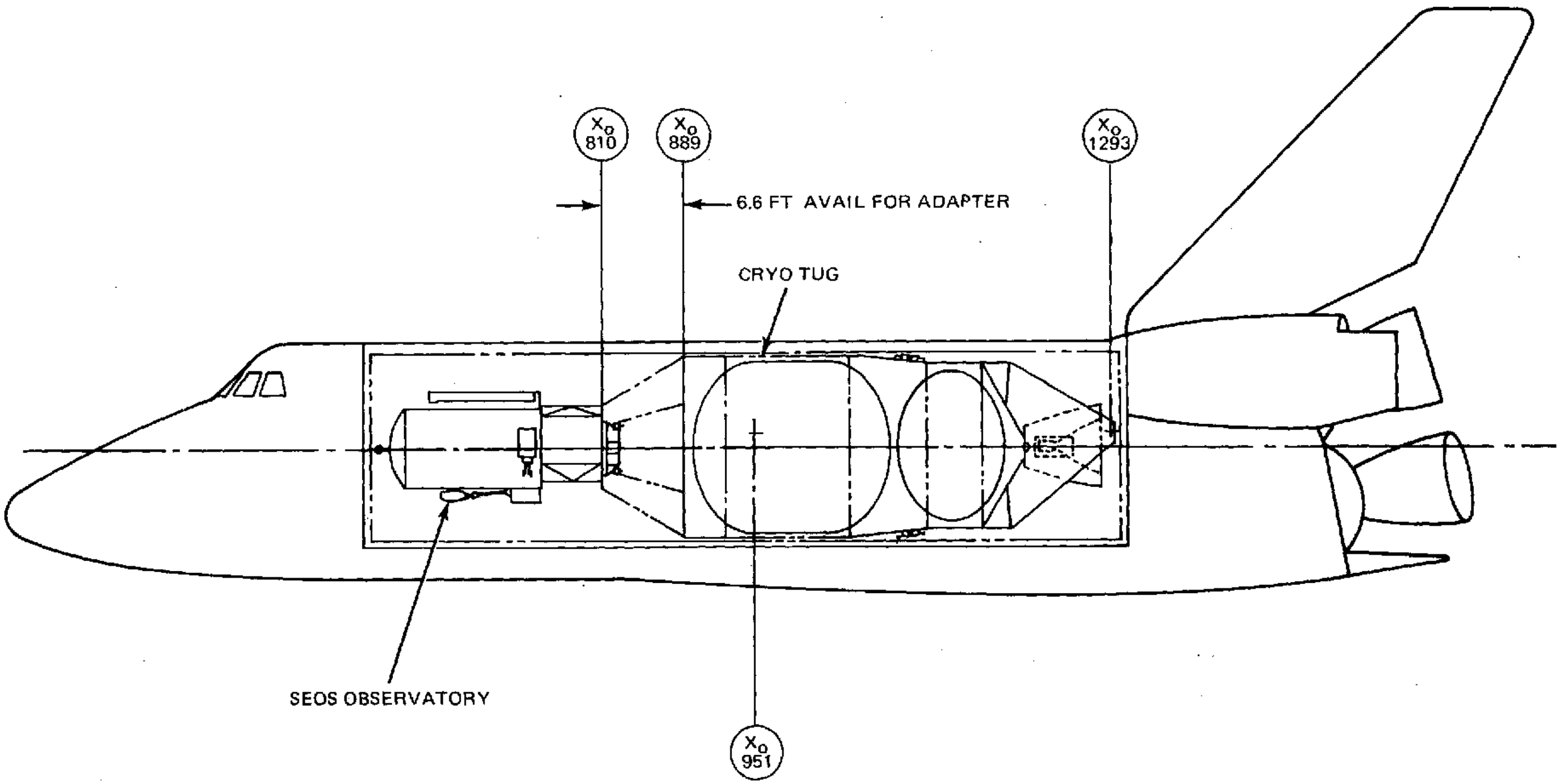


Fig. 5-21 SEOS Mission Configuration

Figure 5-22 shows the payload center of gravity for EOS-A single deploy missions. The single deploy mission requires two OMS kits for spacecraft delivery to the 366 n mi mission altitude, while the dual deploy mission delivers two spacecraft to the 200 n mi parking orbit using the integral OMS system only. In this case the spacecraft includes the four-SRM kick stage required for the round trip to the mission orbit and back for retrieval. Since the baseline EOS-A has no resupply provisions, this mission center of gravity is not shown.

Figure 5-23 shows the payload center of gravity for EOS-B and, since they proved to be nearly identical, EOS-D. Single deploy and single resupply missions require two OMS kits, while dual deploy and dual resupply missions are flown on integral OMS as in the case of EOS-A.

Figure 5-24 shows the payload center of gravity for EOS-C. Since the dual missions exceeded the payload bay length, only single deploy and single resupply missions are shown. Two OMS kits are included in the payload for these missions which are flown directly into the mission orbit (366 n mi). Since EOS-C represents the longest of the observatories, and since it does not require kick stages, these centers of gravity represent the forward limit of the EOS center of gravity range for single spacecraft missions. The addition of the OMS kits, however, drives the center of gravity aft.

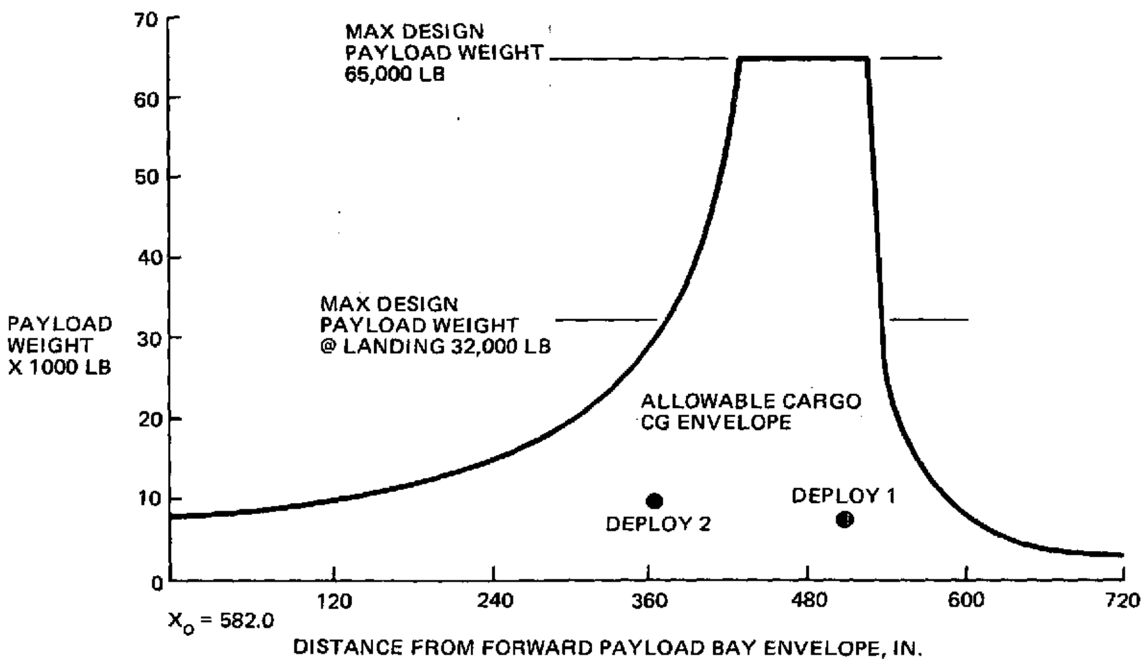


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Fig. 5-22 Cargo CG Limits (Along X-Axis) vs EOS-A

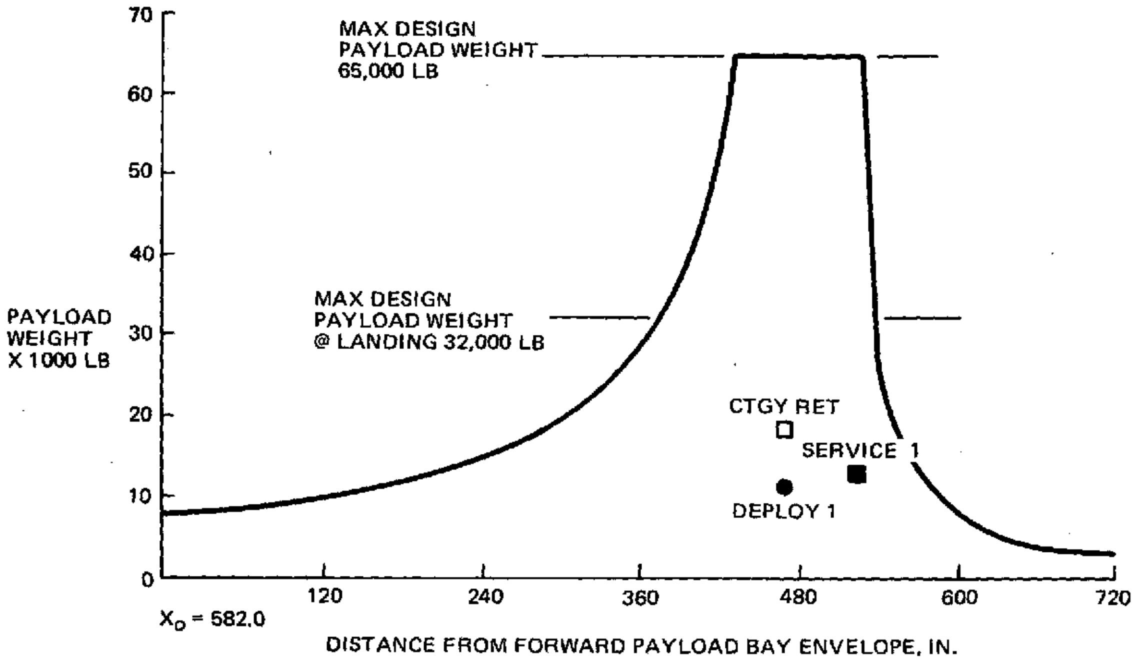

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Fig. 5-24 Cargo CG Limits (Along X-Axis) vs EOS-C

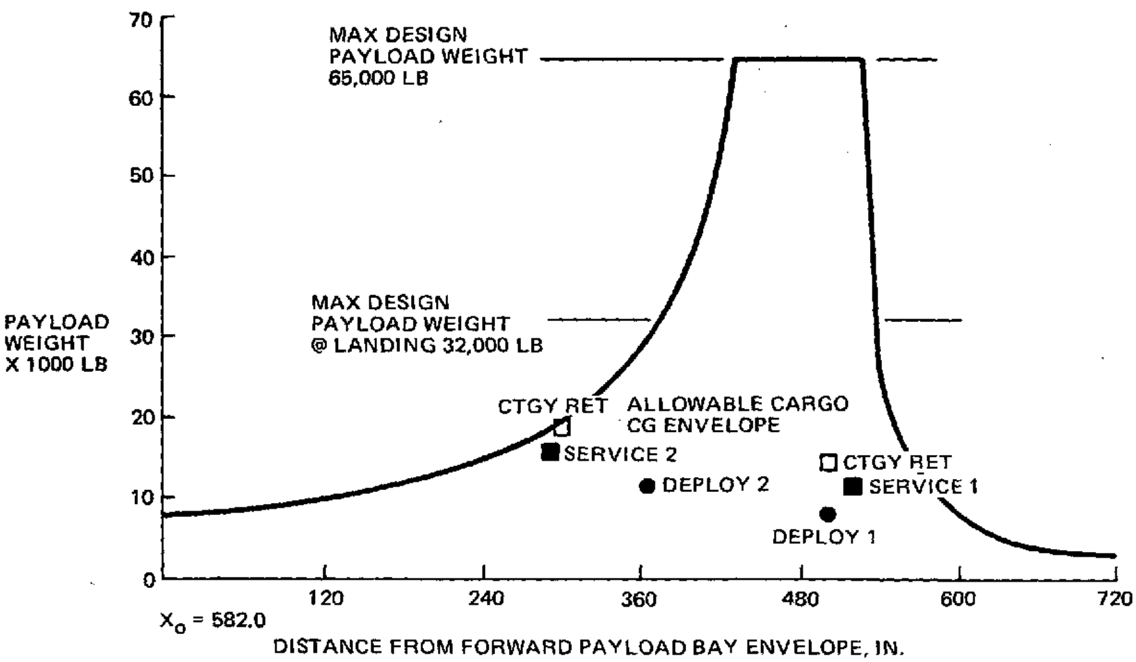

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Fig. 5-23 Cargo CG Limits (Along X-Axis) vs EOS-B/D

Figure 5-25 shows the payload center of gravity range for EOS-F (SEOS). The configuration for this mission is quite different from the rest since it includes a cryogenic Space Tug, along with its swingout adapter instead of OMS kits and FSS. A conical adapter (200 lb) supports the spacecraft off the Tug forward bulkhead for the deploy mission, and for the resupply mission a remote module stowage and manipulator device (550 lb) performs both the support and module exchange functions. Centers of gravity including the wet Tug (total payload weight of 65,000 lb) and the dry Tug are plotted along with the approximate center of gravity travel with propellant usage. It is apparent that the center of gravity at the maximum landing payload weight is well within bounds.

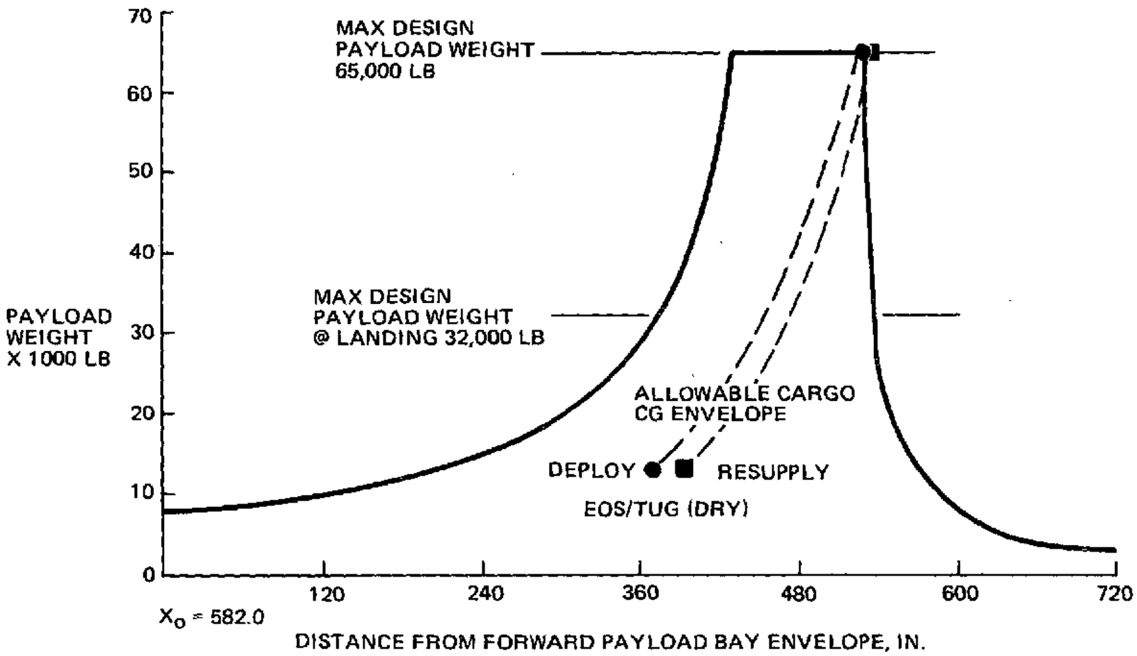

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Fig. 5-25 Cargo CG Limits (Along X-Axis) vs EOS-F (SEOS)

Figure 5-26 shows the payload center of gravity for EOS-E, which uses four-SRM kick stages for all mission modes. Since delivery and resupply are accomplished at the 200 n mi parking orbit, no OMS kits are required, making these single spacecraft centers of gravity the forward limit of the EOS center of gravity range.

Further details concerning the payload weights used in this analysis may be found in subsection 5.1.

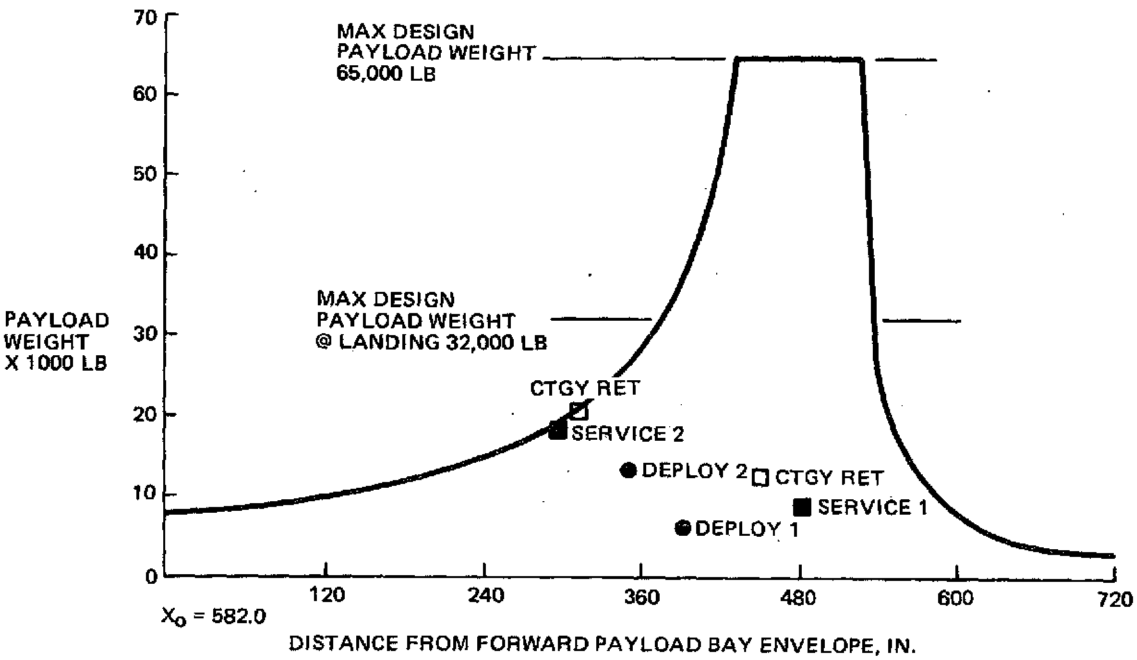

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Fig. 5-26 Cargo CG Limits (Along X-Axis) vs EOS-E

6 - SHUTTLE UTILIZATION

6.1 BASELINE ANALYSIS

The purpose of the Shuttle utilization trade study was to investigate potential utilization modes, determine the optimum mode (lowest cost, best spacecraft and experiment options), and analyze the sensitivities of the input parameters.

6.1.1 PARAMETER SELECTION

To evaluate alternate Shuttle utilization modes, certain parameters of effectiveness and costs were selected. As a measure of effectiveness, we chose spacecraft operating time-on-orbit (uptime). This was defined as the expected number of years of observatory operating time during a ten-year program life. Cost parameters included investment cost, transportation cost and refurbishment cost. We varied Shuttle delay (the time between demand for a Shuttle flight and when it was initiated) and the Shuttle's availability to either deploy, retrieve or service the EOS. For a scheduled maintenance policy, we varied the maintenance (resupply) interval.

We looked at seven deploy/retrieve/resupply cases. They were chosen to answer several questions:

- Should retrieve and/or resupply be scheduled at fixed intervals?
- Should there be a spare vehicle in inventory to replace the one in orbit for a retrieve flight?
- Should the EOS subsystems be designed with a redundancy level to increase design life?
- What is the impact of resupply interval on program cost and total EOS uptime?
- What is the impact of Shuttle delay (the time between an EOS failure and the time a Shuttle can be made available)?
- What is the best mode of operations; deploy (expendable), retrieve (ground refurbish), or resupply (on-orbit refurbish)?

The seven cases were:

1. Deploy
2. Retrieve - w/spare - scheduled Shuttle flights
3. Retrieve - w/spare - unscheduled Shuttle flights

4. Retrieve - w/o spare - scheduled Shuttle flights

5. Retrieve - w/o spare - unscheduled Shuttle flights

6. Resupply - scheduled Shuttle flights

7. Resupply - unscheduled Shuttle flights

For the deploy and retrieve/resupply unscheduled cases, we varied the design life and the Shuttle delay time. For the scheduled cases, we varied the design life and the resupply interval.

6.1.2 METHODOLOGY

In an attempt to perform the trade study with a minimum of extraneous factors, we assumed a ten-year program life, and did not consider initial or end of program conditions. This steady-state analysis allowed us to work with fractional values of such variables as number of flights in the program, etc. This is realistic, in the sense that many of the parameters (e.g., mean mission duration) were average values, with some probability distribution about the mean. Figure 6-1 illustrates the elements of the steady-state analysis. The definition of terms and assumptions made in the study are as follows:

DEFINITIONS

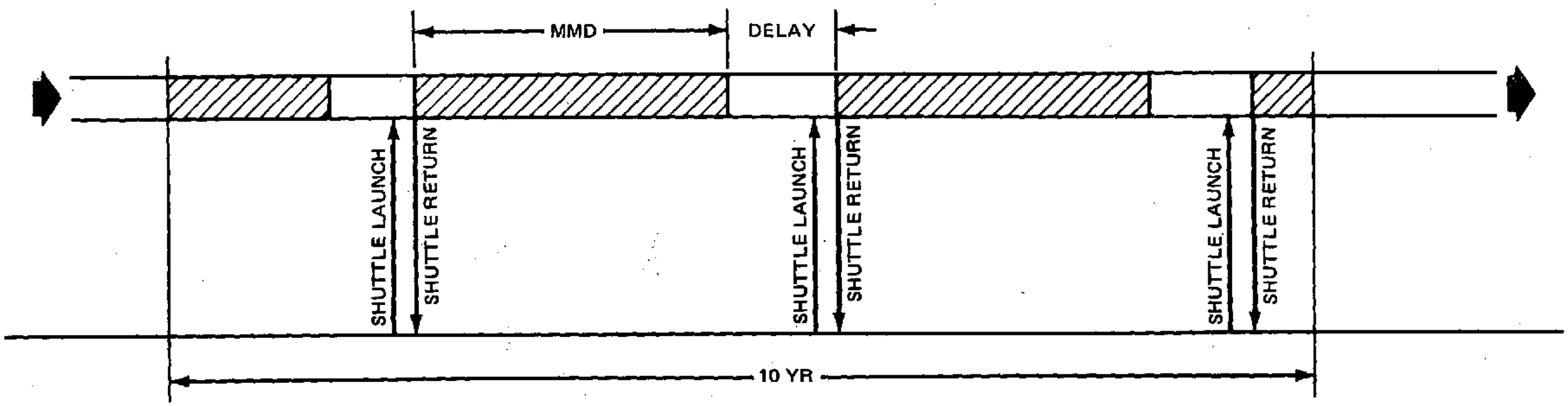
Uptime - Number of years of Observatory operation with at least one TM functioning.

$$\text{Uptime} = \frac{MMD_5}{MMD_5 + \text{Shuttle Delay}} \times \text{Program Life}$$

where MMD_5 = mean mission duration truncated at five years (expected lifetime) = the reliability function R (t) truncated at consumable and/or wearout life (i.e., $\int_0^5 R(t)\,dt$).

Operational Cost - The recurring refurbishment and transportation costs.

Refurbishment Cost - The expected cost of refurbishing either the resupplied modules and/or the ground refurbishment of the observatory. These costs include labor, material and test.

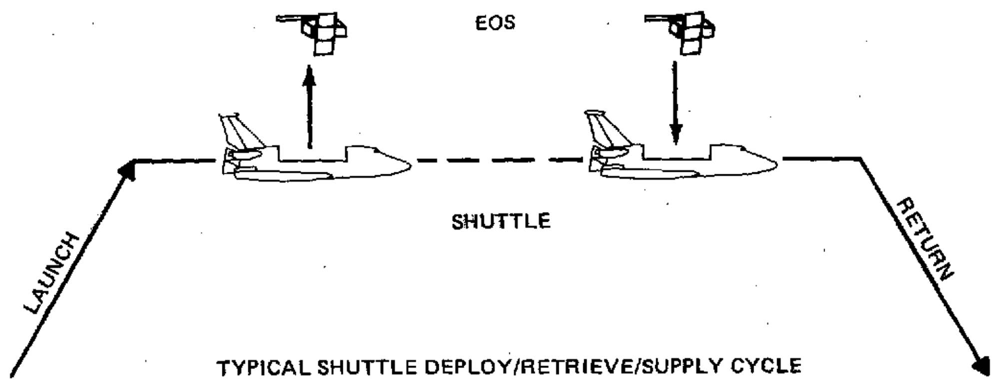


SHUTTLE DEPLOY/RETRIEVE/RESUPPLY TIMELINE

6-3

INSTRUMENT CONFIGURATION	OBS, MMD (YR) EOS B	OBS, MMD (YR) EOS C	DELAY TIME (YR)
			0
UNITY	4.1	4.1	1/4
HIGH RELIABILITY	2.75	3.16	1/2
LOW RELIABILITY	1.12	1.47	1

RELIABILITY/MAINTAINABILITY PARAMETERS



TYPICAL SHUTTLE DEPLOY/RETRIEVE/SUPPLY CYCLE

Fig. 6-1 Shuttle Utilization, Steady-State Analysis

Transportation Cost - User charge for the Shuttle.

Logistics Cost - The cost of either a spare vehicle for retrieve mode or a set of spare modules for the resupply mode.

Initial Investment - The cost of the original Observatory launched prior to Shuttle operations.

ASSUMPTIONS

- EOS-B and EOS-C assumed to be an operational program
- Analysis based on 10-year operational period without regard to startup or end-of program conditions
- Instrument complement

EOS-B	EOS-C
TM	TM (2)
HRPI	HRPI
DCS	SAR
	DCS

- Observatory would be replaced or serviced when subsystems and/or Thematic Mapper failed in such a manner as to prevent useful, full band data from at least one Thematic Mapper
- Observatories are in a 380.8 n mi sun-synchronous orbit
- Direct ascent Shuttle used in all single vehicle cases, except EOS-C resupply. For EOS-C resupply and multiple vehicle cases, the Shuttle operates to 200 n mi and the Observatory orbit transfer stages are used both up and down again to 200 n mi
- Each module would require replacement in at least five years due to wearout and obsolescence
- Resupply would consist of replacement at the module level (subsystem, instrument)
- The DCS instrument is included in the IMP module
- Modules would be resupplied if during a Shuttle visit
  - any redundant elements were failed,
  - the module has failed,
  - the module had not been replaced in five years, or the five-year period would be reached prior to the next expected Shuttle visit

- Shuttle payload capability to 380.8 n mi
  - 9000 lb w/rendezvous
  - 11500 lb w/o rendezvous
- Shuttle payload capability to 200 n mi w/rendezvous = 28,000 lb
  - with two rendezvous (two vehicles) = 20,000 lb
- For resupply, the weight of modules brought to orbit was based on the statistical mean value of expected modules for the resupply cycle
- For resupply and retrieve, the refurbishment cost of the modules was based on the statistical mean cost of failed modules - 40% refurbishment factor for failed modules, and 20% for ground refurbish of the non-failed systems/equipment
- Basic spacecraft has a mean mission duration (MMD) of four years and a survival life of five years
- Instrument reliability was varied over three levels (unity, optimistic and pessimistic).

Figure 6-2 is a logic flow diagram that depicts the study methodology. The initial inputs are the weights, costs, and reliabilities of the various modules, both those of the basic spacecraft and those that are mission peculiar modules. The outputs of interest are the total cost, mission uptime, and the cost per year of uptime.

The first decision made concerns the mission objectives. The determination must be made as to what constitutes a failure of the EOS, conversely, what instruments must be operating for the mission to continue. With this established, and with data on the reliabilities of all the EOS/Instrument components, it is possible to determine the time-to-failure, or MMD (Fig. 6-2, Box 4). This value is defined as the integral.

$$\text{MMD} = \int_0^5 R(t)\,dt$$

which is simply a truncation of the MTBF (mean-time-between-failures) integral at five years.

The MMD, along with the program life and the Shuttle reaction delay time, the time between EOS failure and Shuttle/EOS rendezvous, serve as inputs to determine uptime (Fig. 6-2, Box 7). Uptime, the amount of time the EOS is in a non-failure condition, is given by,

$$\text{Uptime} = \frac{\text{MMD}}{\text{MMD} + \text{Delay}} \times \text{Program Life}$$

The three factors which go into determining total costs are Shuttle transportation costs, refurbishment costs, and investment costs. Transportation costs and refurbishment costs combined are termed operational costs.

Investment costs are dependent upon the Shuttle utilization mode chosen, and consist of initial investment costs of the original Observatory launched prior to Shuttle operations and logistics costs which are the cost of either a spare vehicle for retrieve mode or a set of spare modules for the resupply mode. For the deploy mode, only the initial spacecraft is considered in the investment costs.

Refurbishment costs are a function of the modules which are degraded at the time of servicing, i.e., when the EOS meets the failure criterion. Which modules require refurbishment are determined by the reliabilities of each module. The refurbishment cost is a percentage of the original cost of the degraded module, or the total spacecraft if it is to be refurbished. When resupplying the EOS on orbit, the refurbish costs are calculated as:

Refurbishment Costs = 0.4 x Cost of Degraded Modules.

In the retrieve case, where the spacecraft is ground refurbished, we assumed a refurbishment cost of 40% of the degraded modules and 20% of the balance of the Observatory:

Refurbishment Costs = 0.4 x Cost of Degraded Modules
+ 0.2 x (Cost of Basic Spacecraft - Cost of Degraded Modules).

For the deploy case, we compute refurbishment costs as 100% of Observatory Costs.

Transportation costs are incurred by utilizing the Shuttle. The first determination to be made is that of the Shuttle payload weight for each trip. The payload varies between Shuttle utilization modes: for deploy operations it consists of an entire spacecraft and FSS on ascent with just the FSS on descent; for retrieve missions it is an entire spacecraft and FSS on both ascent and descent; and for resupply missions it consists of the replacement modules and MEM on ascent and the degraded modules and MEM on descent. Once the payload weight has been determined, the Shuttle cost per cycle (Fig. 6-2, Box 12) can be derived if the Shuttle payload capacity and the cost of operating the Shuttle for a round-trip flight are known. Two procedures for determining transportation cost have been chosen. The first procedure, termed "shared cost," charges the Shuttle user a percentage of the \$9.8 million Shuttle cost that equals the proportion of the Shuttle payload capacity the user's payload occupies. The second method, called "dedicated Shuttle costs," charges the EOS the full \$9.8 million round-trip Shuttle cost every time the Shuttle is used.

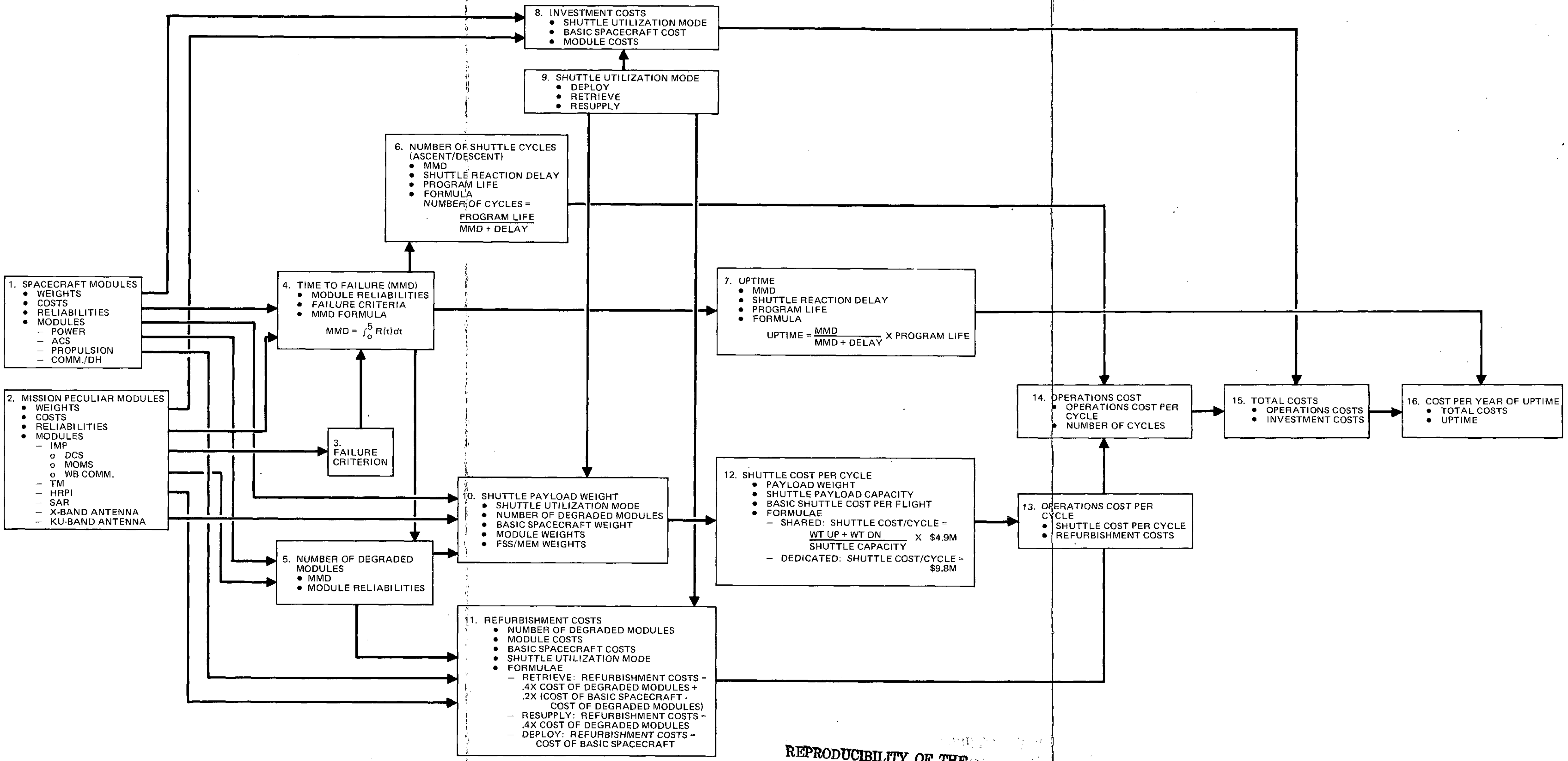


Fig. 6-2 Logic Flow Diagram

Once the refurbishment costs and Shuttle costs per cycle are determined, they are totalled to yield operations cost per cycle. The number of cycles covering the life of the program must then be determined. The input required for predicting the number of cycles is again, MMD, program life, and Shuttle reaction delay time; the formula is

$$\text{Number of Cycles} = \frac{\text{Program Life}}{\text{MMD + Delay}}$$

Multiplying operations costs per cycle by the number of cycles involved in the program yields the operations costs for the program. This figure is added to the investment costs to produce total program costs (Fig. 6-2, Box 15).

An additional figure of merit is the cost per year of uptime. This is calculated by dividing the total program cost by the uptime. The weight and cost data used in the analyses are shown in Tables 6-1 and 6-2.

Table 6-1 Weight Calculations for Shuttle Utilization

ELEMENT	EOS-B			EOS-C		
	DEPLOY	RETRIEVE	RESUPPLY	DEPLOY	RETRIEVE	RESUPPLY
• SUBSYSTEM MODULES						
PWR	264	264	278	296	296	310
ATT. CONTROL	280	280	294	425	425	439
COMM/DATA	250	250	264	250	250	264
ORBIT ADJ/RCS	114	114	125	171	171	962
SOLAR ARRAY/DRIVE	195	195	206	279	279	290
S/S SUB TOTAL	(1103)	(1103)	(1167)	(1421)	(1421)	(2265)
• INSTRUMENT MODULES						
HRPI	400	400	406	400	400	406
TM	400	400	406	800	800	813
SAR	–	–	–	500	500	511
• X-BAND ANTENNA	10	10	16	15	15	21
• INSTR. DATA HANDLING	149	149	155	194	194	200
INST. SUB TOTAL	(959)	(959)	(983)	(1909)	(1909)	(1951)
REPLACEABLE SUB TOTAL	(2062)	(2062)	(2150)	(3330)	(3330)	(4216)
NON REPLACEABLE						
TOTAL OBSERVATORY	3151	3187	3326	4620	4656	5206(1) 5596(2)
FSS	2528	2528		2528	2528	
MEM			6035			6035

NOTES: (1) INITIAL LAUNCH (DEPLOY)
(2) RESUPPLY COMPLETED (RETRIEVE)

T6-51

Table 6-2 Cost Calculations for Shuttle Utilization

	EOS-B			EOS-C		
	DEPLOY	RETRIEVE	RESUPPLY	DEPLOY	RETRIEVE	RESUPPLY
• SUBSYSTEM MODULES						
PWR	759	761	851	759	761	851
ATT. CONTROL	1737	1777	1777	1737	1777	1777
COMM/DATA	1897	1897	1897	2142	2142	2142
ORBIT ADJ/RCS	721	725	725	1103	1108	1108
SOLAR ARRAY & DRIVE	755	755	755	825	825	825
S/S SUBTOTAL	(5869)	(5915)	(6005)	(6566)	(6613)	(6703)
• INSTRUMENT MODULES						
* HRPI	5000	5000	5000	5000	5000	5000
TM	7000	7000	7000	14000	14000	14000
* SAR				2000	2000	2000
• X-BAND ANTENNA	400	400	400	400	400	400
• INSTR. DATA HANDLING	3102	3102	3102	3752	3752	3752
INSTR. SUBTOTAL	(15502)	(15502)	(15502)	(25152)	(25152)	(25152)
REPLACEABLE SUBTOTAL	(21371)	(21417)	(21507)	(31718)	(31765)	(31855)
NON-REPLACEABLE	4136	4216	4358	4936	5016	5158
OBSERVATORY	25507	25633	25665	36654	36781	37013

T6-52

6.1.3 SCHEDULED/UNSCHEDULED RESUPPLY

We found that scheduled resupply intervals are not cost-effective for the single vehicle programs. Lower costs and higher availability result from "on demand" utilization of the Shuttle, even if the Shuttle delays are as high as one year. Figure 6-3 shows the results of an analysis of the EOS-B configuration comparing scheduled vs unscheduled Shuttle utilization policies. It clearly shows that availability is higher and program costs are lower for the unscheduled utilization policy. The lower cost and higher utilization of the unscheduled policy is due to the maximization of spacecraft lifetime by waiting until service or replacement is required, rather than an arbitrary replacement schedule.

6.1.4 GROUND REFURBISH VERSUS ON-ORBIT REFURBISHMENT/REPAIR

We found that if one replaces all replaceable modules during a resupply flight, there is no significant difference in the programmatic costs and availability between Retrieve (ground refurbish) and Resupply modes of Shuttle utilization. We, therefore, investigated the policy of only replacing those modules that had either failed, had some failed components (redundant) within the module, or had reached a wear-out condition. We determined the mix of modules that would require replacement under this criteria. For each Observatory expended life (MMD), we determined the average (mean), the 95th percentile, and the distribution of the weight and cost of the failed modules. We used the 95th percentile weights to determine the Shuttle capability, and in fact, determined that for EOS-C re-

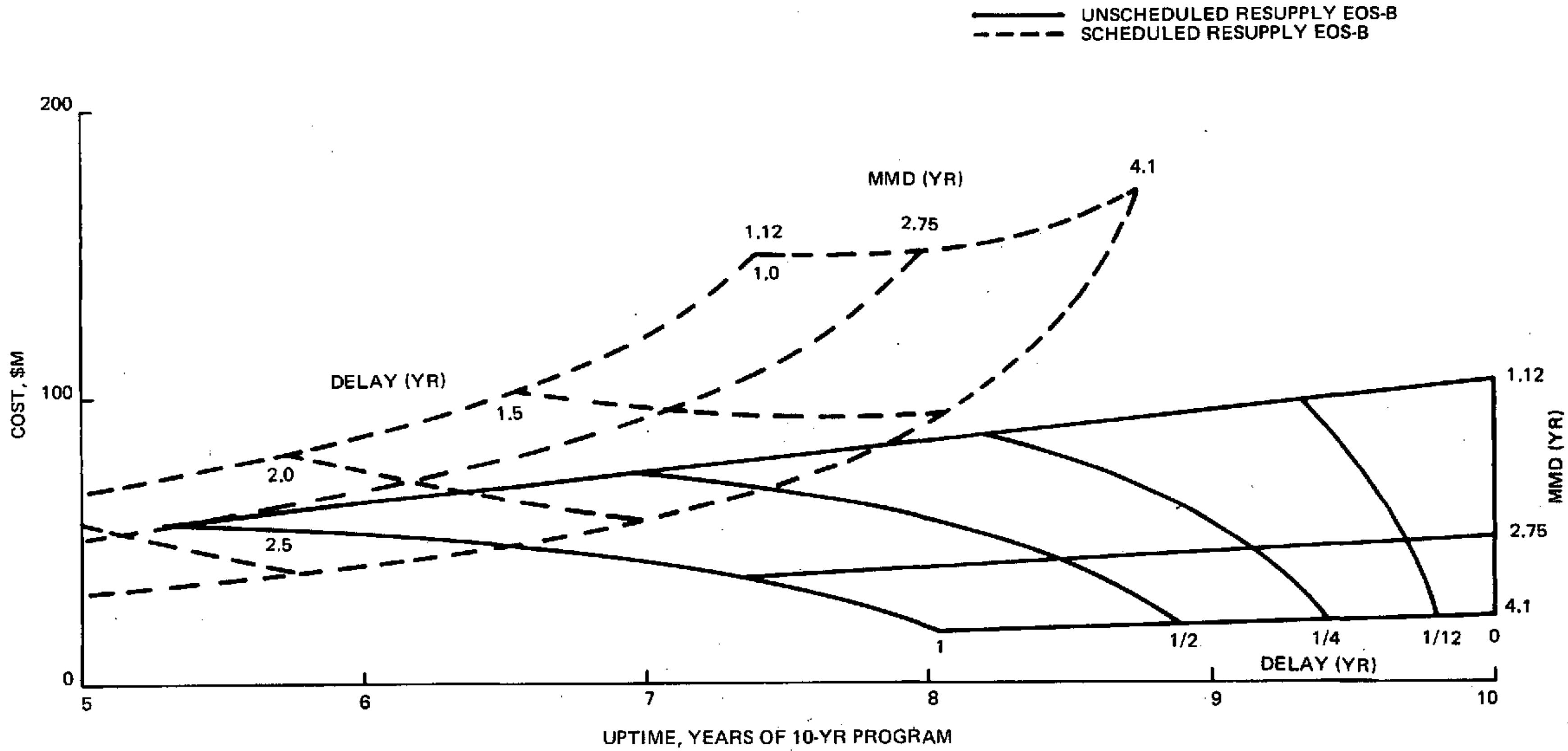


Fig. 6-3 Scheduled vs Unscheduled Resupply

supply we could not use the direct ascent method. Instead, for Mission C we planned to use the Shuttle to 200 n mi, and use an orbit transfer stage to place the Observatory into a 380.8 n mi orbit, and to return the EOS to 200 n mi for servicing.

We used the mean failed module weight to determine the payload weight for resupply missions, and to calculate transportation cost under the shared cost formula.

Refurbishment costs were based on mean repair module cost. We assumed that refurbishment would cost 40% of the cost of the repaired module mix.

Figures 6-4 and 6-5 are histograms of the weight distribution of EOS-B and -C for the on-orbit resupply mode, assuming high reliability experiments.

6.1.5 DEPLOY VS RETRIEVE VS RESUPPLY

We calculated the relative programmatic costs for EOS-B and EOS-C, single Observatory programs for the deploy, retrieve and resupply modes. The cost elements considered were:

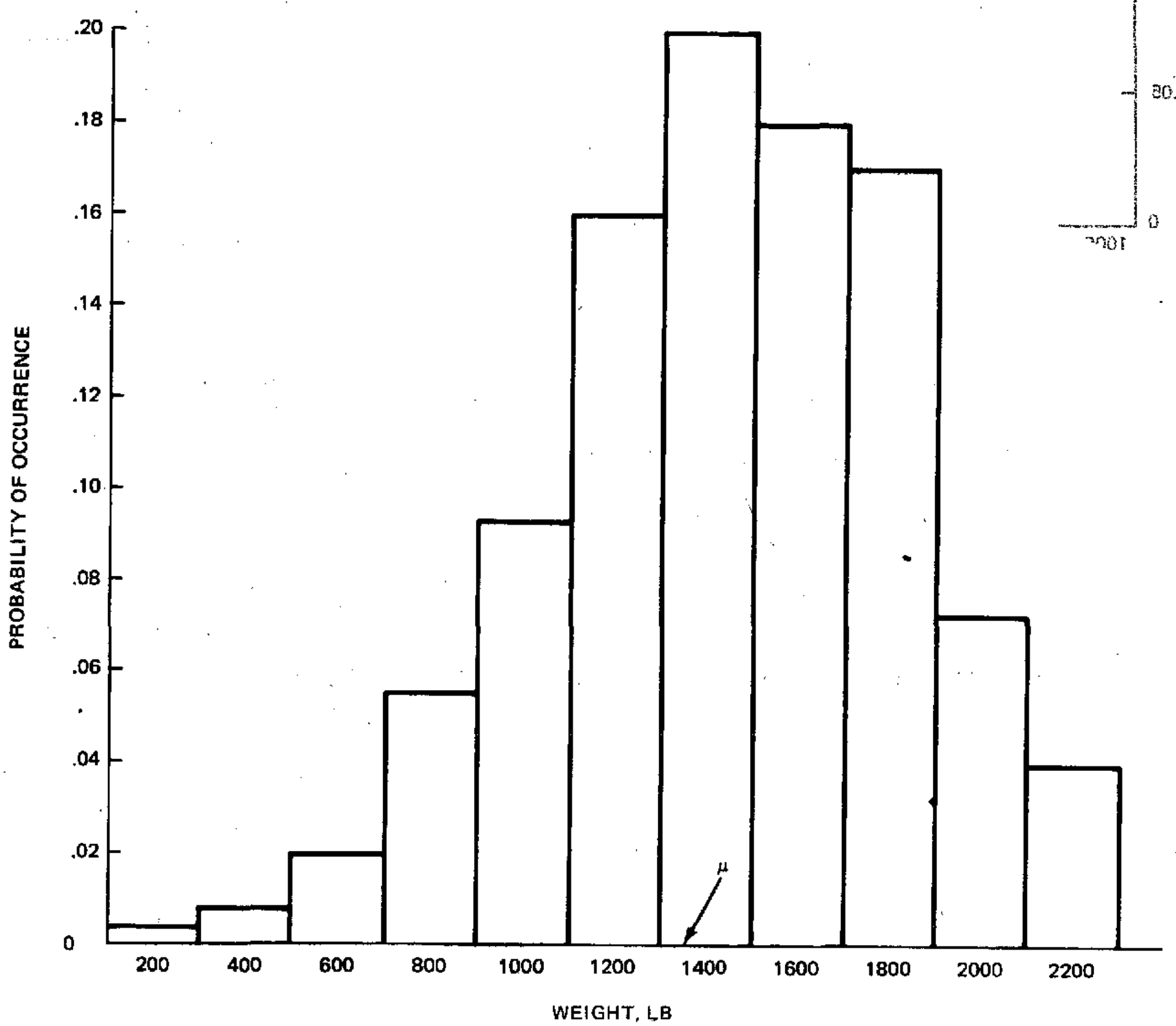
Non-Recurring (cost apportioned over Spacecraft MMD)

- Initial Investment (one spacecraft apportioned over the Spacecraft MMD)
- Initial Logistics (cost apportioned over Spacecraft MMD)
  - Retrieve; One spare spacecraft
  - Resupply; One set of modules

Recurring

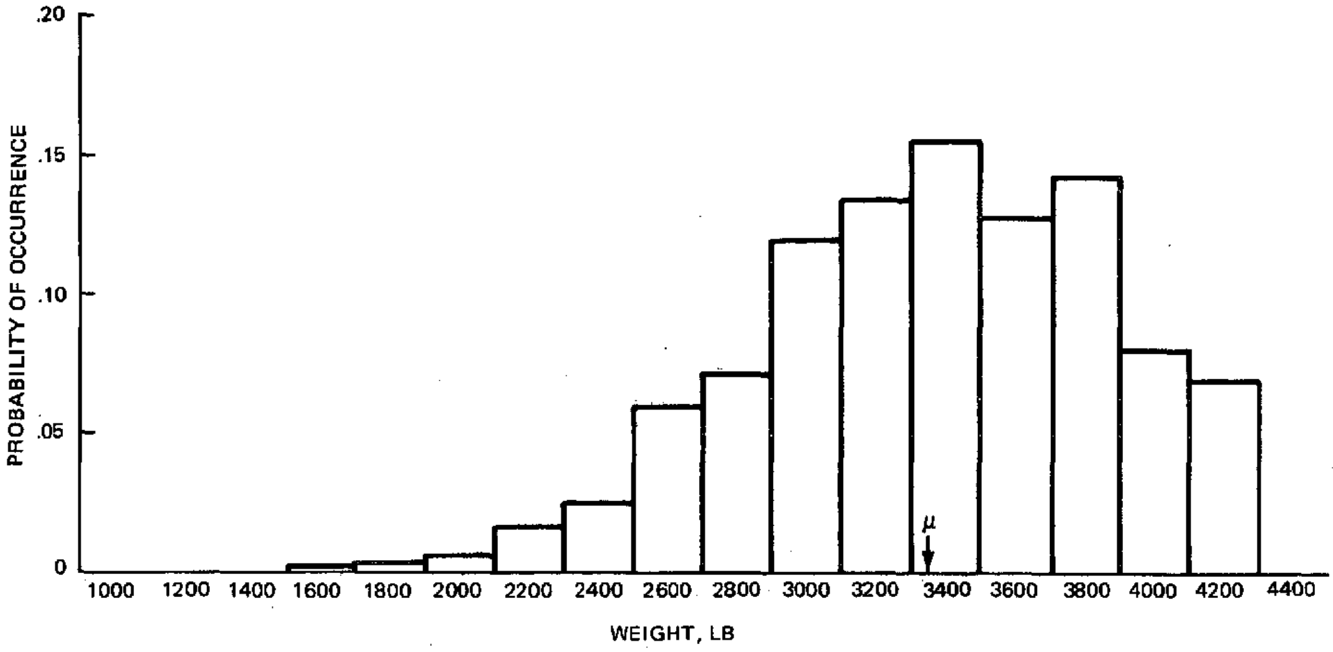
- Transportation (Shuttle Costs)
- Refurbishment (Retrieve and Resupply)
- Replacement Vehicle (Deploy).

Figure 6-6 is a bar chart showing the relative total costs for each mode for EOS-B and EOS-C assumed operating over a 10-year period. Transportation costs are shown using both the shared cost formula and as a dedicated Shuttle flight. If the number of replacement modules can be reduced on each Shuttle flight, Resupply becomes even more attractive. Both refurbishment and shared transportation costs will be reduced. To illustrate this point, Fig. 6-6 compares the Resupply costs for two levels of module replacement, the probabilistic average reflected in Figs. 6-4 and 6-5, and 50% of that level. For EOS-B,



6-41

Fig. 6-4 Weight Distribution, EOS-B Resupply, High Reliability Configuration



6-10 **Fig. 6-5 Weight Distribution, EOS-C Resupply, High Reliability Configuration**

cost can be reduced some $13 million and for EOS-C, $26 million. Dedicated Shuttle flights will reduce these savings slightly.

Figures 6-7, 6-8 and 6-9 show typical breakeven charts of program costs as a function of mission years. Not shown on these charts are the other non-recurring costs of development, training, and flight demonstration that may be required for rendezvous, capture and/or resupply. Also not shown are the ground support and operation cost that may be associated to support on-orbit operations.

6.2 SINGLE vs MULTIPLE SPACECRAFT PROGRAMS

To perform the single vs multiple spacecraft tradeoff, we compared the total program cost of a two EOS-B spacecraft program with a single EOS-C program. Both configurations contain two thematic mappers and could therefore perform the same mission. High reliability Instrument configurations and 3-month delay periods were chosen. We assumed that both EOS-B spacecraft would be refurbished and/or resupplied whenever either one failed. Figure 6-10 shows the programmatic costs of operating two EOS-B spacecraft over a 10-year period. It is not surprising to see that the total program costs in each case are higher than the single EOS-C spacecraft since almost twice the amount of hardware must be main-

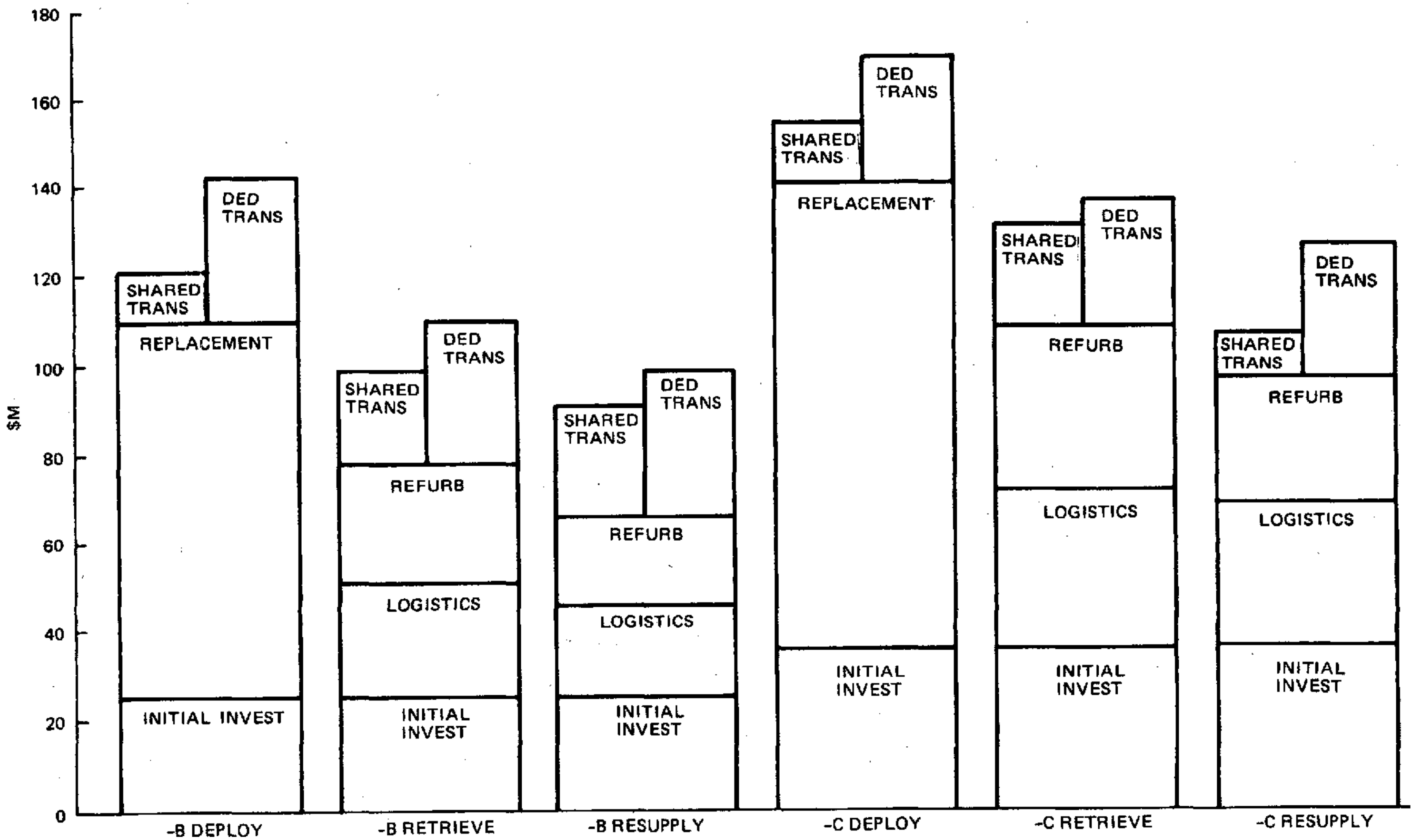


Fig. 6-6 Total Cost for 10-Year Program, High Reliability Configuration, 3-Month Delay

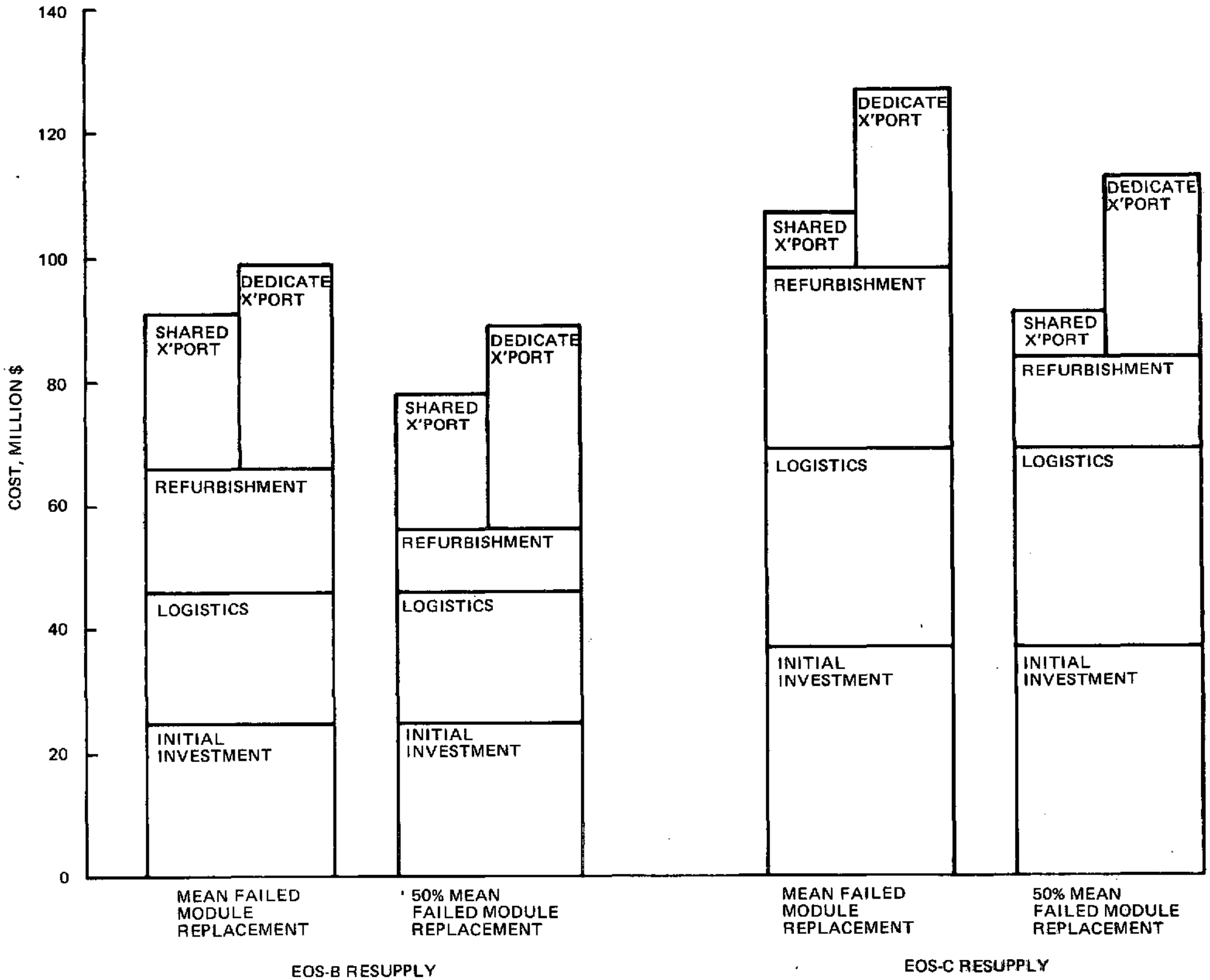


Fig. 6-7 Effect of Module Replacement Level

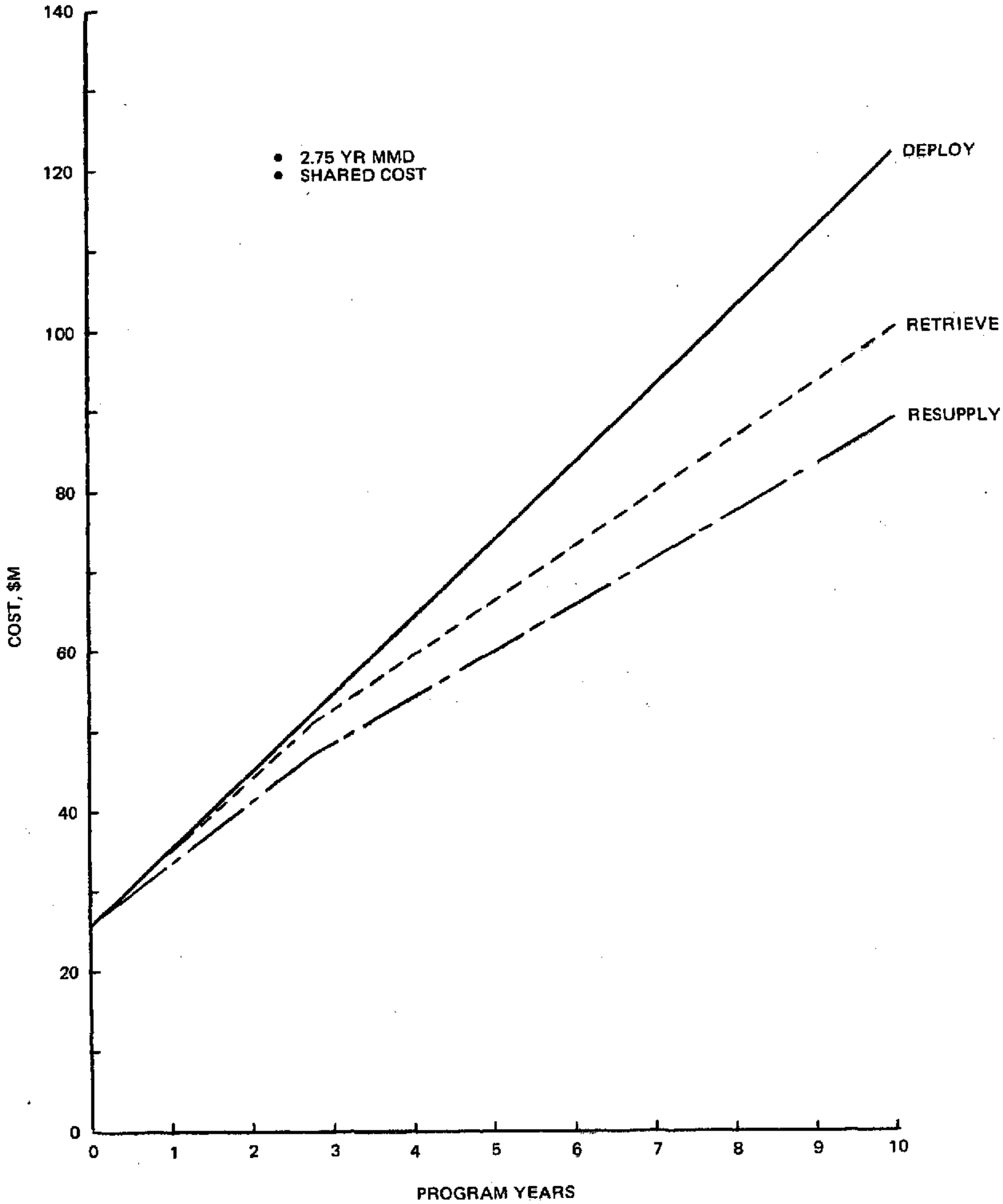


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Fig. 6-8 Cost vs Time, EOS-B High Reliability Configuration – 3-month Delay

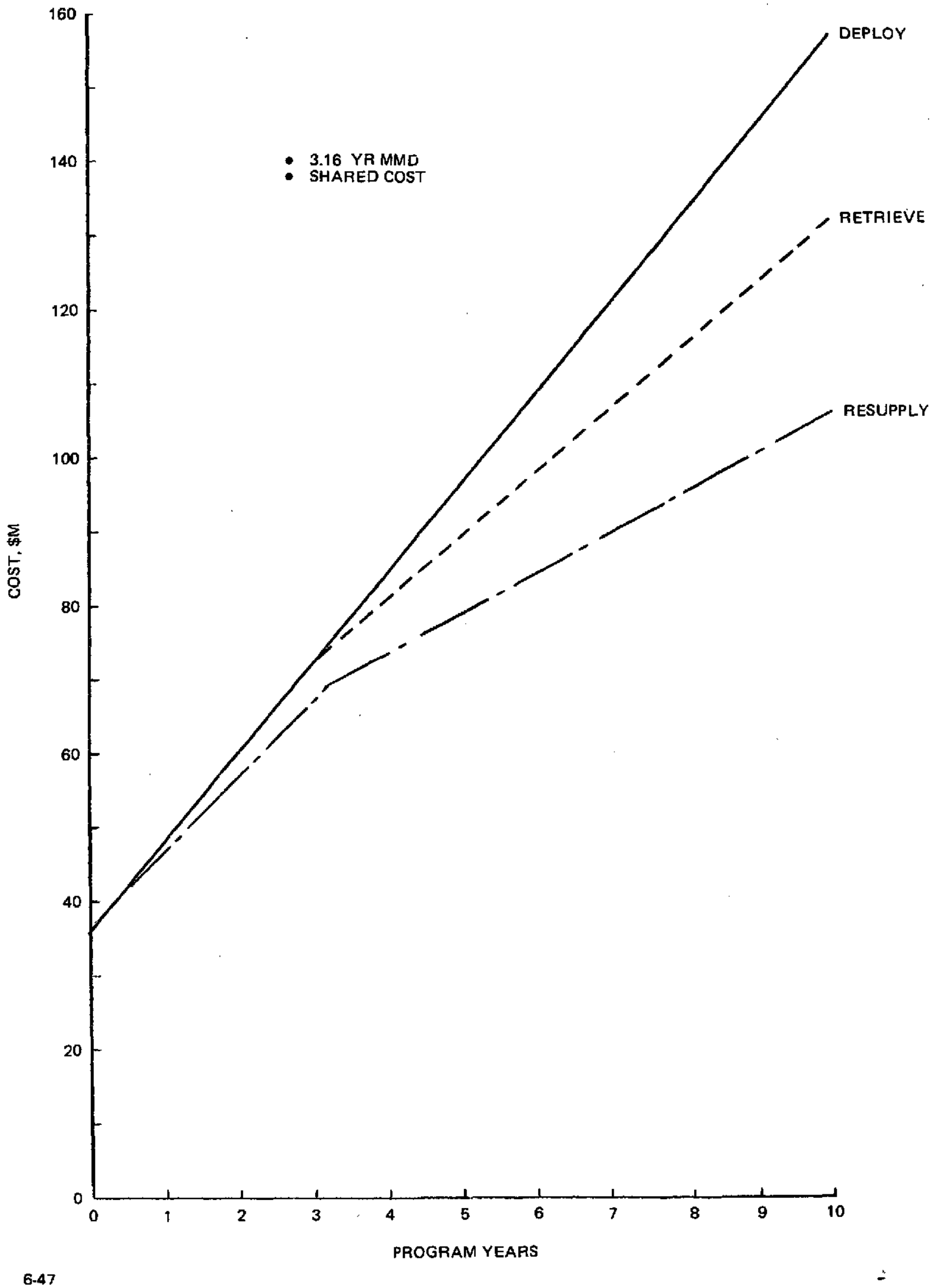

Fig. 6-9 Cost vs Time, EOS-C High Reliability Configuration – 3-Month Delay

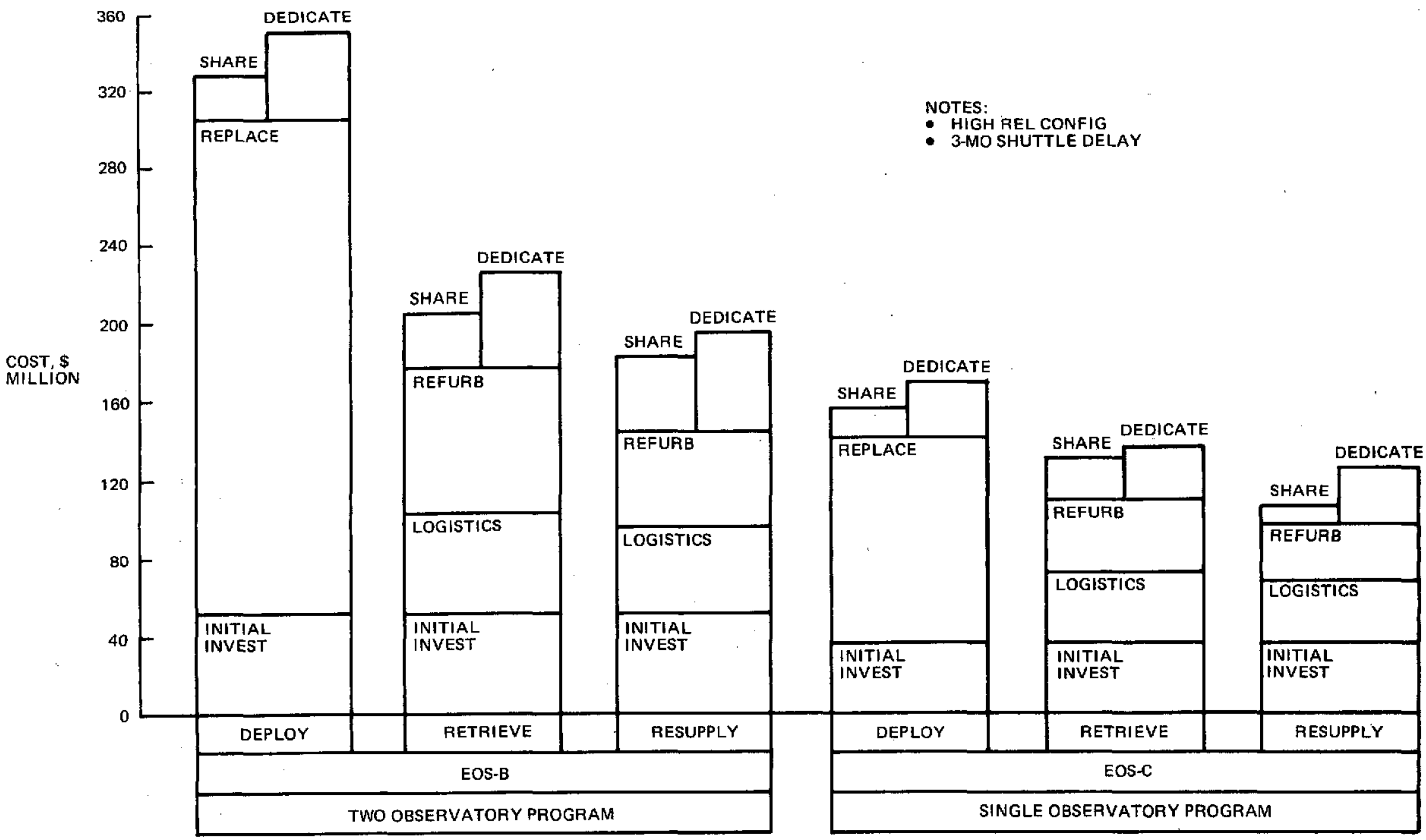

Fig. 6-10 Single/Dual Observatory Program Comparison

tained at a greater frequency. The two spacecraft system, however, achieves higher availability as shown in Table 6-3 because of its total redundancy feature.

It is clearly more cost-effective to have redundant instruments on the same Observatory for normal delay times, since the added costs associated with a two EOS-B spacecraft program result in small increases in uptime. It is only when the delay time becomes very long, i.e., over one year, that the multiple spacecraft configuration merits consideration.

Table 6-3 Uptime of Single vs Multiple Spacecraft Programs

DELAY TIME	UPTIME (YEARS OF 10 YEAR PROGRAM)	
(YEARS)	2 EOS-B	SINGLE EOS-C
1/12	9.99	9.74
1/4	9.97	9.27
1/2	9.89	9.63
1	9.58	7.60

T6-53

6.3 MANUAL ON-ORBIT RESUPPLY

Considerable study has been made on in-flight resupply leading to the current Special Purpose Manipulator System (SPMS) baseline resupply concept. The SPMS concept, however, entails a significant increment of EOS-chargeable weight (2,840 lb) and cost ($ 10 million non-recurring, $2.5 million per ship set recurring, plus Shuttle transportation at approximately $ 1000/lb). Two alternative approaches to resupply are available, Payload Development and Retrieval Mechanism (PDRM) activity controlled from the Orbiter cabin and direct manual operations by EVA crewmen. The viability of a PDRM approach is enhanced by the low latching forces needed by the Grumman latch design concept. Before any conclusions can be reached on the desirability of PDRM vs SPMS resupply, detailed analysis of PDRM dynamics and controllability are required, an effort not possible within the limits of this study. Available information from prior programs indicates that manual resupply may be competitive with both these mechanized approaches.

For all practical purposes, the accomplishments of space crews, in the performance of zero-G EVA, have dispelled speculation concerning the capability and cost-effectiveness of man's utility in space. Each successive mission has demonstrated the ease with which astronauts executed planned operations . . . in many cases surpassing performance levels achieved in neutral buoyancy simulation where these techniques were developed and perfected.

The feasibility of EVA was demonstrated during the Gemini Program and on the Apollo 9 flight. Apollo 15, 16, and 17 astronauts retrieved film and mapped the lunar surface. However, it was not until Skylab that the significance of EVA was realized.

Although Skylab plans called for six EVAs lasting 29 manhours, there were actually a total of 82.5 manhours devoted to this activity occurring over the course of 10 EVA periods. Not only were planned EVA objectives met, an additional 18 extra mission objectives achieved and 13 in-flight repairs accomplished, but the repairs effected though EVA enabled the mission to be successfully completed.

These facts have indicated the value of EVA to mission success and man's potential with respect to Space Shuttle payload operations.

Consequently, an apparent supplement to the Special Purpose Manipulator System (SPMS) would be the utilization of the Shuttle crew, in the EVA mode, as the backup method of accomplishing EOS module maintenance and resupply.

The major consideration for EOS manned servicing is the ability of the EVA crewmen to safely and efficiently handle large packages, some of which, such as the TM and HRPI, weigh as much as 406 lb. Their relative shapes are asymmetrical cylinders with approximate dimensions (overall envelope) of 52 in. x 37 in. x 41 in. The next largest units are the ACS, EPS, and CDH modules weighing 294 lb, 278 lb, and 264 lb, respectively. These are symmetrically shaped rectangles whose dimensions are 48 in. x 48 in. x 18 in. In general, the centers of gravity of these five modules fall close to their geometric centerpoints.

Although none of the Skylab EVAs involved handling or transporting objects as large as these, a significant amount of IVA experience was gained in the manipulation of objects that came reasonably close to being as large and as heavy, within the confines of the Skylab work area. These objects were categorized as follows:

- Small - 11 lb or less
- Medium - 11 lb to 110 lb
- Large - More than 110 lb.

The largest objects handled by the astronauts were the series of food containers that had to be relocated from their launch positions to permanent stowage racks, a distance of approximately 20 ft. Each container weighed 220 lb and was approximately 24 in. x 24 in. x 40 in. The mounting flanges on the containers were used as the gripping points, but they were not designed as efficient handles. The manipulation and transportation of these containers presented no difficulty, even with the absence of adequate hand holds.

Many other items classified as "medium" and "large" were moved with exceeding ease and efficiency over distances of as much as 65 ft. One significant finding was that large objects tended to block the view of the path along which they were being transported, as well as the terminal point interface.

An interesting technique for transporting these objects illustrates the ease of handling. The crewmen would begin to move the object in the desired direction. He would then accelerate past it, reposition himself at the terminal point and proceed to catch the item as it arrived.

Reflecting on their experience, NASA JSC has concluded that:

> "As demonstrated repeatedly throughout the Skylab Program with proper restraints, accessibility, procedures, and adequate worksite, man can conduct in-flight maintenance tasks as effectively in orbit as he can on Earth."

Even in the absence of empirical data with objects the size of the EOS modules, based on the above it is possible to extrapolate from these experiences and conclude the following:

- The weight and size of the EOS modules fall within the capabilities of EVA crewmen to perform the required system servicing functions, given the proper equipment and resources with which to perform, as shown in the following summary.
- EVA is a feasible cost-effective backup for EOS module resupply
- EVA module exchange, as a backup to SPMS failure, should be incorporated into the planning for EOS contingency resupply as a means of assuring mission continuation and success.

BASIC EQUIPMENT REQUIRED FOR ONE-MAN EOS EVA MODULE SERVICING (SUMMARY)

- Space suit and life support system (PLSS and/or umbilical system)
- Stationary or elevating work platform. This platform must be configured with hand rails and/or guard plates to protect delicate EOS surfaces and to preclude damage to the astronaut's space suit. If the work platform is stationary, a motor-driven or hand powered conveyor system is required to raise and lower the EOS modules
- Portable and stationary area and directional lighting
- Hand and foot mobility aids
- Foot, waist, and hand restraint devices in various combinations

- Crew and equipment tethering devices
- Special tools held to a minimum
- Equipment and tool retention devices located on the space suit and on the work station
- Module hand holds and/or handling devices
- Manual disconnect and mating devices
- Visual aids and markings for mating connections and for guiding the movement of modules
- Interim and final stowage areas.

6.4 SPACECRAFT REDUNDANCY LEVEL

Our studies have shown that when utilizing Shuttle, it is cost-effective to include a high degree of redundancy in the spacecraft subsystems for all EOS configurations. The increased mission reliability, and its associated longer mean mission duration, decreases the number of Shuttle flights and/or refurbishments required. We, therefore, baselined redundancy in our spacecraft subsystem modules as shown in Table 6-4.

We varied our estimates of Instrument and mission peculiar module reliabilities to provide a range of results that would indicate the programmatic sensitivities to their reliability. Our reliability estimates ranged from unity (assumed that Instruments never fail) to high reliability (values that we assumed could be achieved in the Instruments and mission peculiar modules were designed with selective redundancy), to low reliability (a pessimistic value).

Table 6-5 shows the failure rates we assumed for instruments and mission peculiar modules.

Figures 6-11 through 6-16 are curves of program cost versus uptime for the family of Instrument reliability levels and for various Shuttle delays.

Table 6-4 Reliability/Redundancy Tabulation

ITEM NO	COST	WEIGHT	LAMBDA	QTY	DUTY CYCLE	DORM FACT	REDUND CODE *	EQUIPMENT NAME
1	57.000	3.0	0.5000E-05	1	0.10	0.0	3	S-BAND TRANSMITTER/MOD
2	50.000	3.0	0.2500E-05	1	1.00	0.0	4	S-BAND RECEIVER/DEMOD
3	16.000	2.0	0.1000E-06	1	1.00	0.0	2	ANTENNA EARTH POINTING
4	16.000	2.0	0.1000E-06	1	1.00	0.0	2	ANTENNA BACKSIDE
5	8.000	2.0	0.1310E-06	1	1.00	0.0	2	DIPLEXER EARTH POINTING
6	8.000	2.0	0.1310E-06	1	1.00	0.0	2	DIPLEXER BACKSIDE
7	2.000	1.0	0.2300E-07	1	1.00	0.0	2	S-BAND HYBRID
8	2.000	1.0	0.1060E-06	1	1.00	0.0	2	COAX SWITCH
9	110.000	34.0	0.7000E-05	1	1.00	0.0	3	COMPUTER
10	19.000	4.0	0.3000E-05	1	1.00	0.0	3	CLOCK
11	44.000	3.0	0.2000E-05	1	1.00	0.0	3	FORMAT GENERATOR
12	32.000	12.0	0.5000E-05	1	1.00	0.0	3	COMMAND DECODER
13	10.000	1.0	0.5000E-06	1	1.00	0.0	3	REMOTE DECOD-MUX
14	37.000	8.0	0.1500E-05	1	1.00	0.0	2	SIGNAL CONDITIONER
15	235.000	4.0	0.2100E-05	1	1.00	0.0	3	GYRO ASSY
16	43.000	17.0	0.5200E-05	1	1.00	0.0	3	STAR TRACKER
17	42.000	1.0	0.1560E-07	1	0.0	0.0	2	DIGITAL SUN SENSOR
18	4.500	1.0	0.1780E-07	1	0.0	0.0	2	COARSE SUN SENSOR (2)
19	30.000	30.0	0.3300E-06	1	1.00	0.0	2	REACTION WHEEL (3)
20	35.000	7.0	0.3000E-07	1	1.00	0.0	2	MAGNETOMETER SENSOR
21	193.000	13.0	0.1700E-05	1	1.00	0.0	2	ELECTRONIC ASSY
22	30.000	10.0	0.3000E-07	1	1.00	0.0	2	TORQUER BAR (3)
23	20.000	2.0	0.2000E-05	1	1.00	0.0	3	REMOTE DECOD-MUX (2)
24	32.800	3.0	0.1000E-07	1	1.00	0.0	2	THRUSTERS 5LB 2/4
25	31.200	4.0	0.1000E-02	1	0.0	0.0	2	THRUSTERS 1.0LB 6/8
26	8.800	2.0	0.1000E-02	1	0.0	0.0	2	THRUSTERS 0.1LB 6/8
27	45.000	7.0	0.1000E-05	1	1.00	0.0	2	PROPELLANT TANK (2)
28	10.500	2.0	0.1000E-07	1	1.00	0.0	2	SOLENOID VALVE,LATCH (3)
29	2.000	2.0	0.2000E-08	1	1.00	0.0	2	FILTER (2)
30	10.000	2.0	0.1000E-05	1	1.00	0.0	3	REMOTE DECOD-MUX
31	18.200	32.0	0.2700E-05	1	1.00	0.0	6	BATTERY
32	55.000	27.0	0.2000E-06	1	1.00	0.0	2	BATTERY CHARGER
33	213.000	23.0	0.6000E-06	1	1.00	0.0	2	CENTRAL PWR CONT
34	27.000	10.0	0.1500E-05	1	1.00	0.0	2	SIGNAL CONDITIONER
35	20.000	2.0	0.1500E-05	1	1.00	0.0	3	REMOTE DECODER-MUX (2)
36	333.000	170.0	0.2000E-07	1	1.00	0.0	2	SOLAR ARRAY
37	52.000	25.0	0.1000E-05	1	1.00	0.0	2	SOLAR ARRAY DRIVE
38	7000.000	406.0	0.1000E-04	1	1.00	0.0	2	THEMATIC MAPPER
39	2000.000	45.0	0.5000E-05	1	1.00	0.0	2	WIDE BAND COMM
40	400.000	21.0	0.1000E-05	1	1.00	0.0	2	X-BAND STEERABLE ANTENNA
41	1000.000	22.0	0.3000E-05	1	1.00	0.0	2	MOMS
42	45.000	64.0	0.1500E-05	1	1.00	0.0	2	SIGNAL CONDITIONER

* redundancy code: 2-none; 3-1 standby; 4-1 active; 6-2 standby

T6-54

Table 6-5 Mission Peculiar Equipment Failure Rates

EQUIPMENT	FAILURE RATE-FAILURE PER MILLION HR	
	OPTIMISTIC	PESSIMISTIC
• THEMATIC MAPPER	10	50
• HRPI	10	50
• SAR	5	25
• X-BAND ANTENNA	1	1
• Ku-BAND ANTENNA	1	1
• IMP MODULE	(14.5)	(66.5)
– DSC	5	25
– MOMS	3	15
– SIGNAL CONDITIONER	1.5	1.5
– WIDE BAND COMM.	5	5

T6-55

6.5 CONCLUSIONS AND RECOMMENDATIONS

- For a 10-year operational program, on-orbit resupply yields the lowest cost
- The cost difference between on-orbit resupply and retrieve with ground refurbishment is small
- The weight of the SPMS (Module Exchange Mechanism and Module Magazine) should be minimized to reduce resupply transportation costs. For a projected low-weight FFS + SPMS (1900 lb), shared transportation cost would be $14 million lower for EOS-B and $4 million lower for EOS-C
- Subsystems and instruments should be designed for high reliability (redundancy)
- A single EOS-C spacecraft with multiple instruments is more cost-effective than two EOS-B spacecraft
- Scheduled retrieve/resupply intervals are not cost-effective. Shuttle should be operated in an "on-demand" mode
- Dedicated Shuttle flights result in higher cost than shared flights. Variations in user-charge methodology (i.e., proportional rate structure) did not impact study results.

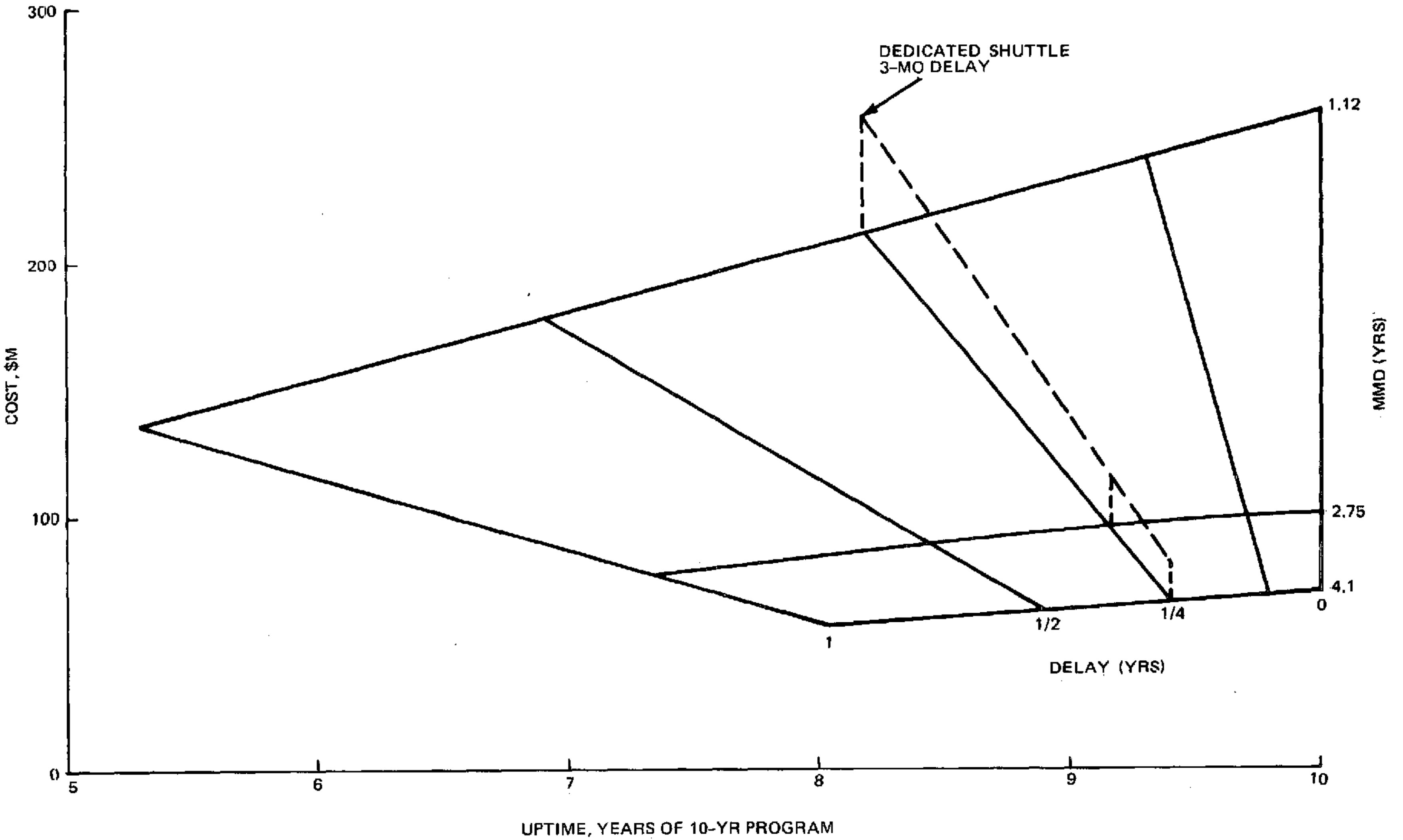

Fig. 6-11 EOS-B Deploy

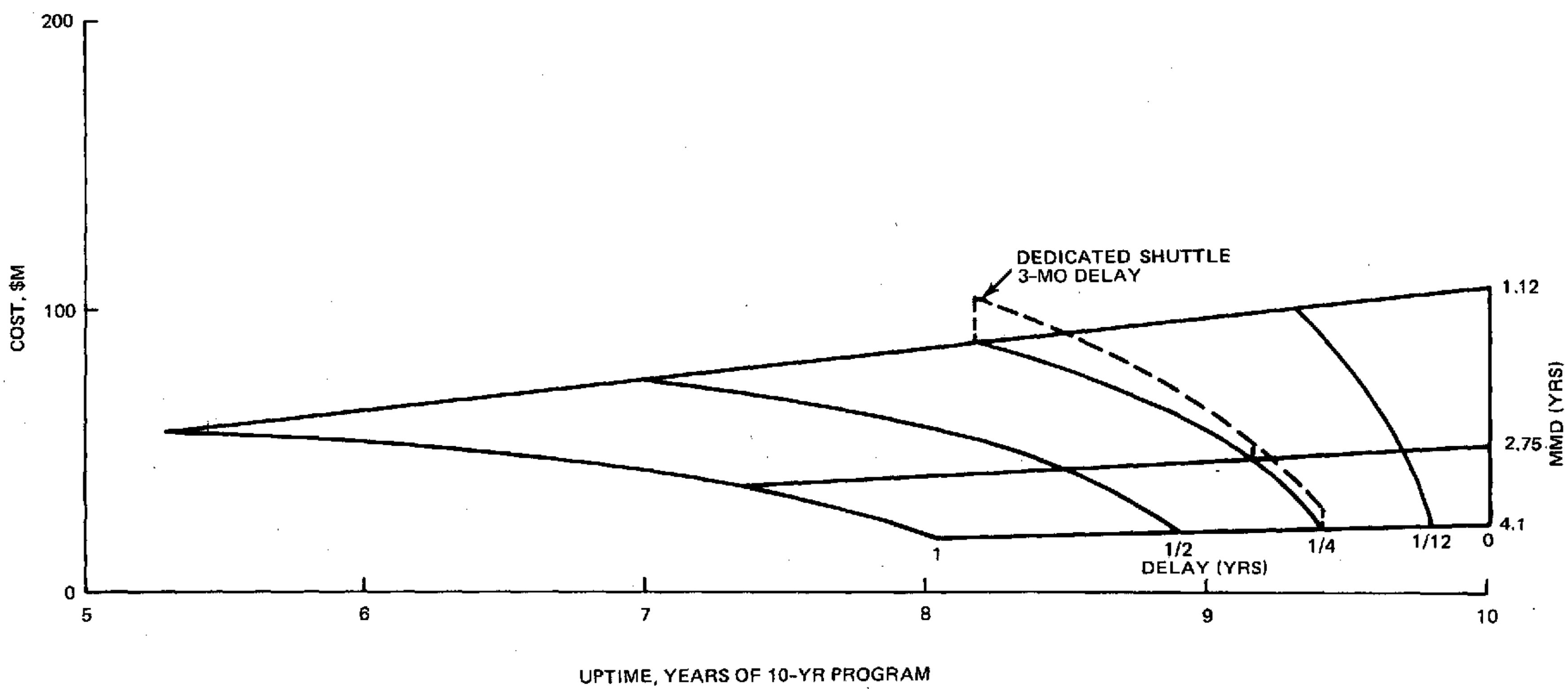

Fig. 6-12 EOS-B Resupply

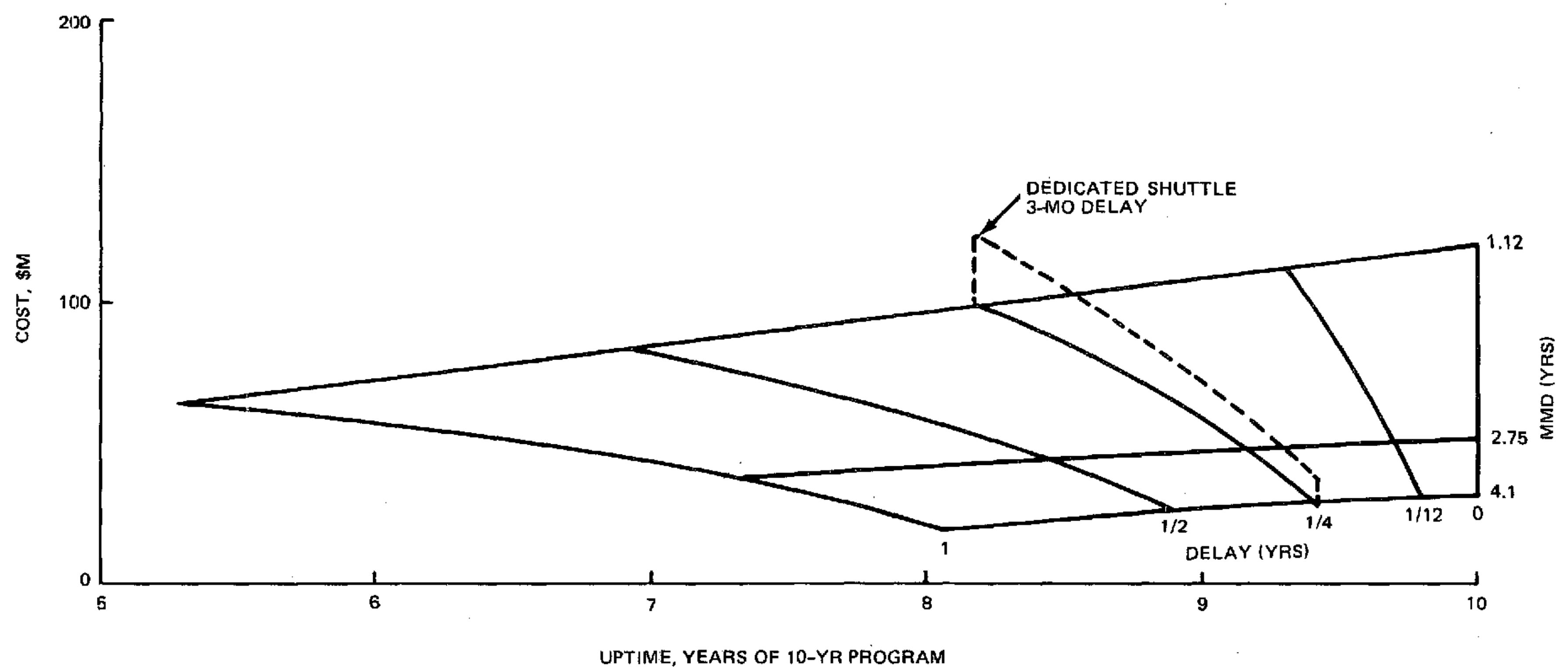

Fig. 6-13 EOS-B Retrieve

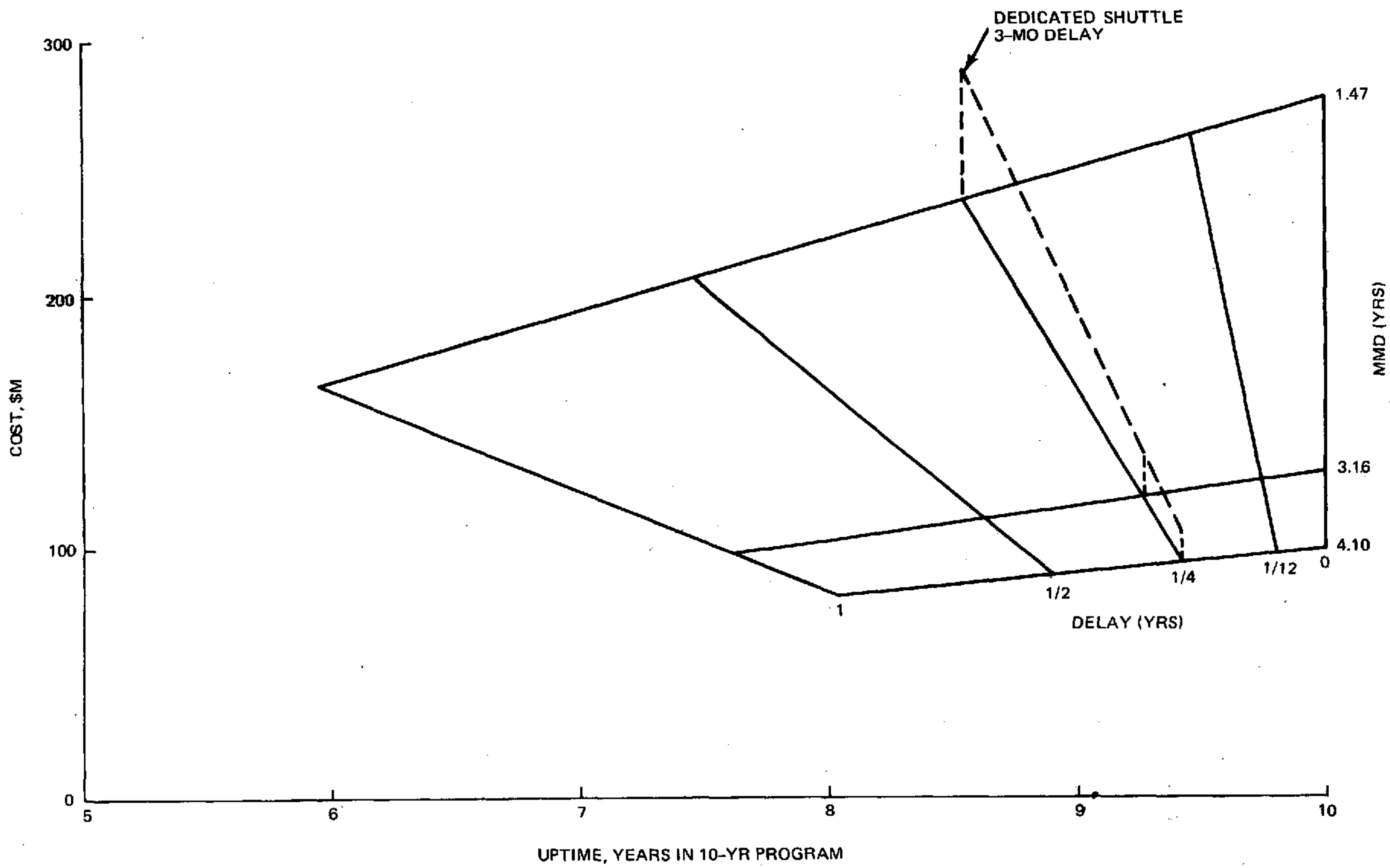

Fig. 6-14 EOS-C Deploy

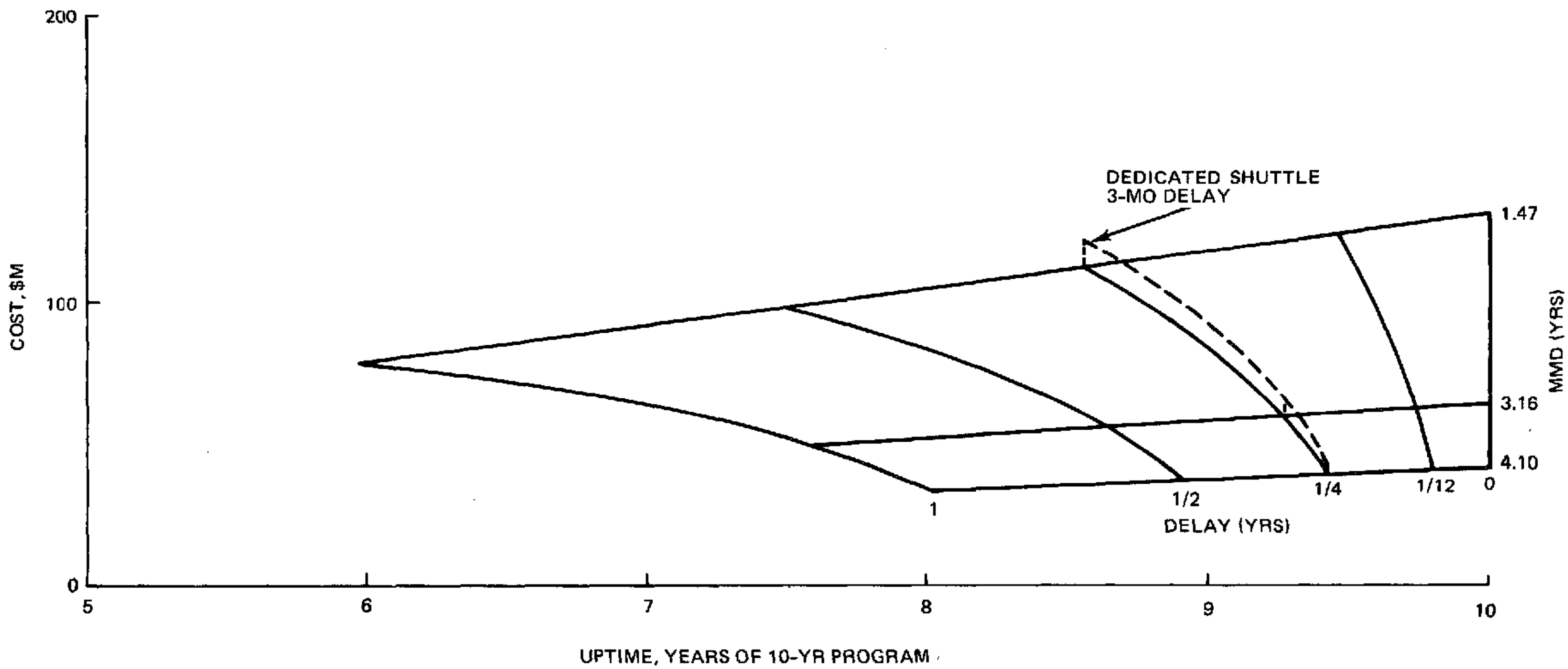

Fig. 6-15 EOS-C Retrieve

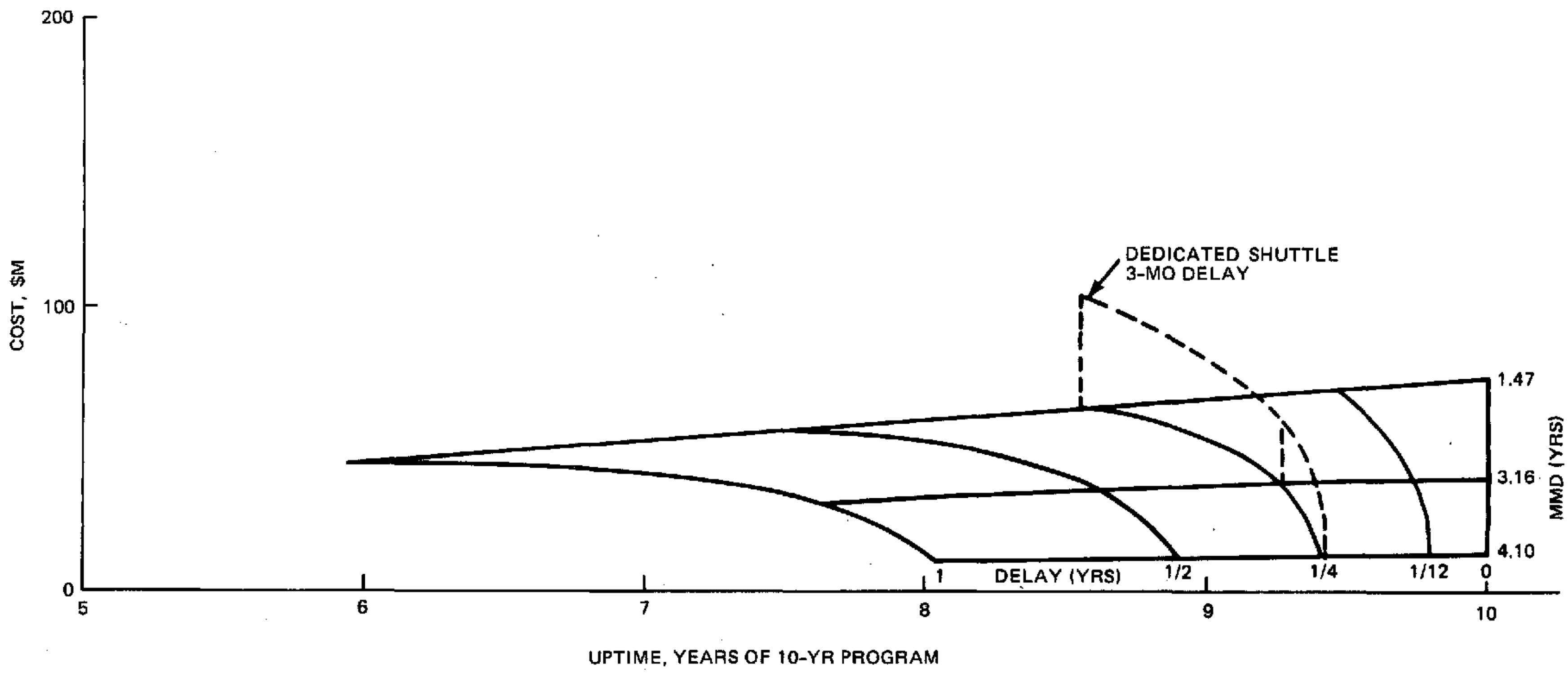

Fig. 6-16 EOS-C Resupply

7 - REFERENCES

In the conduct of this study, significant use was made of prior and ongoing studies related to the EOS or to EOS-Shuttle operations. The following sources have been referenced throughout this report:

(1) GAC Report, "Earth Observatory Satellite System Definition Study Report; Report No. 3, Design/Cost Trade-Off Studies", dated 15 July 1974

(2) RI Report SD-74-SA-0057, "Flight Support System for Earth Observation Satellite (System Definition and Interfaces)", dated June 1974

(3) SPAR Report R-592, "Design Definition Studies of Special Purpose Manipulator System for Earth Observatory Satellites", dated January 1974

(4) NASA Report JSC 07700, Volume XIV, "Space Shuttle System Payload Accommodations", Revision C, dated 3 July 1974

(5) NASA Report JSC 07700, Volume XIV, "Space Shuttle System Payload Accommodations", Revision B, dated 21 December 1973

(6) GAC IOM No. EOM-74-158, "EOS On-Orbit Resupply, Reference Mission Timeline", dated 8 August 1974

(7) RI Report SD-73-SA-0099, "Quarterly Report, EOS Flight Support System Definition Study", dated 16 July 1973

(8) JSC Internal Note No. 74-FM-5, "Effects of an Elliptic Servicing Orbit on Orbiter Rendezvous with the Goddard Earth Observation Satellite", dated 29 January 1974

(9) JSC Internal Note No. 74-FM-6, "EOS Maneuvering to a Shuttle Compatible Servicing Orbit Prior to Shuttle Lift-Off", dated 4 February 1974

(10) JSC Internal Note No. 74-FM-17, "Preliminary Representative Mission Profile and Performance Analysis for a Typical EOS Servicing Mission", dated 7 March 1974