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ORBITAL OPERATIONS STUDY

VOLUME II - INTERFACING ACTIVITIES ANALYSES

PART 4 - SUPPORT OPERATIONS ACTIVITY GROUP

FINAL REPORT

MAY 1972

APPROVED BY

L. R. Hogan

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TECHNICAL REPORT INDEX/ABSTRACT

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DESCRIPTIVE TERMS

*ELEMENT INTERFACES, *ALTERNATE APPROACHES, *DESIGN CONCEPTS, *OPERATIONAL PROCEDURES, *FUNCTIONAL REQUIREMENTS, *DESIGN INFLUENCES, *CREW TRANSFER, *CARGO TRANSFER, *PROPELLANT TRANSFER, *ATTACHED ELEMENT OPERATIONS, *ATTACHED ELEMENT TRANSPORT

ABSTRACT

THIS DOCUMENT IS VOLUME II, PART 4 OF THE FINAL REPORT OF THE ORBITAL OPERATIONS STUDY. ELEMENT INTERFACES, ALTERNATE APPROACHES, DESIGN CONCEPTS, OPERATIONAL PROCEDURES, FUNCTIONAL REQUIREMENTS, DESIGN INFLUENCES, AND APPROACH SELECTION ARE PRESENTED FOR EACH OF THE FOLLOWING INTERFACING ACTIVITIES: CREW TRANSFER, CARGO TRANSFER, PROPELLANT TRANSFER, ATTACHED ELEMENT OPERATIONS, ATTACHED ELEMENT TRANSPORT.

FOREWORD

This report contains the results of the analyses conducted by the Space Division of North American Rockwell during the Orbital Operations Study, Contract NAS9-12068, and is submitted in accordance with line item 7 of the Data Requirements List (DRL 7).

The data are presented in three volumes and three appendixes for ease of presentation, handling, and readability. The report format is primarily study product oriented. This study product format was selected to provide maximum accessibility of the study results to the potential users. Several of the designated study tasks resulted in analysis data across elements and interfacing activities (summary level); and also analysis data for one specific element and/or interfacing activity (detailed level). Therefore, the final report was structured to present the study task analysis results at a consistent level of detail within each separate volume.

The accompanying figure illustrates the product buildup of the study and the report breakdown. The documents that comprise the reports are described below:

Volume I - MISSION ANALYSES, contains the following data:

- o Generic mission models that identify the potential earth orbit mission events of all the elements considered in the study
- o Potential element pair interactions during on-orbit operations
- o Categorized element pair interactions into unique interfacing activities

Volume II - INTERFACING ACTIVITIES ANALYSIS, contains the following data:

- o Cross reference to the mission models presented in Volume I
- o Alternate approaches for the interfacing activities
- o Design concept models that are adequate to implement the approaches
- o Operational procedures to accomplish the approaches
- o Functional requirements to accomplish the approaches
- o Design influences and preferred approach selection by element pairs.

This volume is subdivided into four books or parts which are:

Part 1. INTRODUCTION AND SUMMARY - Condensed presentation of the significant results of the analyses for all interfacing activities

Part 2. STRUCTURAL AND MECHANICAL ACTIVITY GROUP

- o Mating
- o Orbital Assembly
- o Separation
- o EOS Payload Deployment
- o EOS Payload Retraction and Stowage

Part 3. DATA MANAGEMENT ACTIVITY GROUP

- o Communications
- o Rendezvous
- o Stationkeeping
- o Detached Element Operations

Part 4. SUPPORT OPERATIONS ACTIVITY GROUP

- o Crew Transfer
- o Cargo Transfer
- o Propellant Transfer
- o Attached Element Operations
- o Attached Element Transport

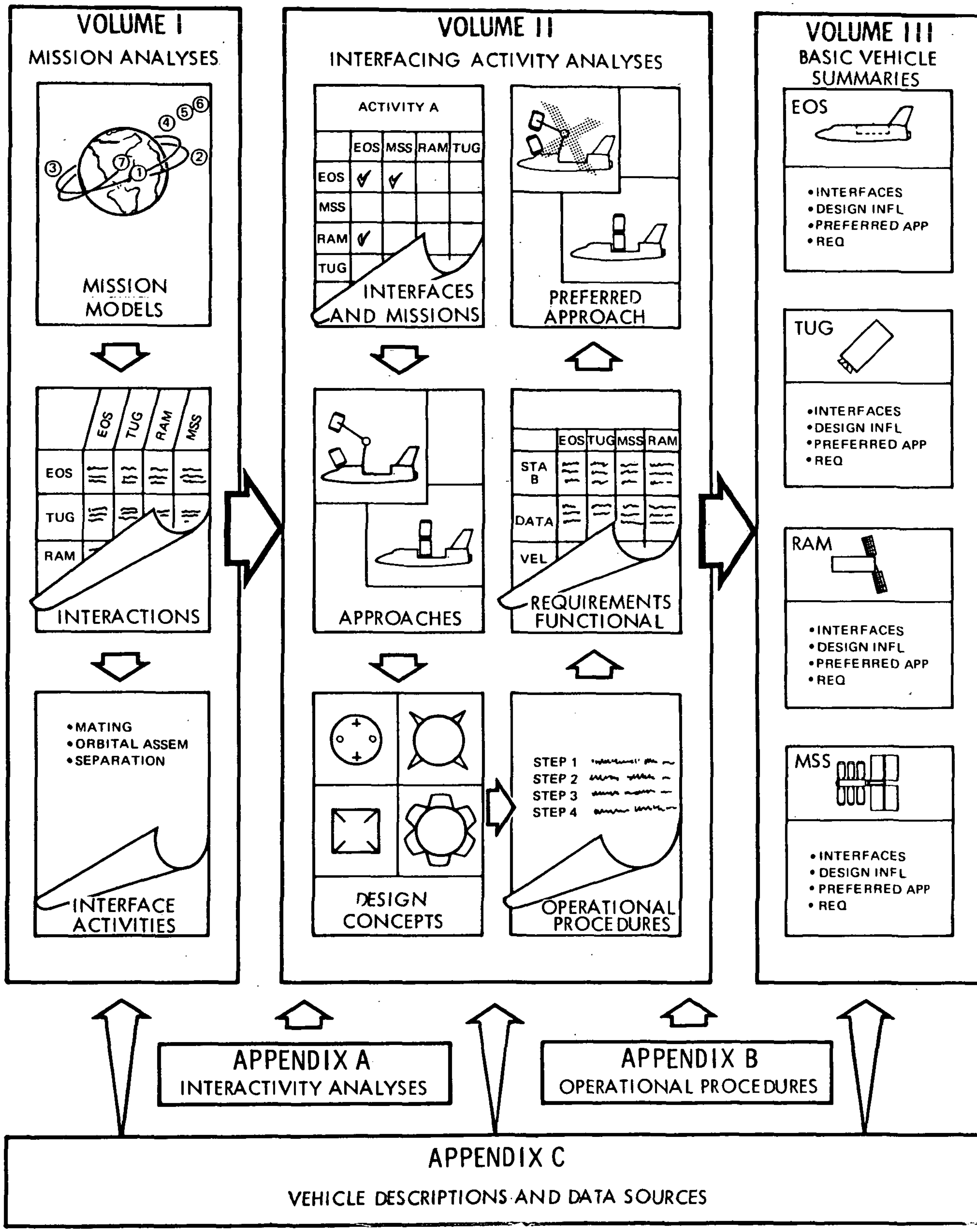
Volume III - BASIC VEHICLE SUMMARIES, contains a condensed summary of the study data pertaining to the following elements:

- o Earth Orbital Shuttle
- o Space Tug
- o Research and Applications Modules
- o Modular Space Station

Appendix A - INTERACTIVITY ANALYSES, contains many of the major trades and analyses conducted in support of the conclusions and recommendations of the study.

Appendix B - OPERATIONAL PROCEDURES, contains the detailed step-by-step sequence of events of each procedure developed during the analysis of an interfacing activity.

Appendix C - VEHICLE DESCRIPTIONS AND DATA SOURCES, presents a synopsis of the characteristics of the program elements that were included in the study (primarily an extraction of the data in Appendix I of the contract statement of work), and a bibliography of the published documentation used as reference material during the course of this study.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INTRODUCTION

This specific book is one part of the analyses conducted for each of fourteen interfacing activities. The results from five of the activities are documented in this book (Volume II Part 4). These activities are as follows:

Section 1.0 CREW TRANSFER

Section 2.0 CARGO TRANSFER

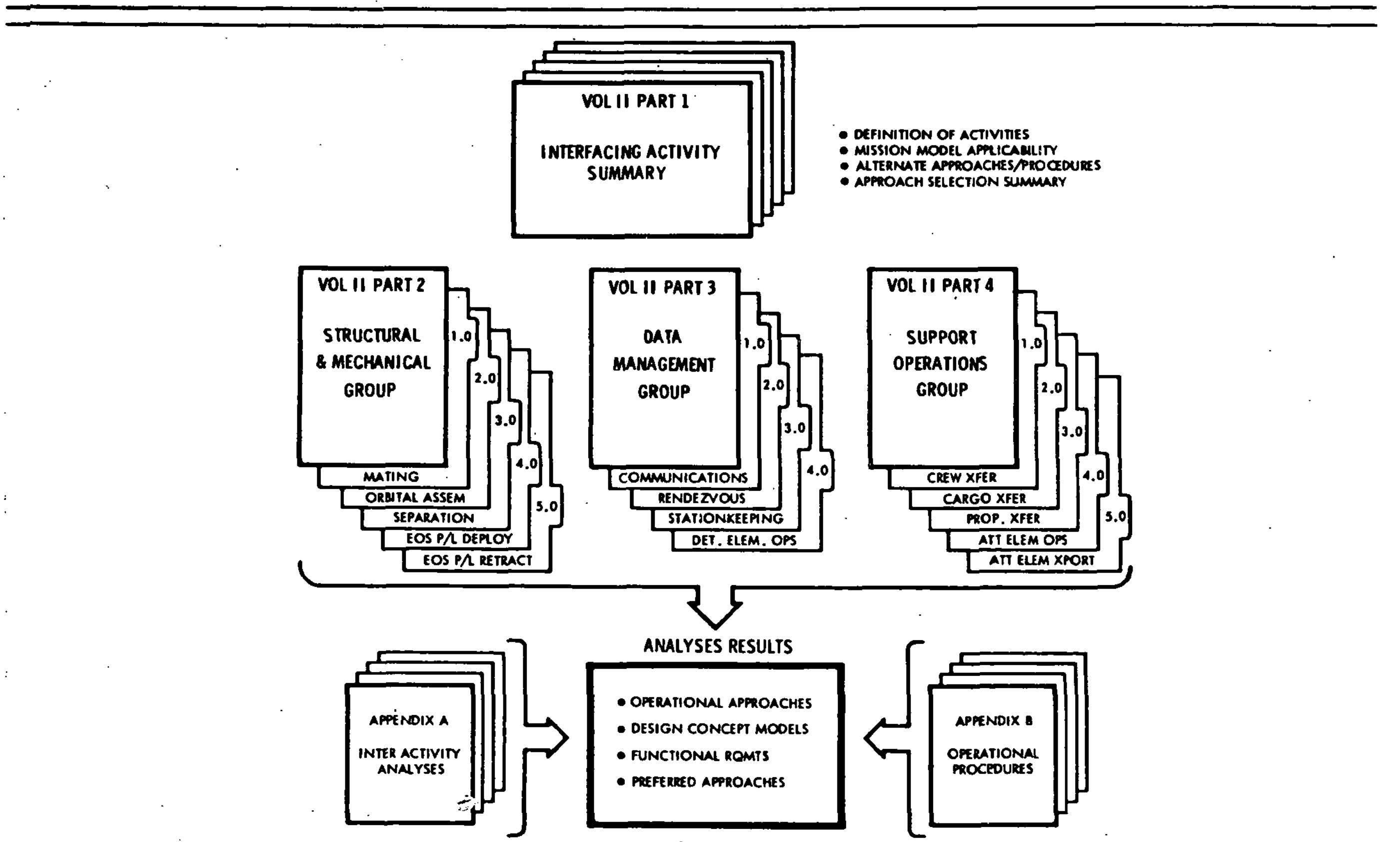
Section 3.0 PROPELLANT TRANSFER

Section 4.0 ATTACHED ELEMENT OPERATIONS

Section 5.0 ATTACHED ELEMENT TRANSPORT

The following illustration shows the relationship of this book to the other related documents.

INTERFACING ACTIVITY ANALYSES DOCUMENTATION



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TABLES

1.0 CREW TRANSFER

The crew transfer activity involves the transferring of personnel from one element into another interfacing element. This study concentrates specifically on personnel transfer between elements and the interfaces associated with this transfer, but does not pertain to personnel transfer within a singular element unless that element is of modular design.

1.1 SUMMARY

Matrix formats are utilized to identify those element interfaces and mission models where the crew transfer activity can occur. Of the 117 potential interactions, 40 are identified as applicable to crew transfer. The majority of the crew transfer interactions occur when one of the elements is a logistics vehicle.

The three alternate approaches for crew transfer are shirtsleeve, intervehicular activity (IVA), and extravehicular activity (EVA). The shirtsleeve and IVA approaches were included in the study as normal operational modes, whereas the EVA approach has been deleted from further in-depth study and is considered an emergency mode only.

Feasible design concepts are presented for both shirtsleeve and IVA approaches. For the shirtsleeve mode, the environmental control system is required to ensure a habitable atmosphere in each element and the interface volume. For theIVA approach a habitable atmosphere is not required at the interface volume nor in the mated elements. However, an airlock and a pressure suit support system are required.

The operational procedures for the shirtsleeve and IVA alternate approaches apply to all the manned-to-unmanned element crew transfer applicable interfaces which have an interfacing airlock. Shirtsleeve operations only apply to manned-to-unmanned element interfaces which do not have an airlock and to all manned-to-manned element interfaces. Their applicability to a shortened inventory of element pairs is described for manned-to-manned and manned-to-unmanned element interfaces.

The functional requirements for crew transfer include consideration for various crew configurations and operations. These include a variety of male and female crew complements, and shirtsleeve and IVA modes. Functional requirements applicability to element pairs and a discussion of quantitative criteria are also presented. Hatch, window, and IVA capabilities requirements are described as being the most significant vehicle requirements.

Analyses are included for determining a selected preferred approach for each applicable element pair. In all cases, except one type of mission, shirtsleeve crew transfer is selected as the preferred approach. This one exception is the maintenance/replenishment crew transfer operations between an EOS and the unmanned tug, CPS, RNS, OPD, satellite and non-mannable RAM. It is recommended that an airlock for IVA crew transfer be a kit installation for this type of EOS mission.

1.2 ELEMENT INTERFACE AND MISSION MODEL MATRICES

Figure 1-1 lists all the elements proposed for this study, utilizing a matrix format to identify those interfaces where the crew transfer activity can occur. The figure shows that of a potential 117 interactions, 40 involving the crew transfer activity. A summary of these interactions is presented in the following paragraphs.

INTERACTIONS SUMMARY

It should be noted that the majority of crew transfer interactions occur when one of the elements is a logistics vehicle (EOS orbiter, tug). The EOS orbiter is involved in logistics crew transfer activities with low earth orbital elements. The ground-based tug is involved in crew transfer logistics with high-energy orbital elements (geosynchronous MSS). The space base tug is involved in crew transfer activities with both low and high energy orbital elements.

The EOS could transport crew to any of the low earth orbital elements, or it could transport an EO resupply module, which contains crew, to any of the low earth orbital elements. The ground-based tug is carried to low earth orbit by an EOS orbiter, then separates and flies to an element in a high energy orbit where the crew transfer operation occurs. The space-based tug rendezvous with the EOS orbiter for transfer of crew, whereupon the space-based tug then transports the crew to one of the low earth or high-energy orbital elements. The resupply module, containing crew, can be transported from the EOS orbiter to the high-energy orbital elements by the ground-based tug or space-based tug, or it can be transported from the EOS to one of the low earth orbital elements by the space-based tug. The cases previously mentioned depict the crew being transported to an orbiting element. Each case is also applicable for crew return to earth.

Crew transfer is considered primarily to include those cases where crew move from one element to another for the conduct of element operations for a period of time (periodic exchange), for rescue from one element to another, or for special orbital assembly or checkout activities. This includes the routine crew exchanges between mated elements, e.g., RAM modules and space station modules. Infrequent crew interfaces such as crew assist to cargo movement is not accounted for. Table 1-1 lists the types of interfaces between modules.

Figure 1-2 utilizes the same matrix that identified the element-to-element crew transfer interfaces to identify those missions where crew transfer

		SPACE VEHICLE INVENTORY																								
			TUG				RAM				SATELLITE				MSS		CPS				LUNAR PROGRAM SYSTEMS					
		EOS	NON RET	RTN	GRD BASED	SPACE BASED	ATT. EOS	DET. EOS	ATT. MSS	DET. MSS	EOS DELIV	EOS + 3RD ST	RETR, RESUP	EO RESUP MODS	LOW EO	GEO SYNCH	OIS	EO SHTL	CLS	RNS	OLS	TUG UNMAN	TUG MAN	RESUP MOD	LSB	OPD
	EOS	C	X	X	C	C	C	C	X	X	X	X	X	C	C	C		C	C	C	C	X	C	X	X	C
TUG	NON RET											X														
	RETURNABLE											X														
	GRD BASED				C	C			X	X		X	X	C		C		X	X	X		X	X	X		X
	SPACE BASED					C			X	X		X	X	C	C	C	X	C	C	C	C	X	C	X	X	C
RAM	ATT. EOS																									
	DET. EOS																									
	ATT. MSS														C	C		X		X						
	DET. MSS														C	C		X		X						
SATEL	EOS DELIV																									
	EOS + 3RD ST																									
	RETR, RESUP																									
	EO RESUP MODS													X	C	C		X	X	X		X	C	X		X
MSS	LOW EO														C											
	GEOSYNCH															C		X		X						
CPS	OIS																	X	X	X	X					X
	EO SHTL																	X								X
	CLS																		X		X	X	X	X	X	X
	RNS																			X	X	X	X	X	X	X
LPS	OLS																				C	X	C	C		
	TUG UNMAN																							X	X	X
	TUG MAN																							X	X	X
	RESUP MOD																							X	X	X
	LSB																								X	
	OPD																									X

LEGEND

Potential Interactions	117
Actual Interactions	40
C - Crew Transfer	40
X - Not Applicable	77

Figure 1-1. Crew Transfer Interactions

Table 1-1. Element Interfaces for Crew Transfer

TRANSFER FROM		TO: EOS	TUG: GND	TUG: SPACE	RAM: A-EOS	RAM: D-EOS	RAM: A-MSS	RAM: D-MSS	EO SUP MOD	MSS: LO	MSS: GEO	CPS: EOS	CPS: CLS	RNS	CPS: UN TUG	CPS: MN TUG	CPS: OLS	CPS: SUP MOD	OPD
EOS	Periodic		X	X	X	X			X	X		X	X	X					
	Rescue	X	X	X						X		X	X	X		X			
	Assy, C/O, Boost									X	X	X	X	X		X	X		X
GND B. TUG	Periodic										X								
	Rescue	X	X	X							X								
	Cargo								X										
SP B. TUG	Periodic									X	X	X	X	X					
	Rescue	X		X						X	X	X	X	X					
	Assy, C/O, Boost									X	X	X	X	X		X	X		X
	Cargo								X										
LPS MAN TUG	Assy, C/O, Boost																X		
	Rescue																X		
	Cargo								X										
LO MSS	Periodic						X	X		X									
	Rescue	X	X	X															
	Cargo								X										
GEO MSS	Periodic						X	X			X								
	Rescue	X	X	X															
	Cargo								X										
OLS	Periodic															X	X		
	Rescue															X			
	Cargo																	X	

activities can occur. The mission identification numbers refer directly to the 11 reference missions identified for this study in Volume 1, Section 2.0.

MISSION DEFINITIONS

Mission 1 is an EOS emplacement mission, in which an EOS places an element or part of an element into a specific orbital position. The crew transfer operation occurs while the element is still attached to the EOS. The purpose of the transfer operation is to check out the element prior to release.

Mission 2 is the EOS logistics mission. EOS logistics include crew and cargo transfer operations with all manned elements in low earth orbit and cargo transfer with all unmanned elements in low earth orbit. It is anticipated that in most cargo transfer activities, crew transfer will accompany the operation. The EOS orbiter also can resupply and service satellites. Crew transfer with satellites may require EVA techniques.

Mission 3 is an EOS orbiter sortie mission, where the EOS orbiter transports a RAM to low earth orbit and remains attached to it while experiments are conducted. The crew can be continually transferring between the two elements.

Mission 4 utilizes the space-based tug to retrieve free-flying elements and return them to another element for subsequent servicing. The retrieval operation does not involve crew transfer; however, the servicing operation that follows can involve the crew transfer activity. This mission is specifically applicable to retrieval and servicing of free-flying RAMs.

Mission 5 is the space-based tug logistics mission. It is similar to the EOS orbiter logistics missions, except that this mission includes the geosynchronous MSS in the array of interfaces.

Mission 6 describes the disposal of large elements (CPS, RNS, and OPD). A space-based tug is utilized to insert the element into a flight profile that ultimately has the element splash down in an earth ocean. The crew transfer activity occurs if the element has any valuable hardware onboard that can be retrieved by the space-based tug crew.

Mission 7 is applicable to crew transfer for the initial module of the geosynchronous MSS. Prior to separation from the space-based tug, the module could be entered and checked out.

Mission 8 is the ground-based tug logistics mission. It is typical to the space-based tug logistics mission, except that it begins all operations from earth and performs crew and cargo transfer activities with the geosynchronous station and its associated RAMs. This vehicle also can service high energy orbit satellites which can require crew transfer if EVA is required to perform the servicing task.

Missions 10 and 11 are geosynchronous, cislunar, shuttle logistics missions.

		SPACE VEHICLE INVENTORY																								
		EOS	TUG				RAM				SATELLITE			EO RESUP MODS	MSS		CPS			RNS	LUNAR PROGRAM SYSTEMS					OPD
			NON RET	RTN	GRD BASED	SPACE BASED	ATT. EOS	DET. EOS	ATT. MSS	DET. MSS	EOS DELIV	EOS + 3RD ST	RETR, RESUP		LOW EO	GEO SYNCH	OIS	EO SHTL	CLS		OLS	TUG UNMAN	TUG MAN	RESUP MOD	LSB	
	EOS	2			2	2,10 11	3	1,2		2				2	1,2	1,2		2	1,2, 10,11	2,10 11	1,2		1,2			1,2
TUG	NON RET																									
	RETURNABLE																									
	GRD BASED				8	8								8		7,8										
	SPACE BASED					5,10, 11								5,10, 11	5	5,10, 11		5,6, 10,11	5,6, 10,11	5,6, 10,11	5		5			5
RAM	ATT. EOS																									
	DET. EOS																									
	ATT. MSS														2,5,8	2,5,8										
	DET. MSS														2,4,5,8	2,4,5,8										
SATEL	EOS DELIV																									
	EOS + 3RD ST																									
	RETR, RESUP																									
	EO. RESUP MODS														2,5,8	2,5,8							2,5,8			
MSS	LOW EO														2,5,8											
	GEOSYNCH															2,5,8										
CPS	OIS																									
	EO SHTL																									
	CLS																									
	RNS																									
LPS	OLS																				2,5,6		2,5,8	2,5,8		
	TUG UNMAN																									
	TUG MAN																									
	RESUP MOD																									
	LSB																									
	OPD																									

Figure 1-2. Applicable Mission Models for Crew Transfer

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1.3 ALTERNATE APPROACHES

Crew transfer normally occurs between mated elements. For transfer between mated elements, two approaches were considered: shirtsleeve and IVA. The shirtsleeve/IVA alternate approaches are illustrated below.

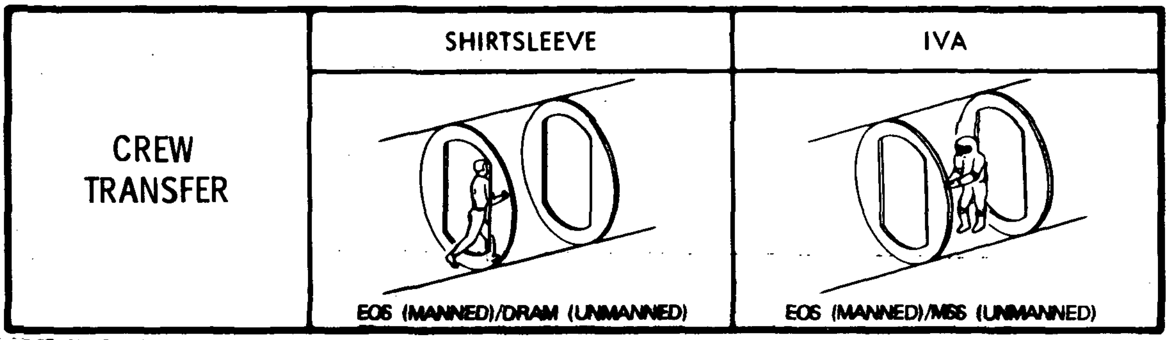


Figure 1-3. Crew Transfer Approaches

The method of crew transfer between attached orbital elements will vary depending upon the orbital vehicle configurations. Transfer may occur between manned elements or from a manned to an unmanned element, and in pressurized or unpressurized conditions. Normally, unpressurized crew transfer will occur between a manned element and a non-mannable element. Exceptions include emergency conditions when crew transfer must be accomplished subsequent to element pressurization failure. Therefore, capability for transferring crew members between unpressurized elements must be provided in the design of any crew transfer method. State-of-the-art docking interface design scheduled for use on Skylab missions utilize an airlock between mating vehicles. The airlock contains mechanisms to achieve hard docking and is pressurizable from either side of the interface.

The selection of one of the two methods to accomplish crew transfer between attached elements is directly related to the configuration of the elements. Shirtsleeve transfer occurs between pressurized vehicles, wherein crew members may maneuver without encumberances of space suits and pressurizing umbilicals. Crew transfer between attached elements where one is unpressurized will require crewmen to wear space suits.

Internal crew transfer in null gravity can be based on one or both of two concepts: (1) provide a substitute for traction to permit "walking" or (2) accept push-off or pull-along translation. Experimentation using magnetic devices or velcro to restrain the foot for walking have shown that these techniques are unsatisfactory. Push-pull techniques have been utilized in Gemini EVA and Apollo shirtsleeve and EVA activities.

1.4 DESIGN CONCEPT MODELS

Design aspects of interfacing elements resulting from procedural assumptions, operations, or requirements have considerable impact on crew transfer activity. An array of possible design combinations are involved in defining an optimum operational procedure and approach. For example, IVA cannot be performed without an airlock as a compartment between interfacing elements. However, if only 3.7 psig pressure suits were available for IVA, the two to four hours time required for pre-breathing may not be affordable, thus making the shirtsleeve operation more attractive. Obviously, other influences such as crew makeup, pressurization capabilities, and hazards must also be considered. Many of the items required for the shirtsleeve design concept model, are also necessary for IVA crew transfer.

SHIRTSLEEVE DESIGN CONCEPT

For crew members to transfer from one element to another in the shirtsleeve mode requires (1) a safe atmosphere in each element which must be verifiable and controllable from either (manned) element prior to initiating ingress, (2) clear passageway, and (3) crew assists (lighting, mobility, viewing). A concept for this approach is shown in Figure 1-4.

IVA DESIGN CONCEPT

IVA may occur between a pressurized and a non-pressurizable element or between two unpressurized elements at least one of which is unpressurizable. The shirtsleeve design requirements, (2) and (3) above, apply for IVA with consideration being given to hatch clearance, hand holds, etc., for suited crewmen. In addition, either an airlock must be provided between elements to accommodate any differential pressure, or the pressurized element must be capable of safe depressurization. An airlock is the preferred accommodation. A design concept is show in Figure 1-5.

As mentioned previously, suit design has a major impact on the crew transfer activity. Between the 3.7 and 8.0 psig suits, the 3.7 suit is seen as the worst case and is therefore selected for use in the operational procedures. While the 8.0 psig suit is still under study, initial analyses indicate that it will be optimum for IVA and EVA operations. Although the initial development cost of the 8.0 suit is a major factor, the saving in on-orbit time and versatility will lead to more applications of IVA operations and thus decrease structure penalities and consumables usage. Comparison timelines for the two suits are presented in Figure 1-6 (reference Appendix C, DS-569). If the pressure garment is to be considered for use as a backup escape volume, then a higher pressure ($\geq$8.0 psi) is considered essential. A 3.7 psi suit (pure O_2) will not protect the crewman from the effects of decompression if cabin atmosphere decreases from 14.7 psi to zero in less than a nominal 2 to 2-1/2 hours.

The concept model for the IVA approach included an airlock capable of supporting two crewmen in a pressurized suited mode as an interface between the elements. Portable/temporary airlocks are viable design concepts. The optimum sizing of the airlock is an issue which is in need of further study.

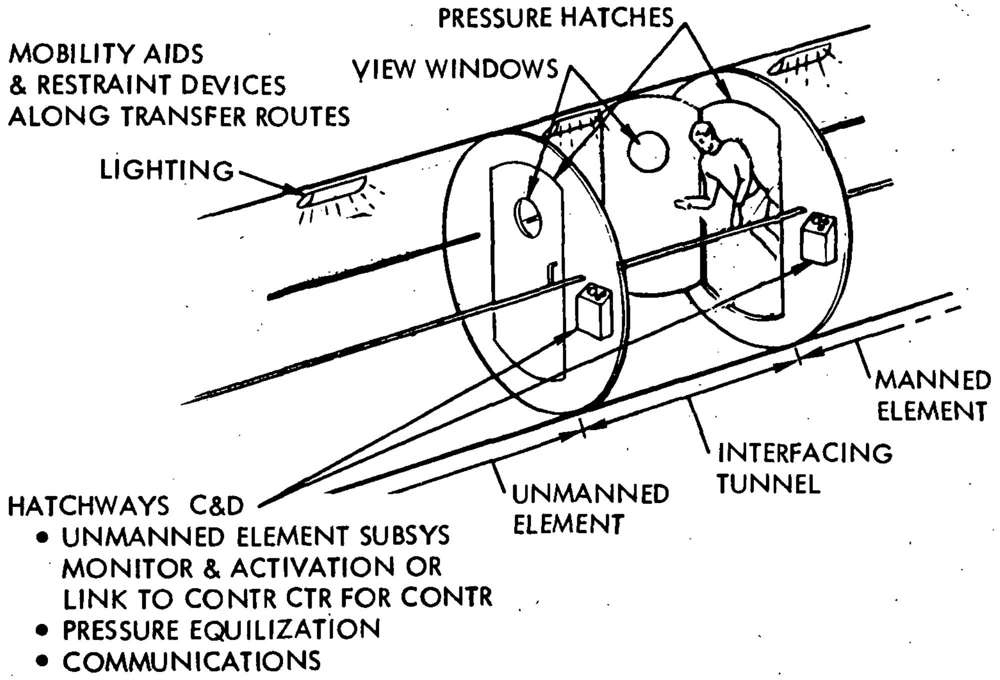


Figure 1-4 Shirtsleeve Concept Model

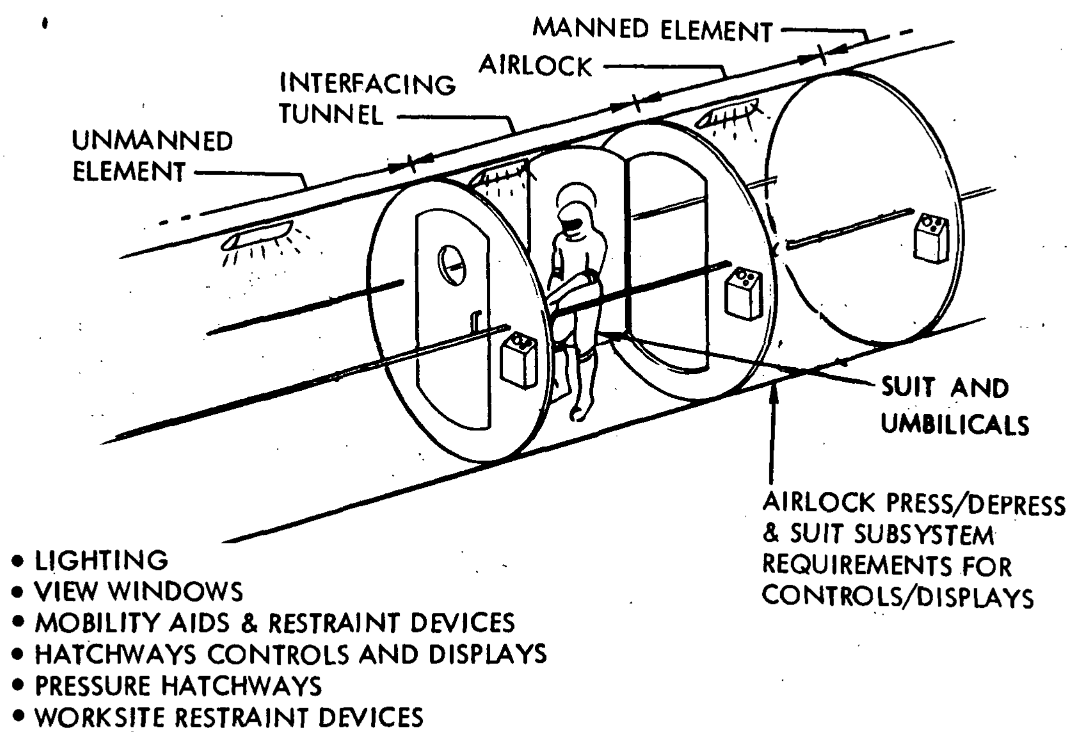


Figure 1-5 IVA Concept Model

A minimum size can be arrived at by the anthropometric measurements of two suited crewmen (discussed in the functional requirements section), but if any cargo items are involved the size must be increased accordingly. This issue is discussed in more detail in the Cargo Transfer Activity.

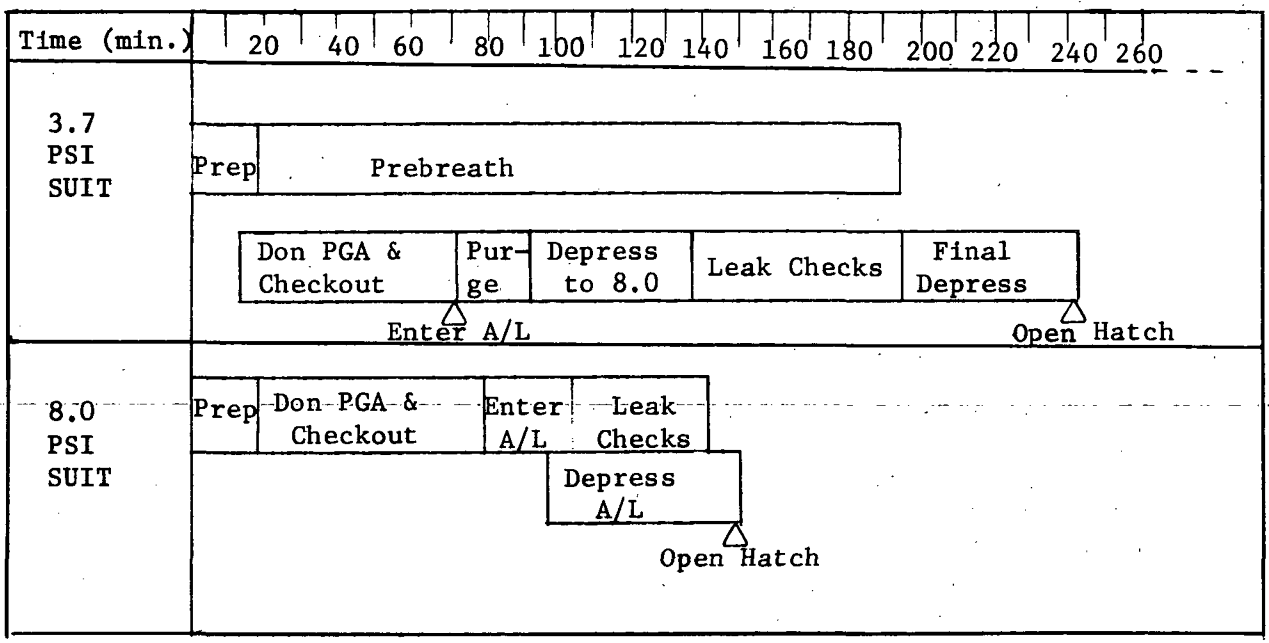


Figure 1-6. Typical IVA Timelines

The pacing activity for the 3.7 psi pure oxygen suit, is the length of time a crewman must be on O_2 to purge himself of nitrogen. While breathing from an O_2 supply, other activities can be conducted in preparation for airlock depressurization. For the 8.0 psi case time to airlock depressurization is only dependent on the mechanics of preparation and checkout. There is no human factor limitation. Certain of these steps could be expedited or omitted in an emergency.

1.5 OPERATIONAL PROCEDURES

Crew transfer operational procedures are included for shirtsleeve and IVA alternate approaches (refer to Appendix B, Section 5). The shirtsleeve procedure considers the transfer operation between an EOS orbiter (manned) and an unmanned detached RAM. This element pair requires pressurization of the unmanned element to establish a habitable environment. This operation would be in addition to that required for two manned elements, which would involve activation, checkout, pressurization of the interfaces, and crew movement.

The procedure for the IVA alternate approach involves crew transfer in suited mode between an EOS orbiter (manned) and an unmanned modular space station (MSS). In lieu of the pressurization operations required for shirtsleeve crew transfer, operations for airlock depressurization/pressurization and suit operations are required for the IVA mode. The procedural deltas between the shirtsleeve and IVA procedures are presented in Figure 1-7.

Figure 2.5-2 (Appendix B) presents the crew transfer procedure applicability for each of the element-to-element interfaces. The matrix indicates where shirtsleeve and IVA operational procedures apply for manned-to-unmanned and manned-to-manned interfaces. In general all manned-to-unmanned element crew transfer applicable interfaces with an airlock will accommodate both shirtsleeve and IVA transfer operations, any interfaces without an airlock would only accommodate the shirtsleeve mode. All manned-to-manned crew transfer applicable interfaces will have the shirtsleeve crew transfer operational procedure apply for normal transfer, with IVA as a backup or for rescue due to loss of pressure. The results are summarized in Table 1-2.

Table 1-2. Procedures Applicability

	Manned-to-Unmanned	Manned-to-Manned
Potential interactions	49	49
Shirtsleeve (procedure 5-1)	22	18
IVA (procedure 5-2)	21	14
Not applicable	27	31

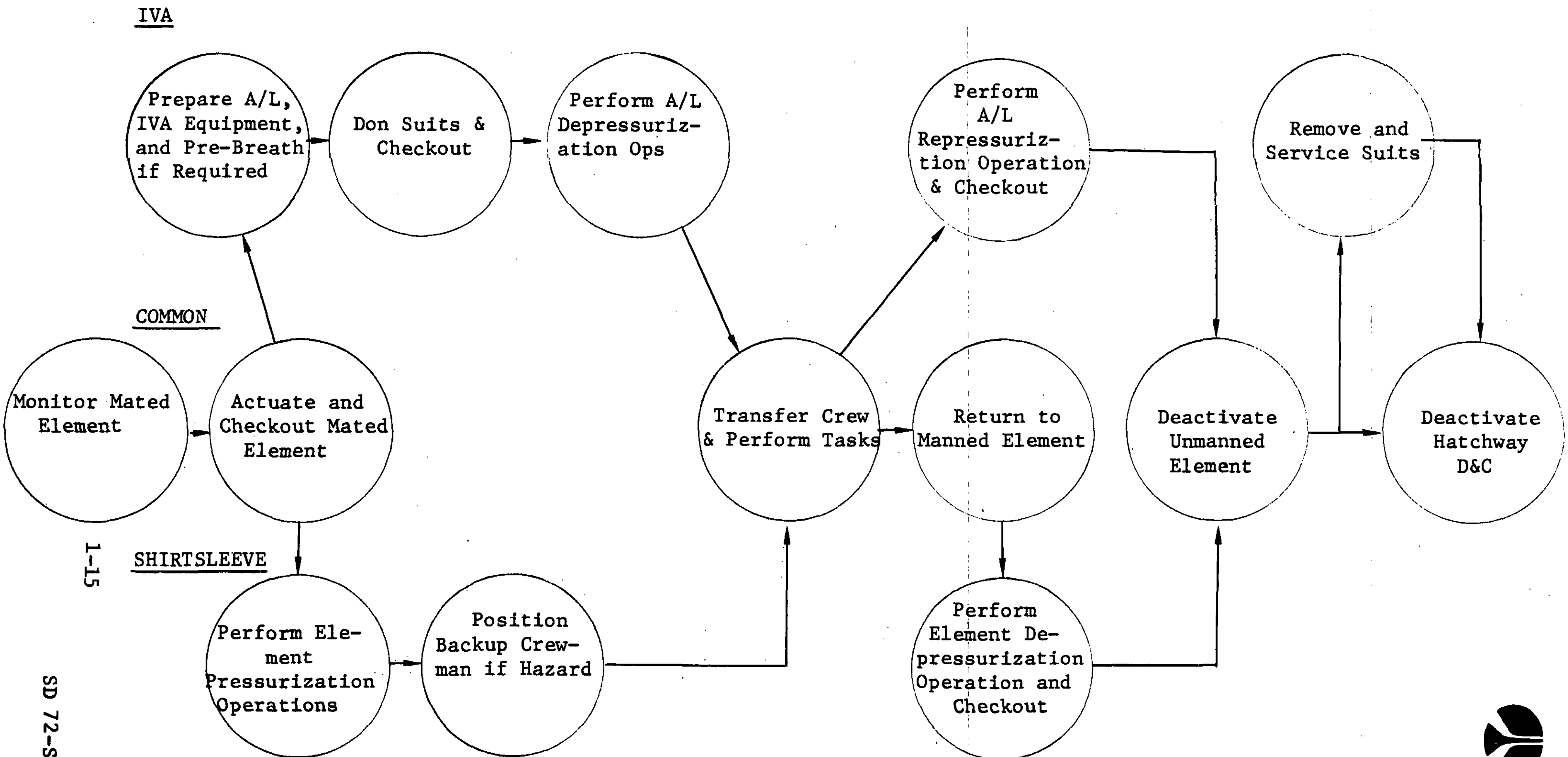


Figure 1-7. Crew Transfer Procedural Comparison (Manned Element to Unmanned Element)

1.6 FUNCTIONAL REQUIREMENTS

Development of functional requirements for interface design to accomplish crew transfer operations must consider all possible combinations of crew configurations. For internal transfer, capability for IVA crewman transfer must be included in the design, which may normally accommodate shirtsleeve crewman. An exception to this design will be the interface requirements associated with internal transfer to an unpressurizable element. In this case the normal shirtsleeve crew transfer requirements are not applicable.

A significant criteria for the development of all crew transfer activities is the shape and flexibility of the crew members. The most stringent criteria is that of a crew member in a pressurized suit. The pressure suit could be utilized for crew transfer operations under emergency conditions or when the transfer involves operations into elements not normally inhabited. Therefore, all element-to-element crew transfer concepts must consider the pressure-suited crew member characteristics.

		Related Procedure	
		Shirtsleeve	IVA
		5-1	5-2
1.	All IVA and hazardous shirtsleeve operations shall be conducted with a minimum of two crew members (buddy system). (Reference Appendix C, DS-208.) Each crew member provides backup and rescue capability to the other.	x	x
2.	The 'buddy' crew members during IVA and hazardous shirtsleeve operations shall be positioned to observe the other crew member and, in the case of IVA/EVA activities will be required to control the other crew member's tether or umbilical to prevent entanglement. A third crew member shall be available for voice communication and C&W monitoring.	x	x
3.	Crew mobility aids shall be provided along crew transfer routes in order to facilitate crew translation and stabilization in zero-g environment.	x	x
4.	Crew mobility aids shall be capable of use by a 5 to 95 percentile crew member in either a shirtsleeve or pressure suited mode of operation. The cross section shape of the aid will be dependent upon whether the crew member is required to apply torque forces while	x	x

Related Procedure	
Shirtsleeve	IVA
5-1	5-2

grasping the hand hold/hand rail. A circular cross section is applicable for non-torque applying forces while an elliptical cross section is required for application of torque forces. One source (reference Appendix C, DS-208) identifies requirements for hand holds and hand rails of 1.0 inch minimum diameter with a 2.0 inch clearance to adjoining structure or surface. Cross run mobility aids (reference Appendix C, DS-509) shall be sized as follows.

Side rail spacing - 18 to 21 inches
Rung spacing - 11 to 12 inches
Rung diameter - - 1.0 to 1.5 inches

Criteria utilized in design of Apollo EVA hand holds/ hand rails are defined in Table 1-3.

Considerations for crew mobility using push-pull techniques are shown in Table 1-4.

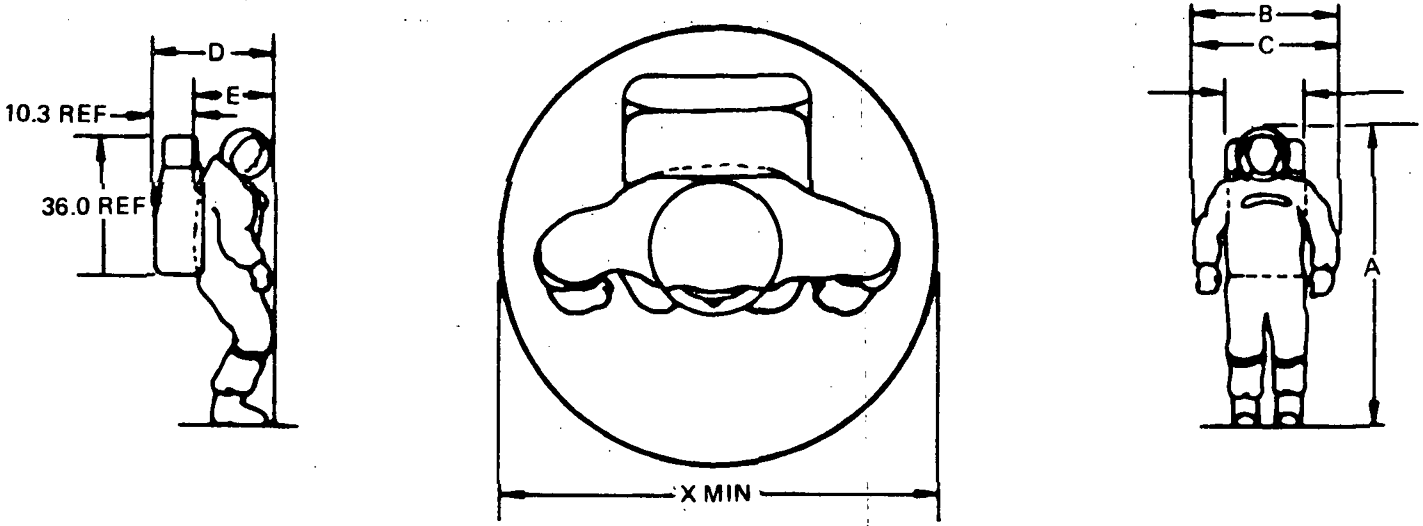
Table 1-3. Translation Aid Criteria
(Reference Apollo EVA Operations)

Task	Nominal Spacing (Inches)	Dimensions (Inches)		
		X-Section	Grasping Length	Clearance
Translation (no torque)	22 lateral translation 18 hand-over-hand	1 dia	3.5 min	2.25 min
Translation (torque)	22 lateral translation 18 hand-over-hand	1 x 1.5 with .5 radius	3.5 min	2.25 min

Table 1-4. Criteria for Crew Translational Mobility

Method	Preferred Area for Use	Hazards or Difficulties	Requirements
Push-off	1. Linear passage 2. Linear tunnels 3. Large rooms	1. Protrusions 2. Sharp corners or edges	1. Flat, load carrying surfaces 2. Recessed or covered fittings 3. Rails or handholds to grasp at terminal point of translation
Hand-over-hand pull	1. Curved passage 2. Cluttered areas	1. Torquing 2. Rail attach fittings	1. Smooth (but not slick) free-standing rails 2. May be located: a. Preferred - normal to direction of travel (as rungs of a ladder) b. Good - along centerline of crewman's route of travel c. Worst - (for torquing) where rail is to one side of crewmen for normal use 3. Rigid tubing preferred

	Related Procedure	
	Shirtsleeve	IVA
	5-1	5-2
5. Surface materials available to touch shall be selected to ensure that high and low temperatures and conductivity are not limiting factors in crew transfer. Reference Appendix C, DS-527 defines physiological limitations based upon Apollo design criteria.	x	x
6. All crew aids shall be capable of use by a 5 to 95 percentile crew member in either a shirtsleeve or IVA/EVA pressurized suited mode of operation. Figures 1-8 and 1-9 define anthropometric data while a crewman is wearing an A7L spacesuit pressurized to 3.8 psig.	x	x
7. Crew aids shall be easily operable, not restrictive of required crew motions, and possess a high degree of crew acceptability.	x	x
8. Crew restraint devices shall be designed to optimize forces which may be applied by a crewman with or without a pressurized space suit. Force data have been measured in numerous experiments, with varying types of restraints, under simulated reduced gravity conditions. Results achieved in one study (reference Appendix C, DS-529) show that over all less than 50 percent of one-g force values can be achieved through a range of restraints. Typical results for the various types of restraints are shown in Table 1-5.	x	x
9. Equipment installations within crew mobility areas shall be capable for use for push-off. A requirement (reference Appendix C, DS-208) that equipment installations be capable of withstanding multi-directional application of crewman push-off and/or impact loads of 300 pounds has been identified.	x	x
10. Equipment susceptible to damage or that is hazardous to crew transfer operations shall be separated from crew mobility areas and color-coded or placarded.	x	x
11. Adequate lighting shall be provided along all personnel crew transfer routes. General illumination criteria for shirtsleeve operations is presented in Table 1-6.	x	x



DIMENSION	PERCENTILE (INCHES) 5	95
A - HEIGHT	68.7	76.8
B - MAX BREADTH AT ELBOWS (ARMS RELAXED)	*	29.4
C - MAX BREADTH AT ELBOWS (ARMS AT SIDE)	*	26.4
D - MAX DEPTH WITH PORTABLE LIFE SUPPORT SYSTEM (PLSS) & BACKUP OXYGEN (OPS)	26.0	28.4
E - MAX DEPTH WITHOUT PLSS/OPS	15.5	17.9
WEIGHT (POUNDS), WITH PLSS/OPS	331.7	404.6
WEIGHT (POUNDS), WITHOUT PLSS/OPS	206.2	278.9

* INDICATES DATA NOT AVAILABLE
FOR DIMENSIONS D & E 2 INCHES HAVE BEEN ADDED TO MAXIMUM CHEST OF SUITED/PRESSURIZED CREWMAN FOR PLSS CONTROL BOX TO OBTAIN ENVELOPE DIMENSIONS
MEASUREMENTS MADE ON A7L PGA, PRESSURIZED TO 3.75 PSIG

Figure 1-8. Envelope Dimensions for a Suited (Pressurized) Male Crew Member

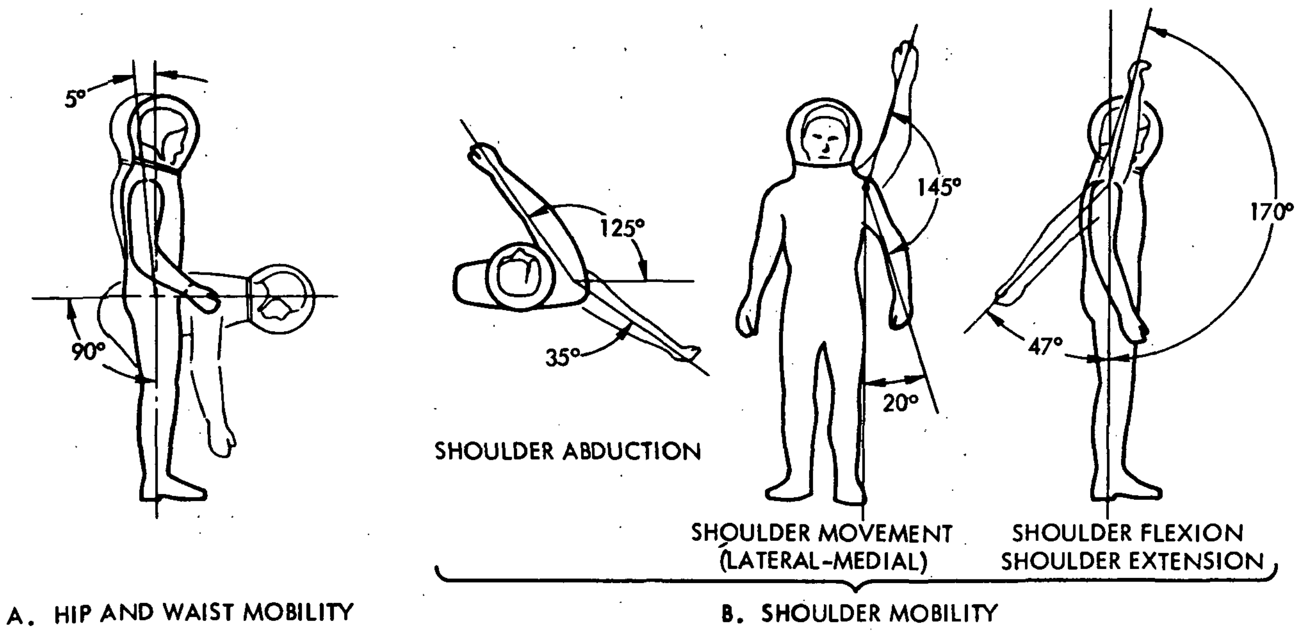


Figure 1-9. A7L Space Suit Mobility Ranges

Table 1-5. Restraint Technique Characteristics

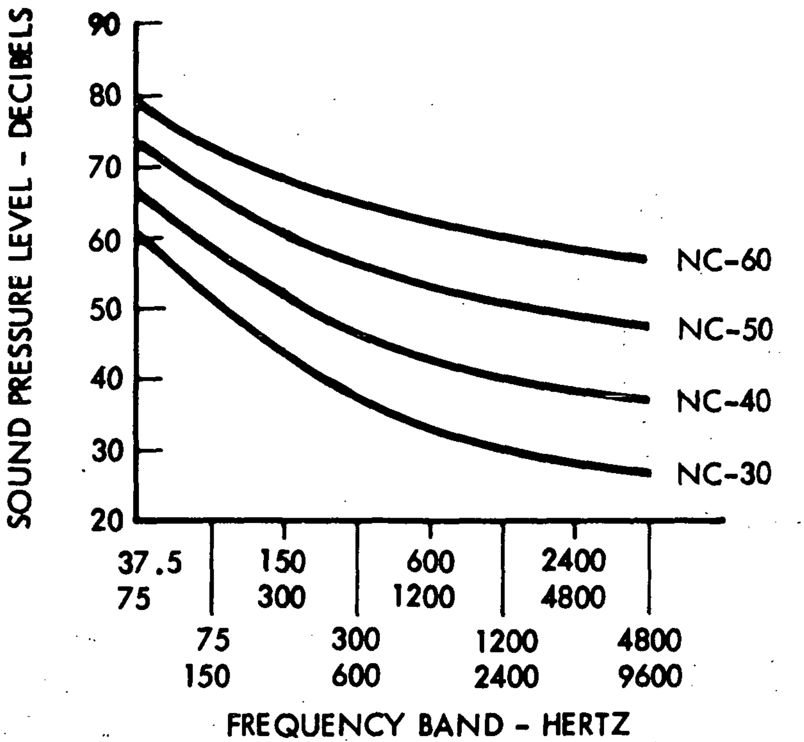
Restraint	Push	Pull	Up	Down	Right	Left
Sustained Force (Means) (pounds)						
None	0	0	0	2	0	0
Handhold	1	2	5	0	10	17
Waist	15	22	10	10	12	12
Shoes	4	4	17	21	9	8
Hand and waist	29	31	14	16	15	17
Hand and shoes	30	35	(18)	(26)	(16)	(21)
Waist and shoes	35	37	17	19	14	15
Hand, waist and shoes	(43)	(38)	17	21	(16)	19
Momentary Force (Means) (Pounds)						
None	35	43	19	23	18	18
Handhold	41	43	21	26	22	29
Waist	43	46	23	23	22	22
Shoes	46	48	28	33	22	23
Hand and waist	57	51	23	26	25	28
Hand and shoes	62	(61)	(31)	(37)	(28)	(34)
Waist and shoes	58	57	28	30	23	25
Hand, waist and shoes	(69)	(61)	29	32	27	30

Note: Circled items indicate the highest force values.

Table 1-6. General Illumination Levels
(Ref. Appendix C, DS-528)

Tasks	Description	Illumination (ft-c)		
		Maximum	Desirable Range	Minimum
General	General lighting reqmts. for proper identification of items and general maintenance	10	5-10	1
Functional	Emphasis placed on efficiency and functional aspects used for investigations	70	50-70	20

	Related Procedure: Shirtsleeve 5-1	Related Procedure: IVA 5-2
12. All hatches utilized for crew transfer between elements shall be capable of operation from either side of the hatch, including a capability for pressure equalization across the hatch (reference Appendix C, DS-234). This permits one crew member operation of opening a hatch. Also included is the capability for pressure monitoring and leak rate checks.	x	x
13. A window shall be provided in each pressure hatch that is capable of being closed for either normal or emergency operations (reference Appendix C. DS-234). This permits crew observation of IVA operations and viewing prior to ingress whenever hatches are closed.	x	x
14. Acceptable noise levels shall be maintained during crew transfer operations to prevent discomfort to crew members and interference with verbal communications (reference Appendix C, DS-208). Figure 1-10 presents acoustic noise levels (reference Appendix C, DS-208).	x	x
15. IVA crewmen shall be provided with two means of ingress from an unpressurized volume to a pressurized volume. Where one dedicated airlock is provided, the second means of ingress may consist of the capability to depressurize cabin atmosphere. The capability is required at the interface of two attached elements. Airlock capabilities include controls, displays, caution and warning, hatch controls, pressurization/depressurization controls (including rapid repressurization) communication and lighting.		x
The need for two capabilities is based upon safety considerations to preclude trapping crewmen in an unpressurized volume with no means of return.		
Storage for suits, PLSS's, tethers, tool kits, and maneuvering units is required in or near the airlock. Drying provisions for the pressure suits are required and may be provided in the airlock as part of the airlock ECS.		
Airlocks shall at a minimum, be sized to allow adequate maneuvering room for at least two EVA configured crewmen (suits and backpacks). Volumetric criteria from NASA MSC document is shown in Figure 1-11.		



NC CURVE	APPLICATION
NC-30	SLEEP/REST AREAS
NC-40	CONTROL AREAS WHERE COMMUNICATIONS ARE CRITICAL: AREAS WHERE SOME CONCENTRATION AND RELAXED COMMUNICATION MAY BE DESIRABLE (RADIO AND TELEVISION LISTENING)
NC-50	AREAS WHERE GOOD COMMUNICATION CONDITIONS ARE NOT ESSENTIAL (SOME DISTRACTION TO EXTERNAL NOISE CAN BE PERMITTED); INTERNAL NOISE GENERATION DUE TO OTHER ACTIVITIES MAY BE PRESENT; GENERAL WORK/LIVING AREAS
NC-60	MAINTENANCE AREAS

Figure 1-10. Acoustic Noise Levels

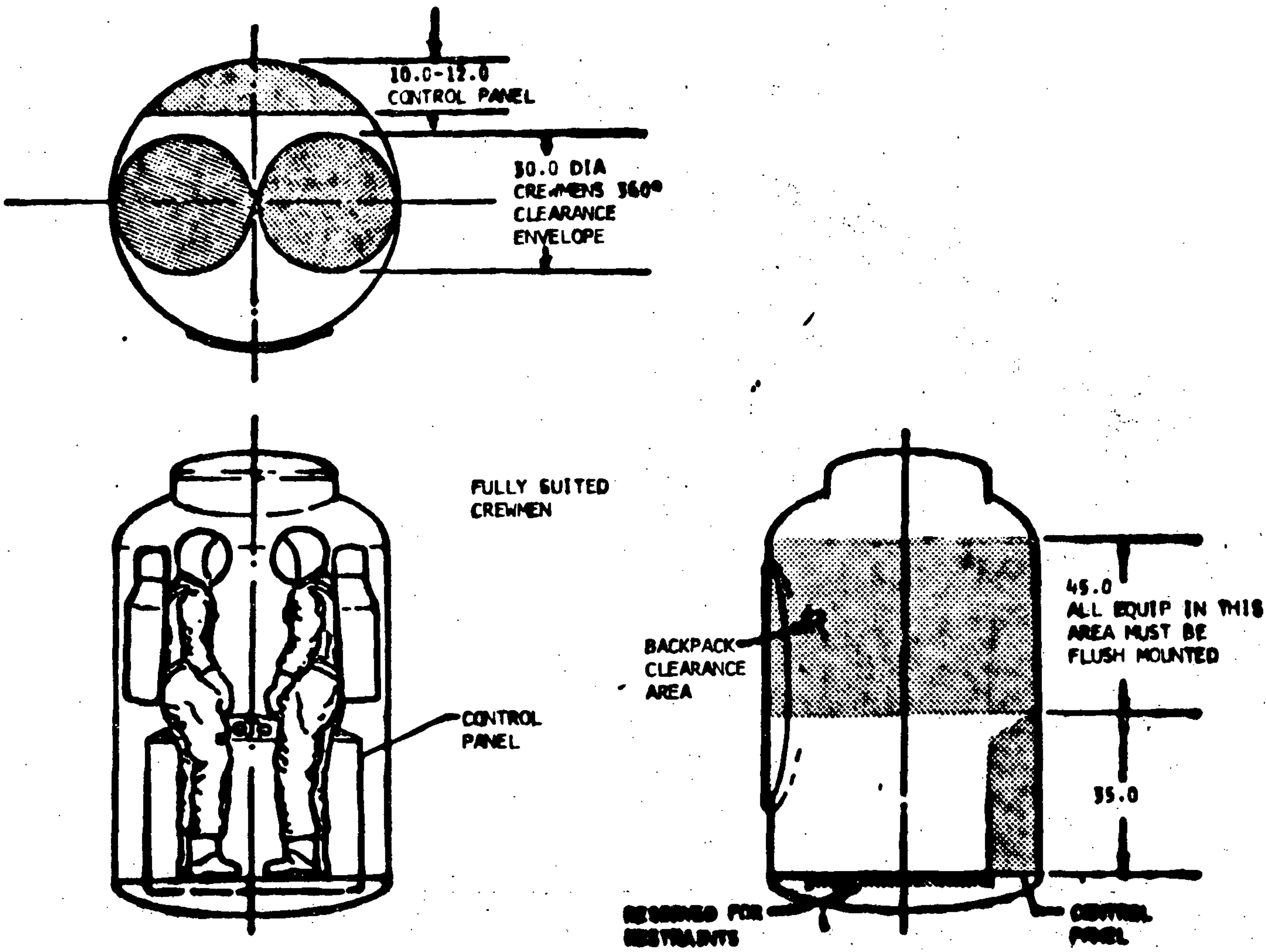


Figure 1-11. Airlock Volumetric Allotment Crew - Equipment

Item	Related Procedure: Shirtsleeve 5-1	Related Procedure: IVA 5-2
16. Communication capability shall be provided for transfer crew members. Two way hardline and RF voice communications must be maintained to IVA crewmen.	x	x
17. Space suit integrity shall be verified prior to element/airlock depressurization and immediately following depressurization. No IVA operations can occur without proper suit functioning.		x
18. Passageways/aisles shall be capable of accommodating crew transfer operational requirements. Figures 1-12, 1-13, and 1-14 present primary passageway criteria. It should be noted that artificial g and ground operations requirements are beyond the scope of this study and will not be considered for functional requirements or preferred approaches. Other data (reference Appendix C, DS-239) indicates a requirement for a nominal aisle/passageway width of 32 inches for crewmen only. The same reference also requires tunnels less than 7 feet in length to be a minimum of 42 inches diameter and tunnels greater than 7 feet in length to be a minimum of 48 inches diameter. A consensus of these data is summarized in Table 1-7.	x	x

Table 1-7. Passageway/Hatch Sizing for Crew Transfer Only

	Minimum (inches)	Nominal (inches)	Preferred (inches)
HATCH SIZE			
One Man	30 d	39.4 d	42 d
Two Man	30 x 60 d	36 x 66	
PASSAGEWAY (see tunnel)			
One Man	42 d	42 d	48 d
Two Man	32 x 64	42 x 66	64 x 82
TUNNEL (one man)			
Less than 7 feet	42 d	-	-
More than 7 feet	48 d	-	-
AIRLOCK (two man)	80 x 60 d	82 x 72 d	82 x 96 d

(All dimensions are for clear area for zero-g mobility)
NOTE: Although shirtsleeve and IVA are selected approach, all data are compatible with current EVA suited requirements.

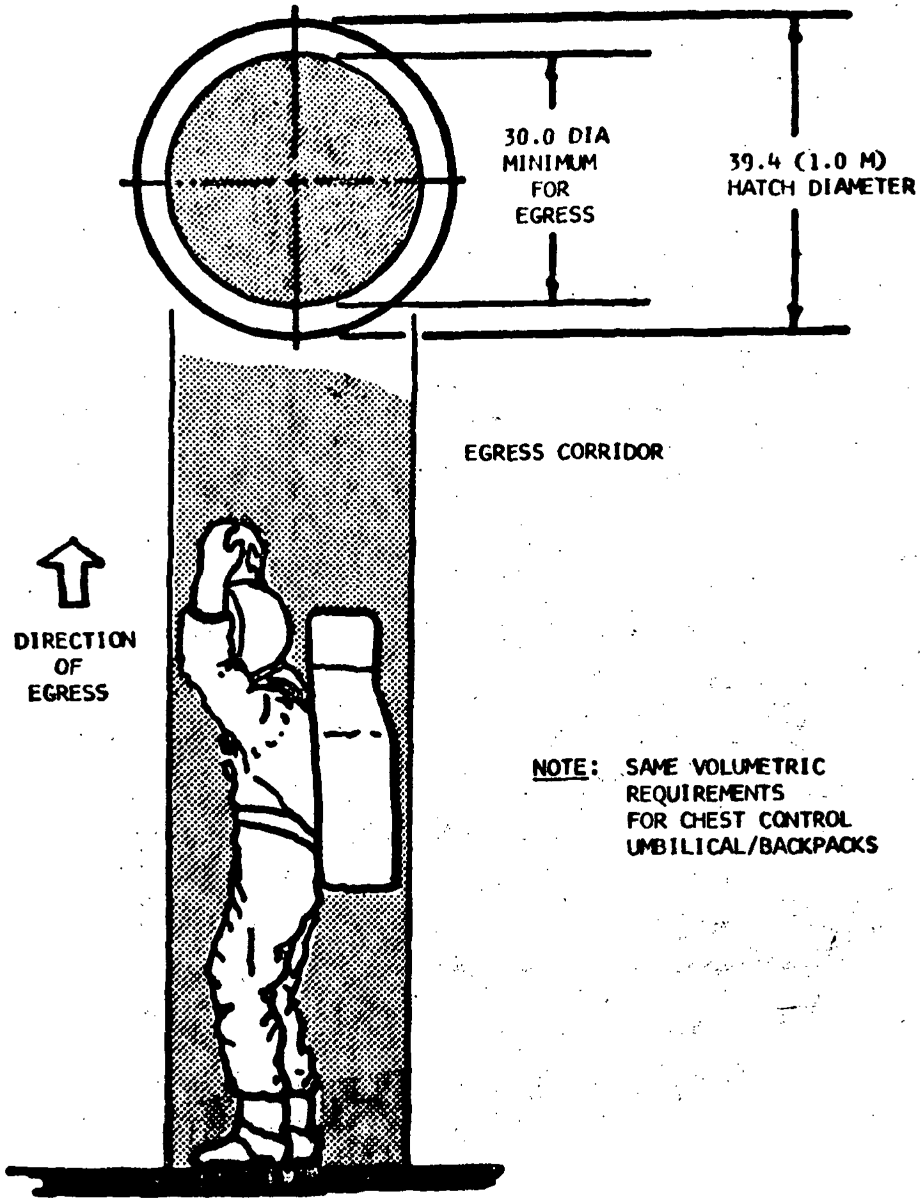


Figure 1-12. Egress Envelope

Egress Motion Parallel to Crewman's Longitudinal Axis

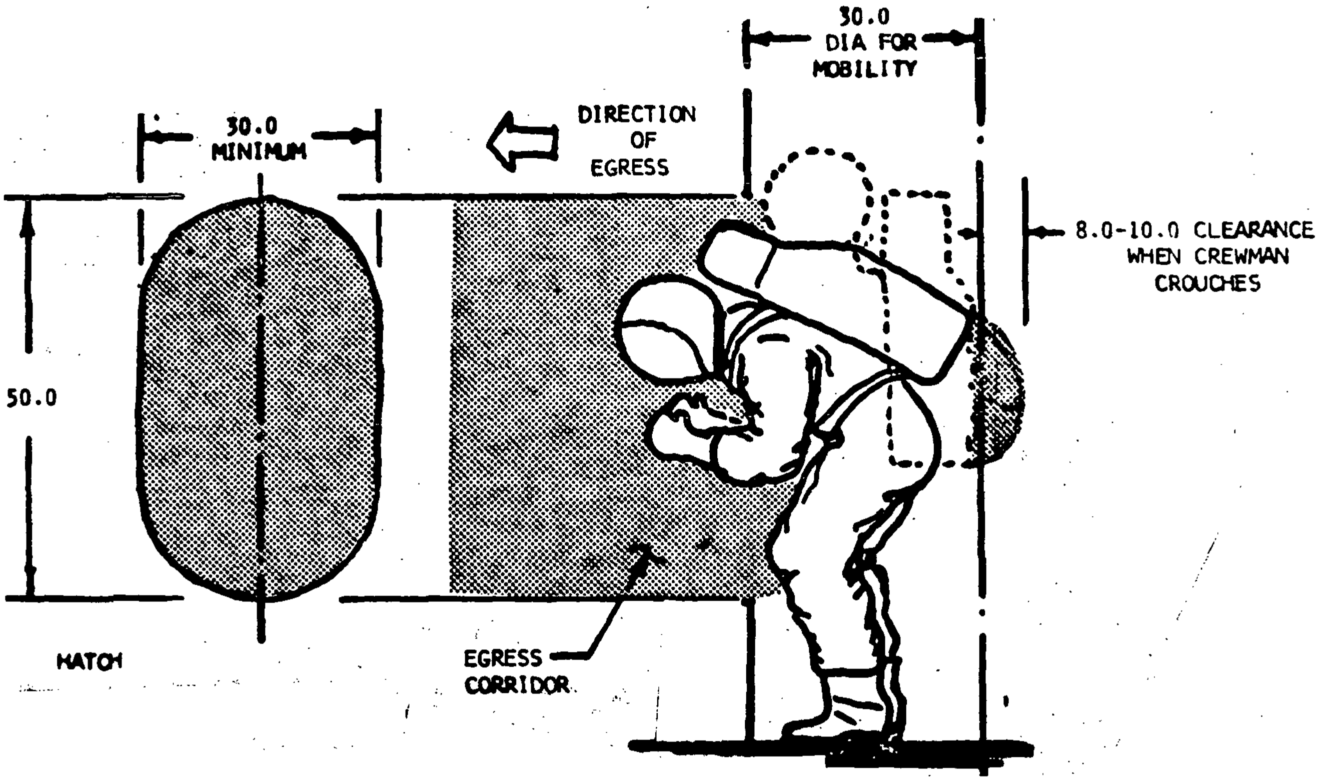
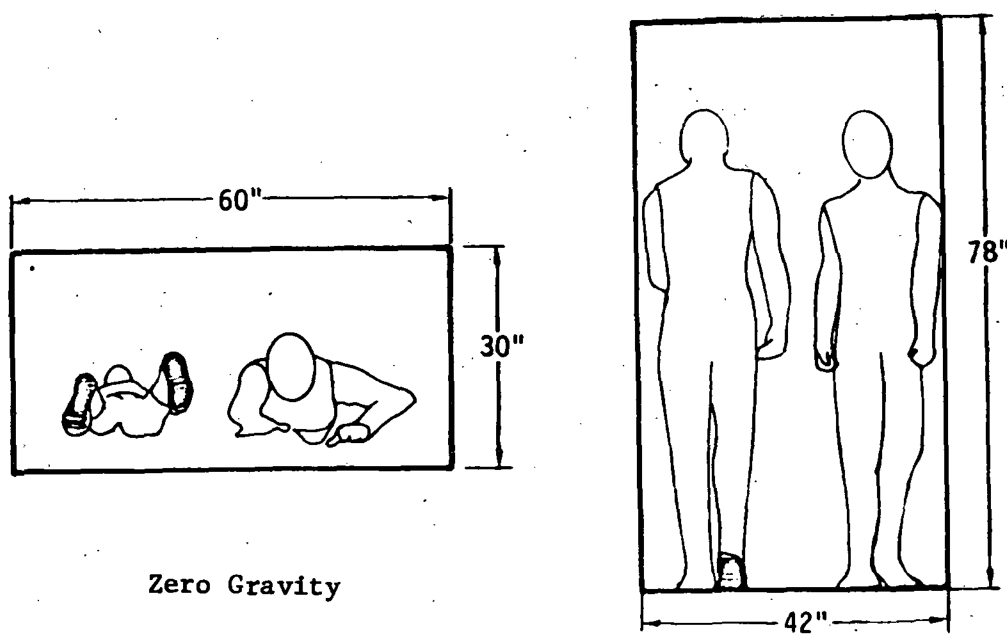


Figure 1-13. Egress Envelope

Egress Motion Normal to Airlock Longitudinal Centerline



Zero Gravity

Partial Gravity

Figure 1-14. Passageway Area

		Related Procedure 5-1	Related Procedure 5-2
19.	Atmospheric contamination levels shall be monitored within habitable areas. This includes verification of habitable atmosphere prior to shirtsleeve entry into a previously non-habitable environment. This includes verification of equalized total pressure, adequate P_pO_2, radiation and toxicity within acceptable levels. Also included is radiation monitoring and checkout for IVA operations. Table 1-9 indicates the radiation and toxicity which shall not be exceeded. Atmospheric criteria for shirtsleeve operations (reference Appendix C, DS-208) are briefly described in Table 1-10.	x	x
20.	Audio and visual alarms shall be provided along crew transfer routes. Audio alarms could be tone or voice with voice alarm defining the action to be taken. Visual alarms shall be of flashing light type and used primarily to alert the crew to the presence of a dangerous or potentially dangerous situation.	x	x
21.	The capability shall be provided to ensure that passageways/hatchways of a normally uninhabited element are free of obstructions so that crew can enter safety and movement will not be inhibited. This may include direct visual inspection through a view window or remotely monitored sensors or closed circuit television.	x	x
22.	Pre-breathing equipment shall be provided for use with the 3.7 psig suits to provide means for which crew can pre-breath oxygen for a sufficient length of time to accomplish denitrogenation. Use of the 8.0 psig suit may avoid need for pre-breathing equipment, operations, or time. The time involved for pre-breathing for the 3.7 suit normally ranges from two to four hours.		x

The functional requirements identified for crew transfer are not uniquely applicable to, or derived for, element pairs. Rather they are applicable to all element pairs that have a crew transfer interface. Preparation for IVA (suit checkout, use of airlock, etc.) is more involved than shirtsleeve, but the requirements associated with actual crew transfer are the same.

Table 1-8. Radiation and Toxicity Levels

Radiation - 50 Rads

Maximum Concentration Trace Contaminants

Contaminant	Concentration (mg/m^3)
Acetone	240
Acetaldehyde	36
Ammonia	3.5
n-Butyl Alcohol	30
Carbon Monoxide	29
Ethyl Alcohol	190
Hydrogen	215
Hydrogen Sulfide	1.0
Indole	126
Methyl Alcohol	26
Methane	1720
Methyl Mercaptan	2
Phenol	1.9
Propyl Mercaptan	92
Pyruvic Acid	0.9
Skatol	141

Table 1-9. Atmospheric Criteria

Humidity	Water vapor partial press: 8-13 mm Hg
Temperature	65 to 85 degrees F
Air velocity	15 (min) to 100 (max) feet per minute 40 feet per minute nominal
Oxygen	Partial pressure 3.1 psi (100 - 120 mm Hg alveolar)
Odor	Controlled
Carbon dioxide	Less than 7.6 mm Hg
Microbilogical, bacteriological contaminants	Controlled

1.7 DESIGN INFLUENCES AND PREFERRED APPROACH SELECTION

Each crew transfer approach was evaluated in general terms (Table 1-10), compared for operational preferences (Table 1-11), and then applied to the individual element pairs (Table 1-12) to establish a preferred approach and identify the design influences. IVA with no airlock is recommended for one space tug case.

APPROACH COMPARISON

Table 1-10. Crew Transfer Comparison

Factors	Shirtsleeve	IVA
Technology status	Present	Present
Checkout and maintenance	Low-medium	Medium
Relative cost	Low	High
Safety	Good	Fair
Additional factors		
Crew acceptability	Good	Fair
Human effort	Low	High
Weight	Low	High

Technology

Both the shirtsleeve and the IVA approaches have been used on past space programs. Suits (3.75 psi) monitoring equipment, and pressurization/depressurization equipment are essentially off-the-shelf hardware.

Checkout and Maintenance

The primary difference is the pressure suit. Checkout and maintenance of the suit is time consuming. All other functions are comparable for the two approaches.

Relative Cost

The cost comparison is essentially between the airlock and pressure suits for IVA and the monitoring sensors for shirtsleeve (initial manning). It is believed that the sensors will be significantly less costly and, of course, can be used continuously after the manning operation as part of the caution and warning system.

Safety

Both approaches have been demonstrated to be safe. The shirtsleeve approach appears to be less hazardous primarily because of the increased flexibility in crew movements.

Crew Acceptability

Shirtsleeve is preferred because of the inherent freedom of movement. Pressure suit operation is cumbersome and awkward at best.

Human Effort

In a pressurized suit, effort is required just to overcome internal suit friction, cables, or pressure rigidity. This increases the work that each crewman must perform and can restrict his movement greatly.

Weight

The weight tradeoff is dependent upon the end results of the crew transfer operation. If the element into which a crewman is being transferred is either already manned or will remain in a manned condition, then shirtsleeve is preferred because the pressurization system, atmospheric storage equipment, and monitor sensors are required anyway. However, if the crew transfer operation is only of a transient nature, IVA with an airlock, could be the lighter concept. For example, the structural requirements for a normally unmanned element would be significantly impacted if it were required to be pressurized for only periodic maintenance/replenishment operations. Also, depending upon the volume that would have to be pressurized, atmospheric storage tanks in the logistics vehicle could become large and heavy. Inclusion of an airlock on the logistics vehicle could result in minimum total on-orbit weight.

OPERATIONAL FACTORS

Table 1-11. Operational Evaluation Factors

Factors	Shirtsleeve	IVA
Mannable elements	Crew rotation/resupply	
Non-mannable elements		Maintenance/Replacement
Frequency of trips	Many	Few
Cargo traffic	High	Low
Type of mission	Regularly scheduled	Unique/unscheduled

Element Manning

If the elements are intended to be manned in their normal mode of operation then full pressurization, habitable environment monitoring, and shirtsleeve transfer is preferred. However for periodic maintenance on non-mannable elements IVA, with airlock, may be preferred because of the potential savings in gross on-orbit weight.

Frequency of Trips

If the interface is going to be traversed frequently, then shirtsleeve is preferred. Donning suits - airlock operations - doffing suits would be a cumbersome and time consuming operation. Included in this factor is the number of crewmen required to transfer. The larger the number the more obvious the preferred approach: shirtsleeve.

Cargo Traffic

Just as important to the selection of the method of crew transfer is the potential cargo that may be carried/transported by the crewmen. Large and/or heavy cargo or numerous pieces tend to drive the selection to shirt-sleeve transfer. Neither handling large cargo in pressurized suits nor multiple airlock operations is desirable.

Type of Mission

A frequent or regularly scheduled crew transfer interface should be accomplished shirtsleeve. Unscheduled operations such as repair should not require incorporation of facilities for shirtsleeve manning operations.

PREFERRED APPROACH SELECTION

All crew transfer operations involving crew rotation should be shirt-sleeve. Thus, all EOS and tug crew rotation interfaces are identified as being shirtsleeve in Table 1-13. All MSS and CPS/RNS (Manned) interfaces are also shirtsleeve either because crew rotation occurs, trips are frequent, or the cargo traffic is high.

EOS and tug crew transfer interfaces with nonmannable elements are all related to maintenance/replenishment operations or to rescue operations to de-pressurized modules. In the case of the EOS an IVA/airlock concept is recom-mended. The frequency of these operations is considered to be very low. There-fore, the airlock should be a cargo bay kit, not a capability of the basic shuttle.

Manned tug maintenance of nonmannable elements is considered to be even more remote. In the analyses associated with propellant transfer (Section 3.0) it was concluded that an OPD was not required. Furthermore, it was established that the EOS can reach the earth parking orbit of the OPD, RNS, or CPS with maximum payloads. Therefore, the only manned tug maintenance missions are with an unmanned tug, CPS, or RNS that has become 'disabled' beyond the range of the EOS. A more viable approach would be to transport the disabled element with the tug to be within reach of the EOS.

Table 1-12. Preferred Approach Selection

Element Pair	Preferred Approach	Rationale
EOS-		
Tug (manned)	Shirtsleeve	Crew rotation
Resupply module (crew)		
MSS		
CPS (manned)		
RNS (manned)		
OLS		
OPD (manned)	Shirtsleeve	
EOS-		
Tug (unmanned)	IVA	Periodic maintenance and unique mission
CPS (unmanned)		
RNS (unmanned)		
OPD		
RAM (nonmannable)	IVA	
RAM (mannable)	Shirtsleeve	Frequent trips, cargo traffic
Tug (Manned)-		
Tug (manned)	Shirtsleeve	Crew rotation
Resupply module (crew)		
MSS		
CPS (manned)		
RNS (manned)		
OLS (manned)		
OPD (manned)		
Resupply module (cargo)	Shirtsleeve	Frequent trips, cargo traffic
Tug (Manned)-		
Tug (unmanned)	IVA(1)	Periodic maintenance and unique mission
CPS (unmanned)		
RNS (unmanned)		
OLS (unmanned)		
OPD (unmanned)		
MSS-		
RAM	Shirtsleeve	Frequent trips, large quantities of cargo
Resupply module (cargo)		
Resupply module (crew)	Shirtsleeve	Crew rotation
CPS/RNS (Manned)-		
Resupply module (crew)	Shirtsleeve	Crew rotation
Resupply module (cargo)	Shirtsleeve	Frequent trips, cargo traffic

(1) Airlock not recommended; see text for rationale.

In the extremely unlikely case that a manned tug did have to "repair" one of these elements, via crew transfer, it is recommended that the basic requirement of an airlock for IVA be rescinded and the tug crew compartment serve as the airlock. This mission would be extremely unique and rare and does not warrant either incorporation of an airlock on the basic tug or development of an airlock "kit" for the tug.

DESIGN INFLUENCES

Table 1-14 summarizes the more significant design influences of the preferred approach selections. Only the EOS requires an airlock, but only as a kit installation. In order to verify the acceptability of the environment prior to manned entry as well as continuous monitoring of that environment, both sensor and monitor provisions are required in all elements that are to be manned. This includes visual inspection capability. Thus, view windows in docking ports are required. The alternative of TV was considered to be too costly and complex.

Table 1-13. Design Influences

Hardware	Element Applicability
Airlock	EOS only (kit installation)
Habitable environment monitor	EOS, MSS, Tug, CPS, RNS, OLS
Environment sensors	MSS, RAM, Tug, CPS, RNS, Resupply modules, OLS
Docking port view window	EOS, Tug, RAM, MSS, CPS, RNS, Resupply modules, OLS
Minimum 30-inch hatch[1]	All elements

[1] Cargo transfer requires larger hatch - see Section 2.0

2.0 CARGO TRANSFER

The cargo transfer interfacing activity encompasses the operations associated with the transfer of packaged resupply and cargo items, and fluids, between elements. Transfer of large quantities of propellants to storage depots or propulsive elements is defined as the propellant transfer activity and is not included under cargo transfer.

2.1 SUMMARY

Element interfaces and mission models where the cargo transfer activity can occur are identified in matrix formats. Of the 117 potential interactions, 45 are identified as applicable to cargo transfer. As expected, the majority of the cargo transfer interactions occur when one of the elements is a logistics vehicle.

The cargo transfer activity is essentially divided into two subactivities which are packaged cargo transfer and fluid cargo transfer. The three alternate approaches for packaged cargo transfer are manual unaided, manual aided, and automated. The alternate approaches for fluid cargo transfer are manual temporary, manual plumbed, and automatic plumbed. All six of these approaches are considered in conjunction with shirtsleeve, IVA, and EVA crew operational modes.

Design concept models describing feasible hardware solutions for each of the approaches for both packaged and fluid cargo transfer are included. Differences in the design models include the type of transfer system, the restraints involved, and the types of fluid interfaces. Also involved are the differences in equipment between crew operational modes.

Five operational procedures were selected to provide a representative sampling of the procedures for element interfaces and mission models for each of the crew operational modes and alternate approaches. Their applicability to a shortened inventory of element pairs is described for manned-to-manned and manned-to-unmanned interfaces. Rationale for the selection of the representative procedures and the differences between those selected and those not selected is described as follows.

All of the operational procedures selected, except for the manual-unaided EVA, are applicable to all of the manned-to-unmanned element cargo transfer applicable interfaces when an interfacing airlock is provided. The EVA procedure is only applicable to the returnable and resupply satellite missions. The three shirtsleeve operational procedures apply to all of the manned-to-manned element interfaces.

The functional requirements for the cargo transfer activity include consideration for combinations of crew complement varieties and operational modes, and various cargo transfer systems. Functional requirements applicability to element pairs and a discussion of quantitative criteria are also presented. Hatch, window, and IVA/EVA capabilities requirements are described as being the most significant vehicle requirements.

Selection of preferred approaches for each applicable element pair are presented. A process of analyses for determining these selected approaches is described for both fluid cargo transfer and packaged cargo transfer. For packaged cargo transfer either the manual-aided or the manual-unaided approach has been selected for most element pairs. The automated approach was selected only for some retrievable satellite missions and unmanned element to unmanned element interchanges. For fluid transfer, the manual plumbed concept was selected as the preferred approach except for some satellite replenishments and of course unmanned to unmanned element interfaces. These exceptions clearly identify the requirement for a remote control grappling device. It could be as simple as a probe or probes with a clamping end effector or as complex as a multi-degree-of-freedom manipulator. In either case the cargo interchanges requiring remote control are very infrequent. Thus, a kit installation on the logistics vehicle is recommended.

The manual plumbed concept illustrates the desirability of an optimized/standardized docking interface. This concept incorporates such characteristics as simplicity, flexibility, light weight, operational safety, and non-stringent alignment requirements. But it also points out the requirement for standardized provisions for fluid transfer accross many elements.

2.2 ELEMENT INTERFACE AND MISSION MODEL MATRICES

Figure 2-1 lists all the study elements and in matrix form cross-references the viable interactions. Of the potential 117 interactions, 45 involve the cargo transfer activity. The majority of the cargo transfer activities, as would be expected, involve logistic vehicle interfaces and interfaces between modules of elements that can be or are assembled modularly (MSS, RNS, OLS, LSB, and OPD). A summary of the interactions are presented in the following paragraphs.

EOS orbiter cargo transfer activities are apparent when the interface involves a RAM, satellite resupply, or MSS. The other EOS orbiter cargo transfer activities are:

1. EOS to EOS - This interface occurs if an EOS is required to rescue crew from another EOS that is planned to be abandoned. If the transfer time is not critical, valuable equipment could be salvaged and carried from the disabled vehicle into the rescue craft. It is also feasible, if time permits, that equipment would be transported from the rescue craft to the disabled craft (e.g., medical supplies and low-power signal transmitter and power pack for tracking the disabled craft after abandonment).

2. EOS to Ground-Based Tug - One potential cargo transfer interaction between these elements is the transfer of any cargo the tug crew may store with them in the EOS orbiter crew compartment prior to entry into the tug (e.g., EVA suit).

3. EOS to Space-Based Tug - Because the space-based tug is utilized to perform interorbital logistics missions, it will be called upon to receive cargo from the EOS orbiter for delivery to other earth orbital elements and also will deliver, to the EOS orbiter, cargo for return to earth.

4. EOS to CPS/RNS/OPD - Cargo transfer interactions in this function represent resupply of consumables other than propellants and replacement of hardware (inflight replaceable units).

5. EOS to OLS - During the intermediate assembly of this element for boost to a lunar orbit, crew and equipment would be transferring between the elements to perform checkout operations.

6. EOS to Manned Lunar Tug - Cargo transfer interactions with these elements are envisioned when the tug is being checked out in low earth orbit. If the tug returns from lunar orbit with crew because the lunar station is being abandoned, some type of cargo may be brought along (e.g., records or specimens).

The matrix identifies many EOS orbiter potential interfaces that do not involve cargo transfer. These interfacing elements, even though they can be transported by the EOS, are planned to be fully self-contained.

		SPACE VEHICLE INVENTORY																								
		EOS	TUG				RAM				SATELLITE			EO RESUP MODS	MSS		CPS			RNS	LUNAR PROGRAM SYSTEMS					OPD
			NON RET	RTN	GRD BASED	SPACE BASED	ATT. EOS	DET. EOS	ATT. MSS	DET. MSS	EOS DELIV	EOS + 3RD ST	RETR, RESUP		LOW EO	GEO SYNCH	OIS	EO SHTL	CLS		OLS	TUG UNMAN	TUG MAN	RESUP MOD	LSB	
	EOS	C	X	X	C	C	C	C	X	X	X	X	C	C	C	C		C	C	C	C	X	C	X	X	C
TUG	NON RET											X														
	RETURNABLE											X														
	GRD BASED				C	C			X	X		X	C	C		C		X	X	X		X	X	X		X
	SPACE BASED					C			X	X		X	C	C	C	C	X	C	C	C	C	X	C	X	X	C
RAM	ATT. EOS						X	X																		
	DET. EOS																									
	ATT. MSS														C	C		X		X						
	DET. MSS														C	C		X		X						
SATEL	EOS DELIV																									
	EOS + 3RD ST																									
	RETR, RESUP																									
	EO: RESUP MODS													X	C	C		X	X	X		C	C	X		X
MSS	LOW EO														C											
	GEOSYNCH															C		X		X						
CPS	OIS																	X	X	X	X					X
	EO SHTL																	X								X
	CLS																		X		X	X	X	X	X	X
	RNS																			X	X	X	X	X	X	X
LPS	OLS																				C	X	C	C		
	TUG UNMAN																							X	X	X
	TUG MAN																							X	X	X
	RESUP MOD																							X	X	X
	LSB																								C	
	OPD																									X

LEGEND

Potential Interactions	117
Actual Interactions	45
C - Cargo Transfer	45
X - Not Applicable	72

Figure 2-1. Cargo Transfer Interactions

Ground-based tug cargo transfer interactions are summarized as follows:

1. Ground-Based Tug to Ground-Based/Space-Based Tugs - The cargo transfer activity for these interfaces occurs during a crew rescue operation. The types of cargo involved are the same as those identified for rescue operations with an EOS orbiter.

2. Ground-Based Tug to Satellites Requiring Resupply/Geosynchronous MSS - Cargo transfer activities are normal periodically planned operations.

3. Ground-Based Tug to EO Resupply Module - If the tug were to fly a prolonged mission, it may carry with it an EO resupply module. The additional provisions that could be stored in a resupply module would be transferred to the tug as on-board supplies are consumed.

Because the ground-based tug is primarily designed for operations between ground and high-energy orbits, many of the potential interfaces identified with EOS orbiters and space-based tugs are not considered candidates for ground-based tug operations.

The space-based tug is planned to perform logistics operations between earth orbital elements. It acquires ground-supplied cargo from an EOS orbiter in a low orbit (approximately 100 n mi) and transports this cargo to user elements in higher orbits. The space-based tug cargo transfer interfaces are the same as the EOS orbiter interfaces with the exception of the EOS orbiter supported RAM's and the earth orbital resupply modules. The RAM interfaces are programmatically tied to the EOS orbiter operations. The earth orbital resupply module, like the ground-based tug interface, could be carried by the space-based tug to supply provisions during prolonged missions.

Cargo transfer operations will be carried out regularly between MSS elements and associated RAM elements.

Earth orbital resupply modules are physically mated to the noted user elements, and cargo is transferred at will.

When the OLS is being assembled for launch to lunar orbit, provisions can be supplied by the low earth orbital logistics elements or by the lunar program tug. Also, if resupply modules are utilized, either the earth orbital resupply module or the lunar resupply module can be utilized.

Figure 2-2 utilizes the same matrix that was used to identify cargo transfer interactions to identify the types of missions where this activity may occur. Eleven reference missions have been identified for this study and are shown in detail in Volume I, Section 2. The matrix cross-references the applicable mission using the corresponding mission identification numbers 1 through 11. Figure 2-2 shows that Missions 2, 5, and 8, are most consistently mentioned. These missions are logistic missions and, as expected, involve the cargo transfer activity. The other noted Missions 1, 3, 4, 6, 7, 10, and 11 utilize cargo transfer activities indicated as follows.

		SPACE VEHICLE INVENTORY																								
		EOS	TUG				RAM				SATELLITE			EO RESUP MODS	MSS		CPS			RNS	LUNAR PROGRAM SYSTEMS					OPD
			NON RET	RTN	GRD BASED	SPACE BASED	ATT. EOS	DET. EOS	ATT. MSS	DET. MSS	EOS DELIV	EOS + 3RD ST	RETR, RESUP		LOW EO	GEO SYNCH	OIS	EO SHTL	CLS		OLS	TUG UNMAN	TUG MAN	RESUP MOD	LSB	
	EOS	2			2	2,10,11	3	1,2					2	2	1,2	1,2		2	1, 2 10,11	2,10,11	1,2		1,2			1,2
TUG	NON RET																									
TUG	RETURNABLE																									
TUG	GRD BASED				8	8							8	8		7,8										
TUG	SPACE BASED					5,10,11							4, 5	5,10,11	5	5,10,11		5,6 10,11	5,6 10,11	5,6 10,11	5		5			5
RAM	ATT. EOS																									
RAM	DET. EOS																									
RAM	ATT. MSS														2,5,8	2,5,8										
RAM	DET. MSS														2,4 5,8	2,4 5,8										
SATEL	EOS DELIV																									
SATEL	EOS + 3RD ST																									
SATEL	RETR, RESUP																									
	EO. RESUP MODS														2,5,8	2,5,8						2,5,8	2,5,8			
MSS	LOW EO														2,5,8											
MSS	GEOSYNCH															2,5,8										
CPS	OIS																									
CPS	EO SHTL																									
CPS	CLS																									
	RNS																									
LPS	OLS																				2,5,8		2,5,8	2,5,8		
LPS	TUG UNMAN																									
LPS	TUG MAN																									
LPS	RESUP MOD																									
	LSB																								2,5,8	
	OPD																									

Figure 2-2. Applicable Mission Models for Cargo Transfer

Mission 1 is an EOS emplacement mission, in which an EOS places an element or part of an element into a specific orbital position. The cargo transfer operation occurs while the element is still attached to the EOS. Cargo transfer may be required for check out of the element prior to release.

Mission 3 is an EOS orbiter sortie mission where the EOS orbiter transports a RAM to low earth orbit and remains attached to it while experiments are conducted. The crew can be continually transferring between the two elements and transfer of cargo will occur periodically.

Mission 4 - This mission involves elements that are retrieved from some point in earth by a space-based tug and returned to a MSS for servicing and resupply.

Mission 6 - The purpose of this mission is to utilize a space-based tug to assist with the disposal of an orbital element by injecting it into a path that ultimately ends with splashdown in an ocean. The cargo transfer activity will be utilized if salvage operations are warranted prior to disposal.

Mission 7 is applicable to cargo transfer for the initial module of the geosynchronous MSS. Prior to separation from the space-based tug, the module could be entered and checked out.

Missions 10 and 11 are geosynchronous cislunar shuttle logistics missions. Cargo transfer involved in payload transfer operations or when personnel and cargo is transferred from the EOS to the tug for subsequent tug operations.

2.3 ALTERNATE APPROACHES

The operations associated with the transfer of cargo between elements is dependent upon the type of cargo and proposed method of transfer. Development of interface requirements for cargo transfer must consider each element-to-element interface and the resulting interactions of each cargo transfer approach. The general types of cargo to be transferred and the feasible modes to accomplish the transfer are defined below:

Bulk (container/pallet)	Manual, aided Automatic
Bulk (individual control)	Manual, aided Manual, unaided Automatic
Fluid	Manual, unaided, temporary Manual, plumbed Automatic, plumbed

For purposes of this study, cargo can be categorized as: (1) bulk--container/pallet, (2) bulk--individual container, and (3) fluid. Bulk cargo is further categorized dependent upon size and mass that a crewman is capable of handling in the space environment. Cargo for resupply purposes generally will be adaptable to containerization, in that predictable and preplanned quantities of like items will periodically be required. Specialized cargo items, such as unique science payloads, individual crewman supplies, and items that are small because of ultimate use locations/access, may be categorized as individual cargo transfer items. Fluid transfer is a category wherein fluids are transferred through use of interconnecting umbilicals. Transfer of fluids by any other method is applicable to requirements associated with bulk cargo types. The following items are listed as representative cargo items applicable to orbital transfer requirements:

<u>Consumables</u> - These include gases, chemicals, food, personnel hygiene, and medical supplies.

<u>Logistics/Maintenance</u> - This includes modules, housekeeping supplies, and equipment spares/replacements.

<u>Science</u> - These items include film, samples, scientific instruments, and recording tapes.

ALTERNATE APPROACHES

Bulk Cargo Transfer Modes

As in any land-based cargo transfer system, transfer of bulk cargo between elements will range from purely manual to full automatic. The absence of gravity in the space environment will dictate application of unique transfer and handling requirements to achieve capability throughout the manual to automatic spectrum. Three alternate approaches for bulk cargo transfer between elements are illustrated below.

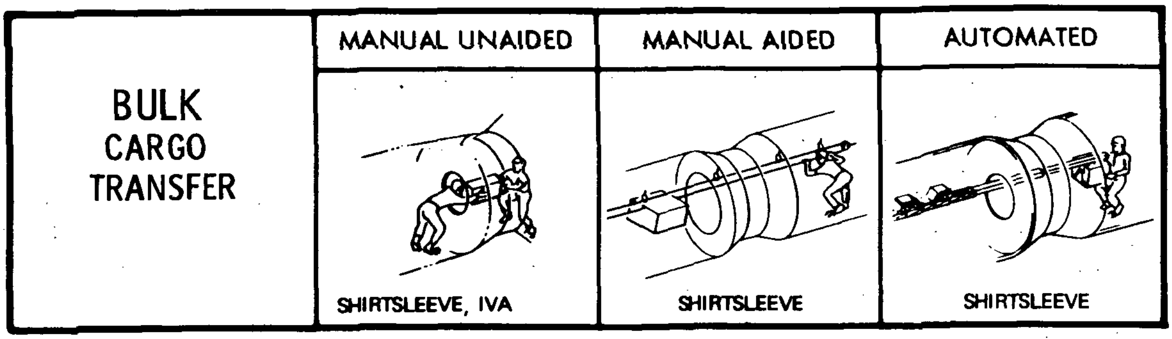


Figure 2-3. Package Cargo Alternate Approaches

Manual - Unaided

This method of cargo transfer (Figure 2-3) relies upon the individual crewman and his capability to handle cargo items without mechanical aids. This capability is applicable to a crewman in either shirtsleeve or IVA (pressurized spacesuit - umbilical). During the IVA mode, additional constraints are imposed by the pressurized spacesuit, which will further limit the crewman's ability to perform useful work. Devices and mechanisms such as tethers, straps, handles, and spacesuit restraints are applicable to this approach. They assist the crewman in his maneuvers, but do not directly aid the transfer of the cargo (see Figure 2-4).

The manual-unaided approach has been utilized in the Apollo program both in a shirtsleeve mode and on extra vehicluar activity (EVA) mode. Cargo transfer between the Apollo and LEM is a handcarry operation. Apollo 15 utilized the EVA mode to retrieve cargo from the scientific instrument module (located in the Apollo service module) and transfer it to the command module. The forthcoming Skylab program also will utilize shirtsleeve and EVA modes for cargo transfer.

Use of the manual-unaided cargo transfer approach is applicable to transfer of items between a resupply element and either a manned or unmanned orbital element.

Manual - Aided

This category of cargo transfer methods employs mechanical devices for actual transfer functions with the crewman essentially performing control and operator tasks. Through the use of mechanical systems, the greatest diverse capability exists for transfer of cargo between elements. Mechanisms to aid transfer of cargo items including rails for guiding cargo, tethers and cables for propelling and restraining items, manipulators and articulating arms, and manual conveyor systems. Figure 2-5 shows some representative manual-aided cargo transfer techniques.

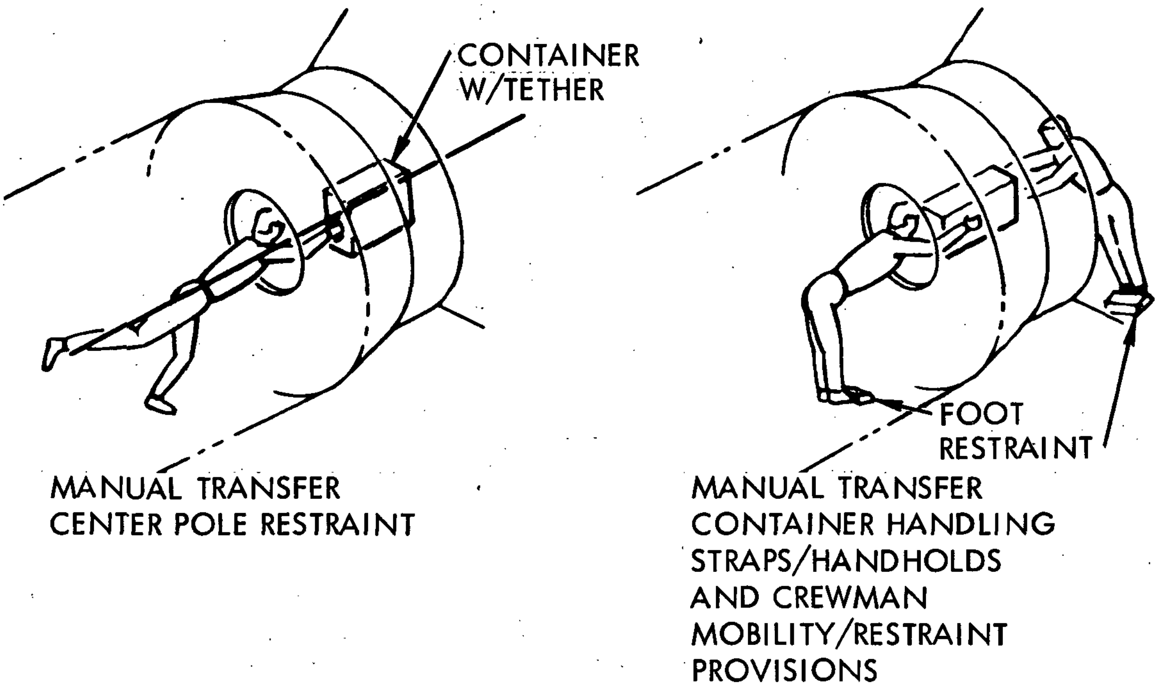


Figure 2-4. Manual Cargo Transfer Techniques

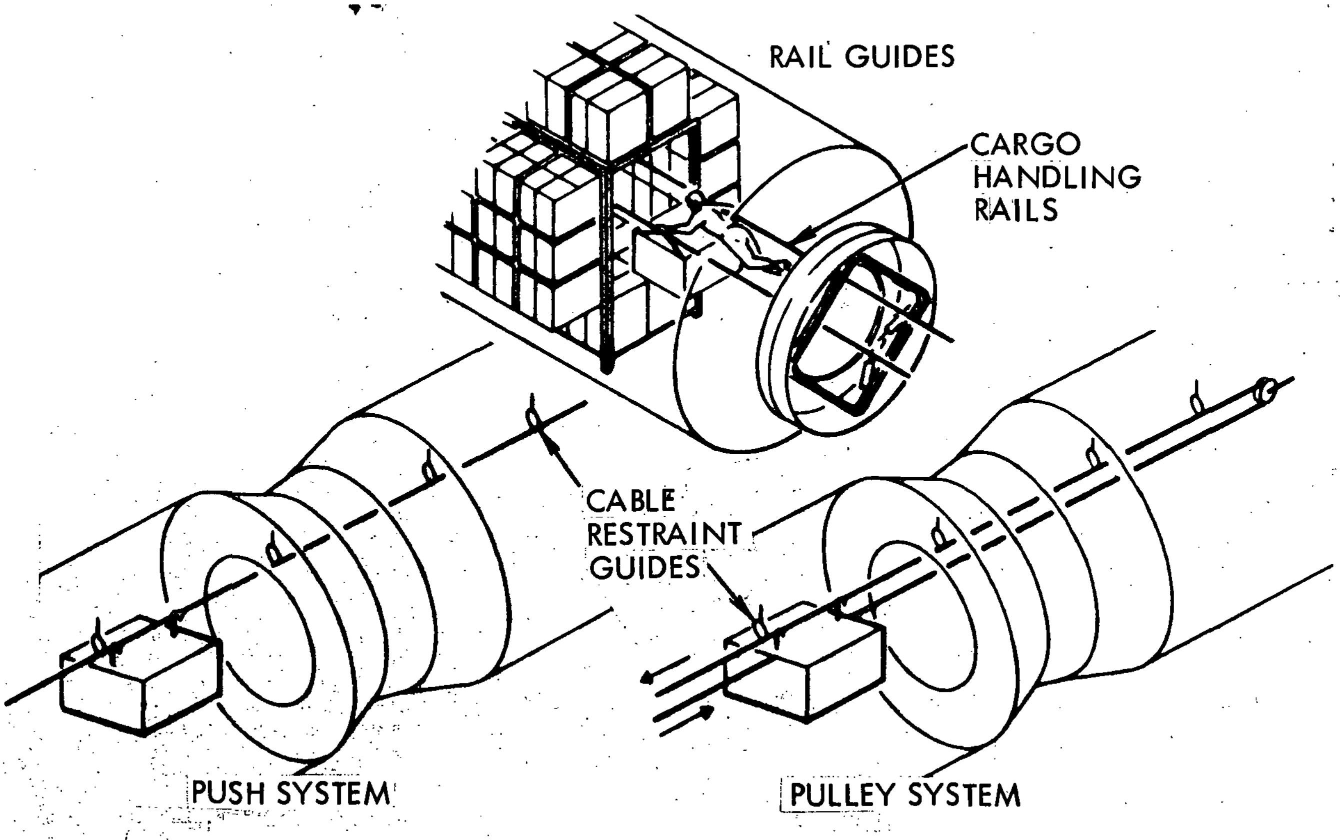


Figure 2-5. Manual-Aided Cargo Transfer Techniques

Automatic

The automatic approach utilizes a mechanization such as a telescoping boom to actually transfer the cargo across the interface. Normally, the manual tasks of loading and unloading the cargo at the terminal ends of the transfer are still required. Typical concepts of an automatic system are illustrated in Figure 2-6.

A fully automatic system could be used for cargo transfer between manned and unmanned elements. This approach would be applicable for the resupply and servicing of unmanned elements that cannot accommodate a manned interface other than by means of EVA. A plug-in resupply package could be extended on a telescopic boom to serviceable elements such as satellites (Figure 2-7) or small RAM's that cannot accommodate a docking/airlock interface.

Fluid Cargo Transfer Modes

As stated previously, transfer of fluids across the interface in containers is included in bulk transfer. Fluid flow across the interface requires unique considerations and obviously different approaches. The approaches are: (1) manual temporary, (2) manual plumbed, and (3) automated plumbed and are illustrated in Figure 2-8.

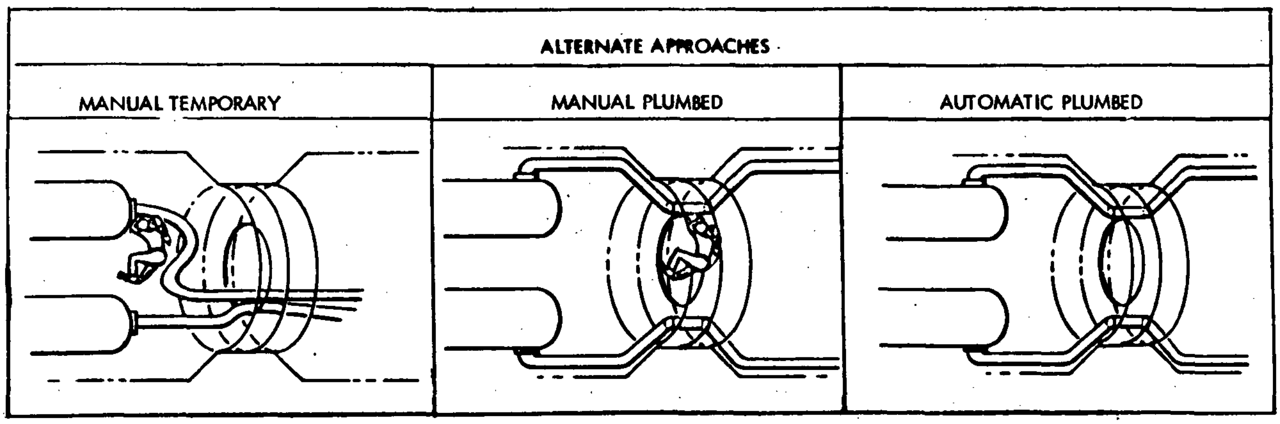


Figure 2-8. Fluid Transfer Approaches

Manual Temporary

This approach requires crewmen to manually install and connect lines, pipes, hoses, etc., across the element-to-element interfaces to accommodate the fluid transfer. The installation could be shirtsleeve or IVA.

Manual Plumbed

Plumbed lines are incorporated in the utilities collar of the mating interface and are manually connected upon completion of the mating activity. These lines and connects are considered as being isolatable from the habitable compartment.

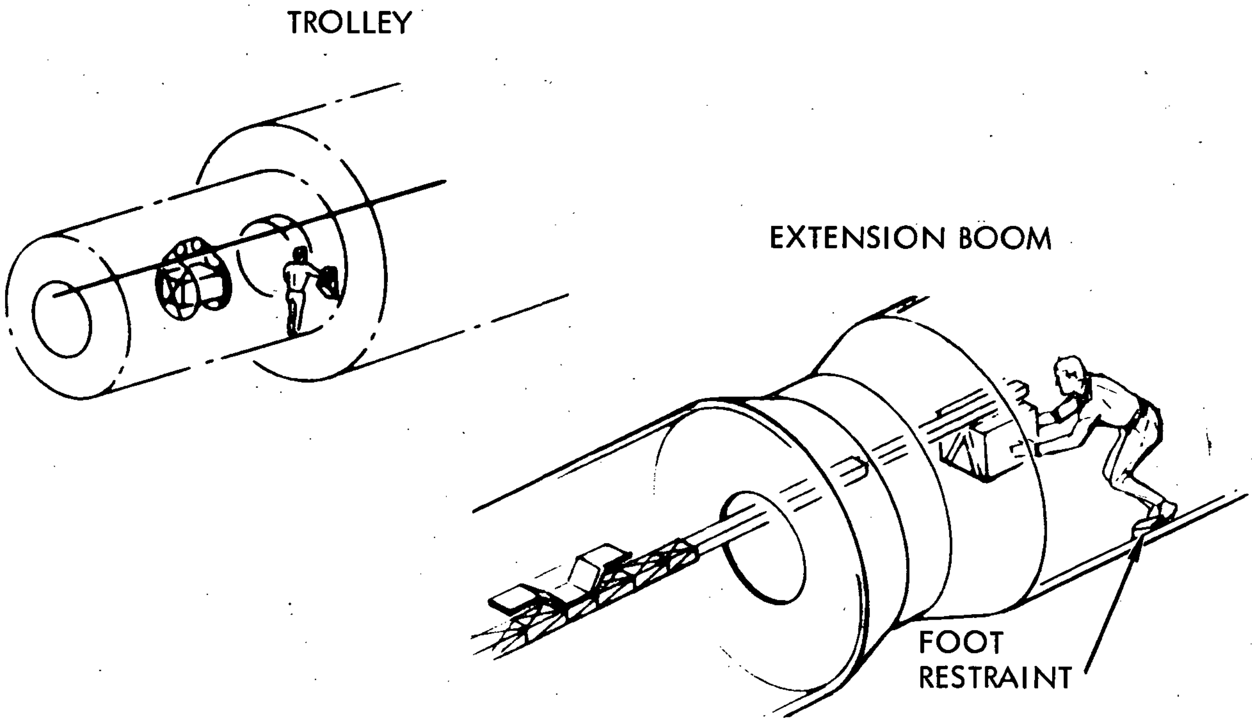


Figure 2-6. Automatic Cargo Transfer

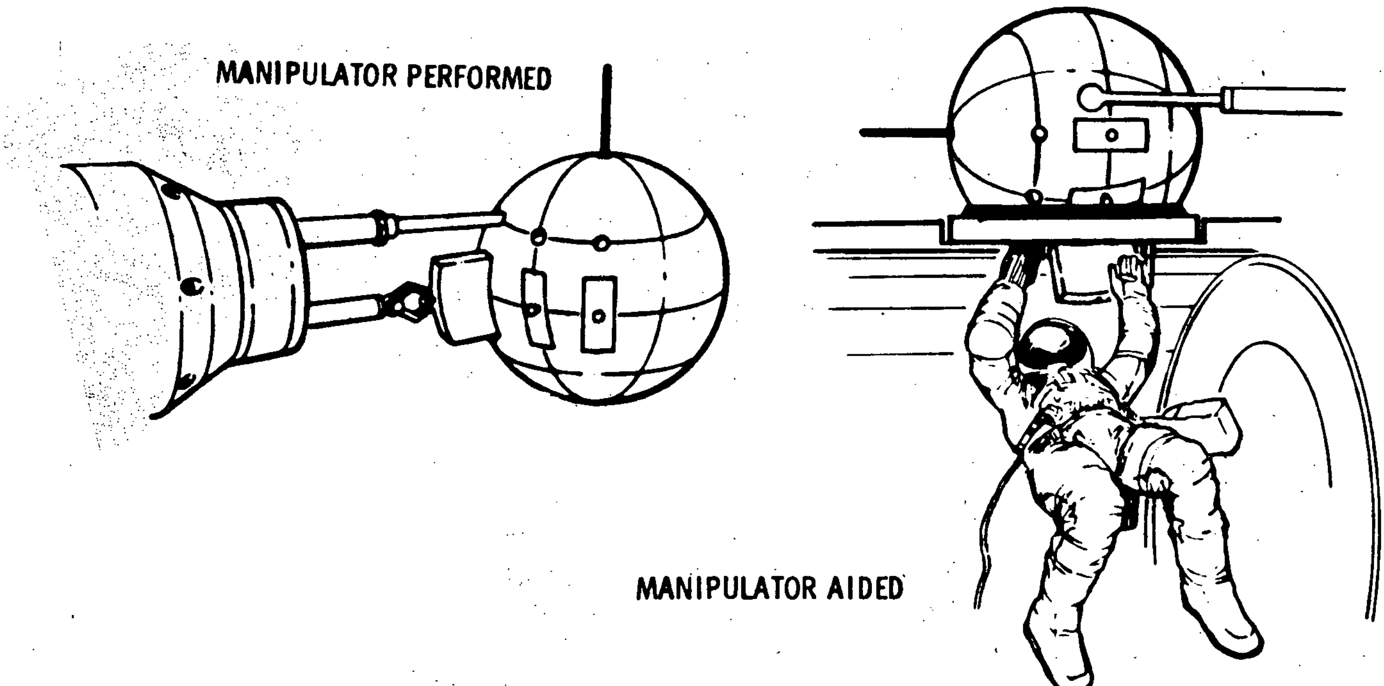


Figure 2-7. Satellite Power-Pack Exchange

Automatic Plumbed

Plumbed lines are incorporated in the utilities collar of the mating interface and are automatically connected upon completion of the mating activity. This approach would be especially applicable for resupply of fluids to unmanned vehicles that will not accommodate a manned interface through an airlock.

2.4 DESIGN CONCEPT MODELS

Design concepts will, of course, vary with each type of transfer system. The design concepts are impacted by the procedural assumptions, operations, or requirements. Design concept models are presented here to implement each approach. Figure 2-9 describes the manual-unaided approach (shirtsleeve) and its associated hardware. If the manual-unaided approach is by IVA, the design model will be as shown in Figure 2-10.

The design concept model selected for the manual-aided approach utilizes the guiderail transfer system. This model more effectively accommodates large sized packages which are a main driver for selection of this approach.

Two automatic packaged cargo transfer design concept models must be considered. The first is one in which the man is performing loading and/or unloading operations and then activates the transfer system. The second is where the man only controls the transfer system and has no manual participation in the cargo loading and unloading. A good example of this would be a satellite resupply with a manipulator.

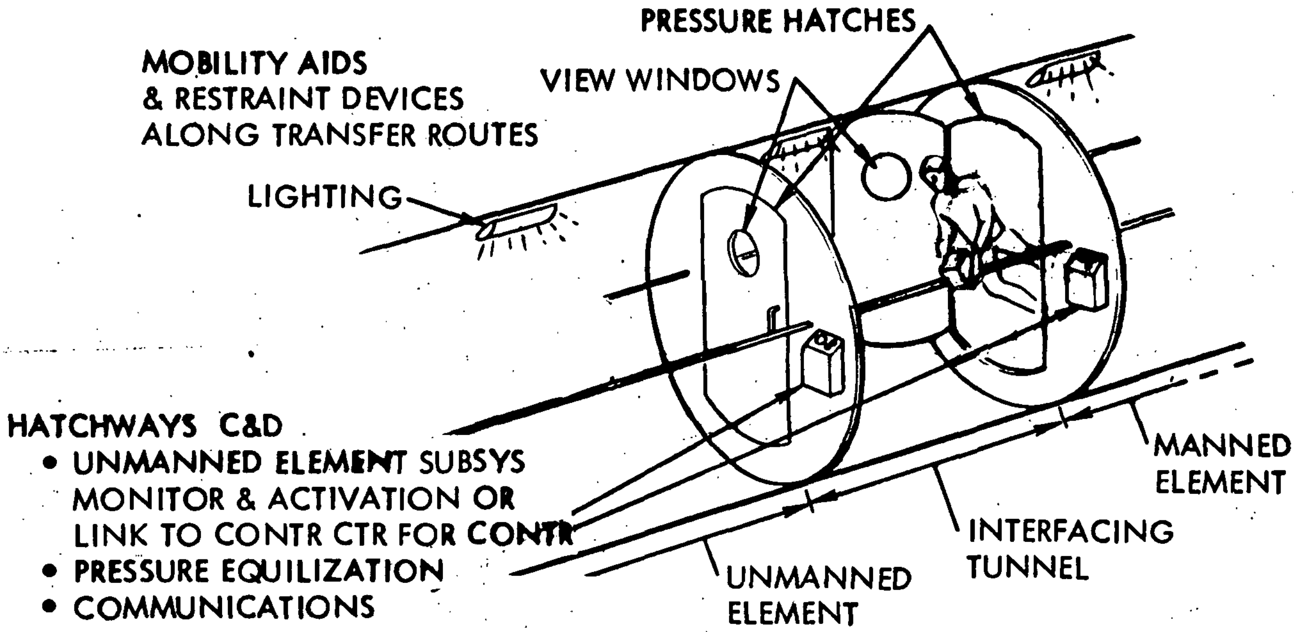


Figure 2-9. Manual-Unaided Concept

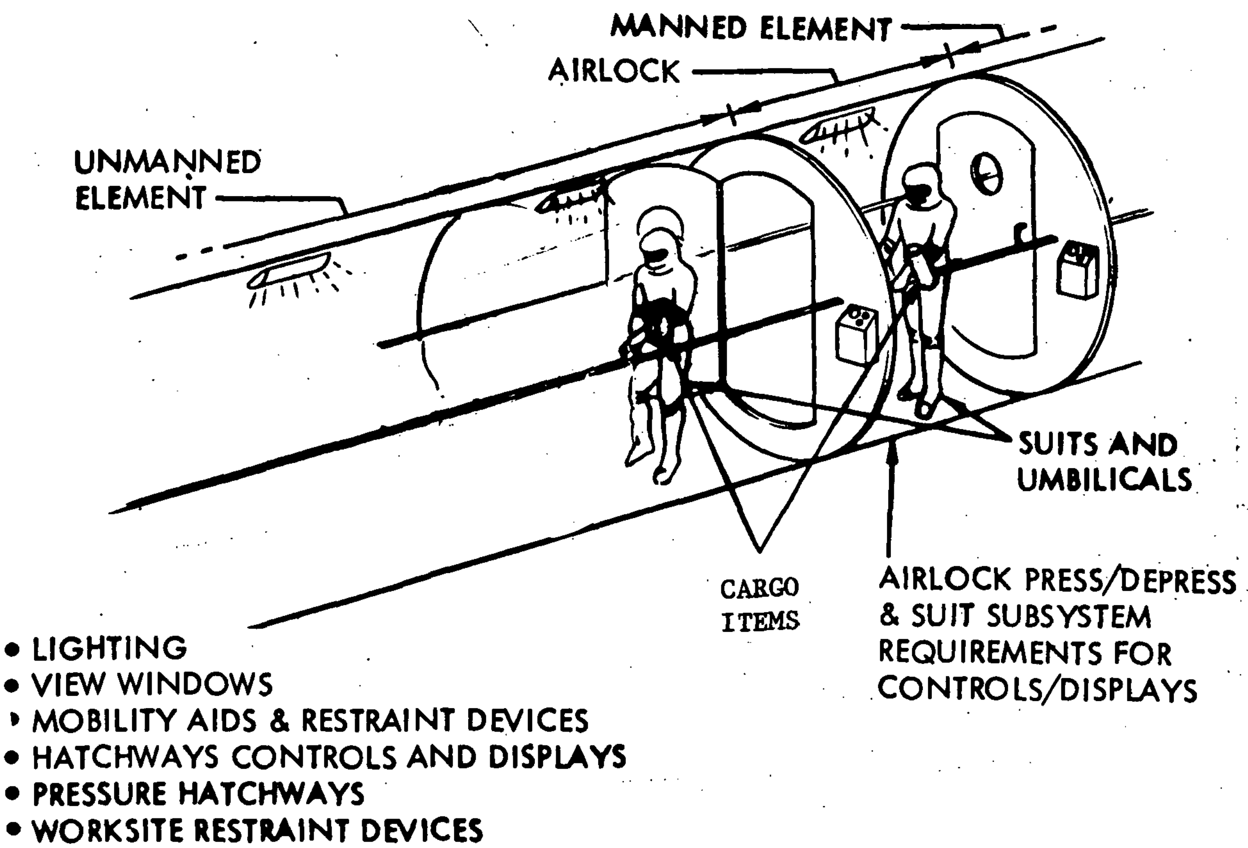


Figure 2-10. IVA Concept

2.5 OPERATIONAL PROCEDURES

Cargo transfer operational procedures have been developed for manual-unaided, manual-aided, and automatic cargo transfer alternate approaches (refer to Appendix B, Section 4). The shirtsleeve, IVA, and EVA manual-unaided operational procedures (No. 1, 2, and 3, respectively) present the alternative crew operational modes for the manual-unaided approach. Procedure number 4 presents a representative operational procedure for the manual-aided approach in a shirtsleeve operational mode. This procedure is applicable also to the automated approach since the difference between the automated and the manual-aided approaches is only that the former does not require manual translational energy for movement of cargo items. A representative operational procedure for fluid cargo transfer is presented in procedure number 5. This procedure presents the operations for the manual plumbed mode of fluid transfer. No procedure was written for the automatic plumbed mode since it would be identical to the manual plumbed mode less the manual interconnect operations. No procedure was written for the manual temporary since it would be the same as manual plumbed but would also involve stowage, transfer, and restraint of the temporary fluid lines.

For the manual-aided and the fluid-transfer operational procedures, numbers 4 and 5, respectively, the shirtsleeve crew operational mode was selected as the most representative. Furthermore, the differences for these procedures between the shirtsleeve, IVA, and EVA modes would be similar to the differences for the manual-unaided approach; i.e., procedures 1, 2, and 3. Common operations and comparisons between the manual-unaided and the manual-aided/automatic procedures are shown in Figure 2-12. Procedural comparison for shirtsleeve and IVA/EVA modes are described under the crew transfer activity (Section 1). Since the fluid cargo transfer activity has its unique operations, it was not included in the comparison described in Figure 2-12.

Figure 2-4-2 (Appendix B) presents the cargo transfer procedure applicability for each of the element-to-element interfaces. The matrix indicates where the manual-unaided (shirtsleeve, IVA, and EVA), and manual-aided procedures apply for manned-to-unmanned and manned-to-manned interfaces. In general, all the manned-to-unmanned element cargo transfer applicable interfaces with an airlock can support shirtsleeve and IVA, manual-unaided, manual-aided, and fluid transfer.

It is assumed that depressurization of an entire habitable volume is a contingency operation and normal IVA or EVA operations would occur with a dedicated airlock.

The manned-to-unmanned interfaces involving a returnable and resupply satellite can involve the manual-unaided EVA procedure in addition to the other procedures for manned-to-unmanned interfaces with an airlock. All manned-to-manned cargo transfer applicable interfaces may involve shirtsleeve, manual-unaided, manual-aided, and fluid-transfer operational procedures. Table 2-1 summarizes the results of the procedures applicability matrix.

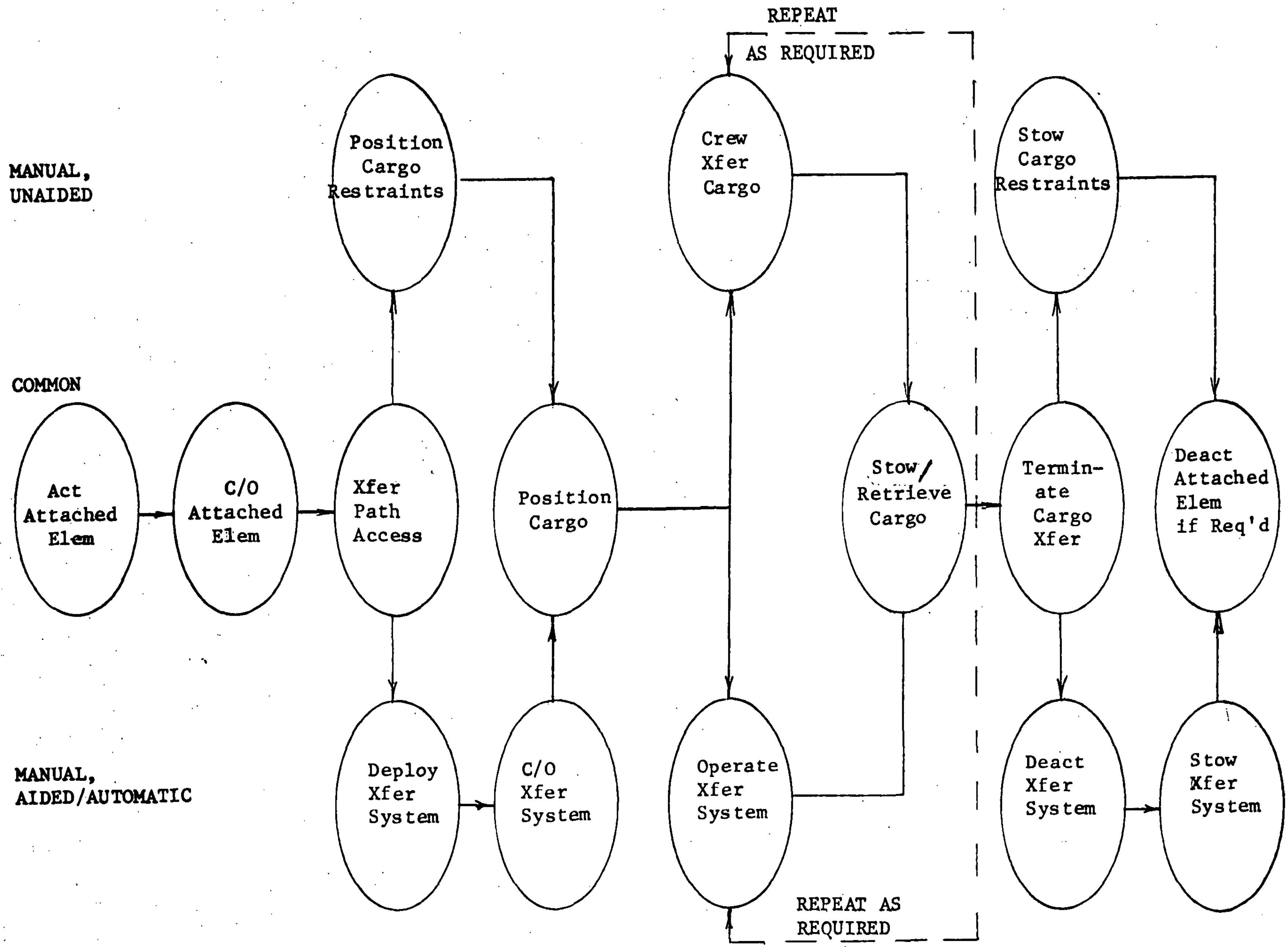


Figure 11. Cargo Transfer Procedural Comparison

Table 2-1. Procedures Applicability

	Manned-to-Unmanned	Manned-to-Manned
1. Manual-unaided, shirtsleeve	26	
2. Manual-unaided, IVA	17	0
3. Manual-unaided, EVA	2	0
4. Manual-aided/automatic, shirtsleeve	25	19
5. Manual-unaided, shirtsleeve, fluid	25	19
Not applicable	24	29

2.6 FUNCTIONAL REQUIREMENTS

To select a single cargo transfer concept that is optimal for all element interfaces is highly unlikely. Optimization is dependent upon numerous criteria such as, package sizes, transport path clearances, permanency of installation, usage rates, hazardous nature of cargo, control requirements, etc. These criteria are variables for each element. Note that those functional requirements unique to fluid cargo transfer are included in the propellant transfer activity. The following functional requirements will serve as a guide for development of total cargo transfer system design criteria.

Where cargo transfer requires crew transfer or crew ingress into element interfaces, the requirements of Section 1, Crew Transfer, apply especially in respect to ensuring a safe, habitable environment and to aid crew mobility or force applications and clearance. This section will take into account the additive clearance for hatches and passageways, etc., for cargo plus crew or cargo handling device.

Related Procedure	Man Unaided - SS	Man Unaided - IVA	Man Unaided - EVA	Man Aided/Auto-SS	Fluid - SS
	4-1	4-2	4-3	4-4	4-5
Item 1	X	X	X	X	
Item 2	X	X	X	X	

CARGO TRANSFER FUNCTIONAL REQUIREMENTS

1. The weight (mass) of cargo/resupply items requiring manual handling will be limited by the crew maneuvering capabilities. All cargo transfer approaches, excepting fluid transfer, require a crewman to maneuver cargo to some degree. In a true zero-g environment the weight (mass) a crewman will be expected to maneuver will equal 65 percent of his body weight. Under partial gravity conditions the weight limit is further reduced. A 120-pound mass is considered the upper limit for one man with a body weight of 180 pounds. For the same man, 60 pounds (35 percent of body weight) is an upper limit at 1-g. It seems reasonable to extrapolate through a partial gravity as shown in Table 2-2 below. For 2 equivalent men, a 250-pound mass is considered the upper limit.

Table 2-2. Crew Cargo Mass Handling Limits (180-pound Crewman)

g-level	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
% body wt.	65	62	59	56	53	50	47	44	41	38	35
Mass (lb)	120	115	109	103	97	90	85	79	73	66	60
Eq. wt. (lb)	0	11.5	22	31	39	45	42	55	58	59	60

2. The dimensions (volume) of cargo/resupply items requiring manual handling will be limited by the crewman maneuvering capabilities. Also, transfer of cargo items between orbital elements will be dependent upon volumetric capability of the physical access path.

   Studies conducted at the NASA (MSFC) indicate that the most important single characteristic of a package that effects its maneuverability is package moment of inertia about the handle. The following table summarizes these findings by identifying the moment of inertia limits for package transport. All packages were maneuvered utilizing a single pistol-grip handle with the carrier traversing a fireman's pole in simulated zero-g and neutral buoyancy (reference Appendix C, DS-573).

Moment of Inertia ($in\text{-}lb\text{-}sec^2$)	Remarks
0 to 65	Easily maneuvered, precisely positioned
66 to 150	Reasonable transfer and positioning ease
150 to 240	Fair maneuverability, difficult to position
240 to 300	Package can be transferred through large open area
300 to 350	Upper limit for one man transfer in a reasonable time frame

3. All cargo transfer devices shall be capable of maintaining full control of cargo items at all times. For manual, unaided cargo transfer, tethers and/or restraints will be required to affix the cargo item to the operator in order to inhibit inadvertent cargo motion. For manual, aided and automatic transfer methods, positive control (attachment) between the cargo item and transfer system will be required. Attachment may be provided by direct mechanical fasteners, snaps, hooks, cables or bungee, depending upon transfer design.

4. Restraint devices shall be capable of single hand attachment operations by a crewman in a pressurized space suit.

5. Adequate lighting shall be provided to ensure visibility in the immediate area of cargo handling and along the cargo transfer path as for crew transfer.

Item	Related Procedure: Man Unaided - SS (4-1)	Man Unaided - IVA (4-2)	Man Unaided - EVA (4-3)	Man Aided/Auto-SS (4-4)	Fluid - SS (4-5)
3.	X	X	X	X	
4.	X	X	X	X	
5.	X	X	X	X	

	Related Procedure				
	Man Unaided - SS	Man Unaided - IVA	Man Unaided - EVA	Man Aided/Auto-SS	Fluid - SS
	4-1	4-2	4-3	4-4	4-5
6. Individual cargo items within a general container shall be packaged to prevent movement or damage during transfer.	X	X	X	X	
7. Containers that enclose pressure vessels shall be connected to vents prior to and after transfer. The purpose of this requirement is to protect against package explosion and the localized concentration of hazardous gases.	X	X	X	X	
8. Cargo transfer systems across element interfaces shall not limit performance of crew transfer operations. Rails, guides or mechanisms utilized for manual aided or automatic transfer methods across an element interface shall be easily removed and normally stowed, or shall be outside the clear diameter required for crew transfer.				X	X
9. Cargo transfer systems shall not compromise emergency element interface undocking and pressure sealing capabilities. Provision for automatic or rapid disconnection of transfer system interfacing components will be required to maintain emergency capabilities.				X	X
10. Automatic cargo transfer systems shall be capable of checkout prior to operation. Checkout will confirm alignment of interfacing elements and system components, system control and transfer readiness and transfer path clearances.				X	X
11. Mobility aids for cargo transfer operations shall meet crew transfer criteria.	X	X	X	X	X
12. Backup crewman for interfacing element cargo transfer activities will monitor the operations of the active crewman at all times for IVA modes or hazardous cargo handling.		X	X		

	Related Procedure				
	Man Unaided - SS	Man Unaided - IVA	Man Unaided - EVA	Man Aided/Auto-SS	Fluid - SS
	4-1	4-2	4-3	4-4	4-5
13. The backup crewman will assist in control of cargo or crew restraints, tethers or umbilicals to prevent entanglement and be available for rescue operations if necessary.		X	X		
14. Mobility aids, cargo, and cargo transfer components shall be capable of being handled by a crewman in shirtsleeve or space suit. Surface materials shall be selected to ensure that high and low temperatures and conductivity are not limiting factors in using the equipment.	X	X	X	X	X
15. Crew restraint devices shall be provided along the cargo transfer path and at cargo transfer worksites to provide capability for crew positioning and stabilization. Restraints such as foot restraints, flex/rigid waist tethers and tether attach fittings shall affix to the crewman's lower body, legs and feet to permit freedom of movement of the upper torso, arms and hands. Crew restraint devices shall accommodate a 5 to 95 percentile crewman wearing a pressurized space suit. Development of worksite requirements will be dependent upon the reach capability of the 5 to 95 percentile crew population while restrained by lower torso mobility restraints. Section 1 defines anthropometric data while a crewman is wearing an A7L space suit pressurized to 3.8 psig.	X	X	X	X	X
16. Mobility aids and restraint devices shall be capable of withstanding any combination of loads which may be imposed by a crewman with or without a pressurized space suit for the cargo mass being handled unaided (reference requirement No. 1).	X	X	X	X	X
17. Communication capability shall be provided between crewman transferring cargo and control/monitoring crewman.	X	X	X	X	X

	Related Procedure				
	Man Unaided - SS	Man Unaided - IVA	Man Unaided - EVA	Man Aided/Auto -SS	Fluid - SS
	4-1	4-2	4-3	4-4	4-5
18. All cargo items requiring crewman handling shall have handles and/or handholds. In general, handholds shall be 1.0 inch in diameter, 3.0 inches long for single hand grasping and 2.0 inches away (or recessed) from surrounding structure (reference Appendix C, DS-208).	X	X	X	X	
19. An airlock will be provided to interface with the space environment or an unpressurized attached element. Volumetric criteria developed in the MSC report (DS-569) is shown on Figure 2-12, modified to reflect cargo packages.		X	X		
20. Equipment installations within crew mobility areas shall be capable for use for push-off of crewman with cargo. Based on the requirement (Section 1) that equipment be capable of withstanding multidirectional application of push-off or impact loads of 300 pounds, then a 500 pound load limit would be required for a crewman plus his largest unaided cargo mass.	X	X	X	X	X
21. Equipment susceptible to damage or that is hazardous to cargo transfer operations shall be separated from cargo transfer passages and color-coded or placarded.	X	X	X	X	X
22. All hatches utilized for cargo transfer between elements shall be capable of operations from either side of the hatch as for crew transfer (Section 1.0).	X	X	X	X	X
23. Windows shall be provided in hatches or doors along opening into cargo transport paths. This permits crew observation of operations and viewing prior to ingress whenever hatches are closed.	X	X	X	X	X
24. Cargo transfer operations shall meet acceptable noise levels as defined in Section 1.0.	X	X	X	X	X

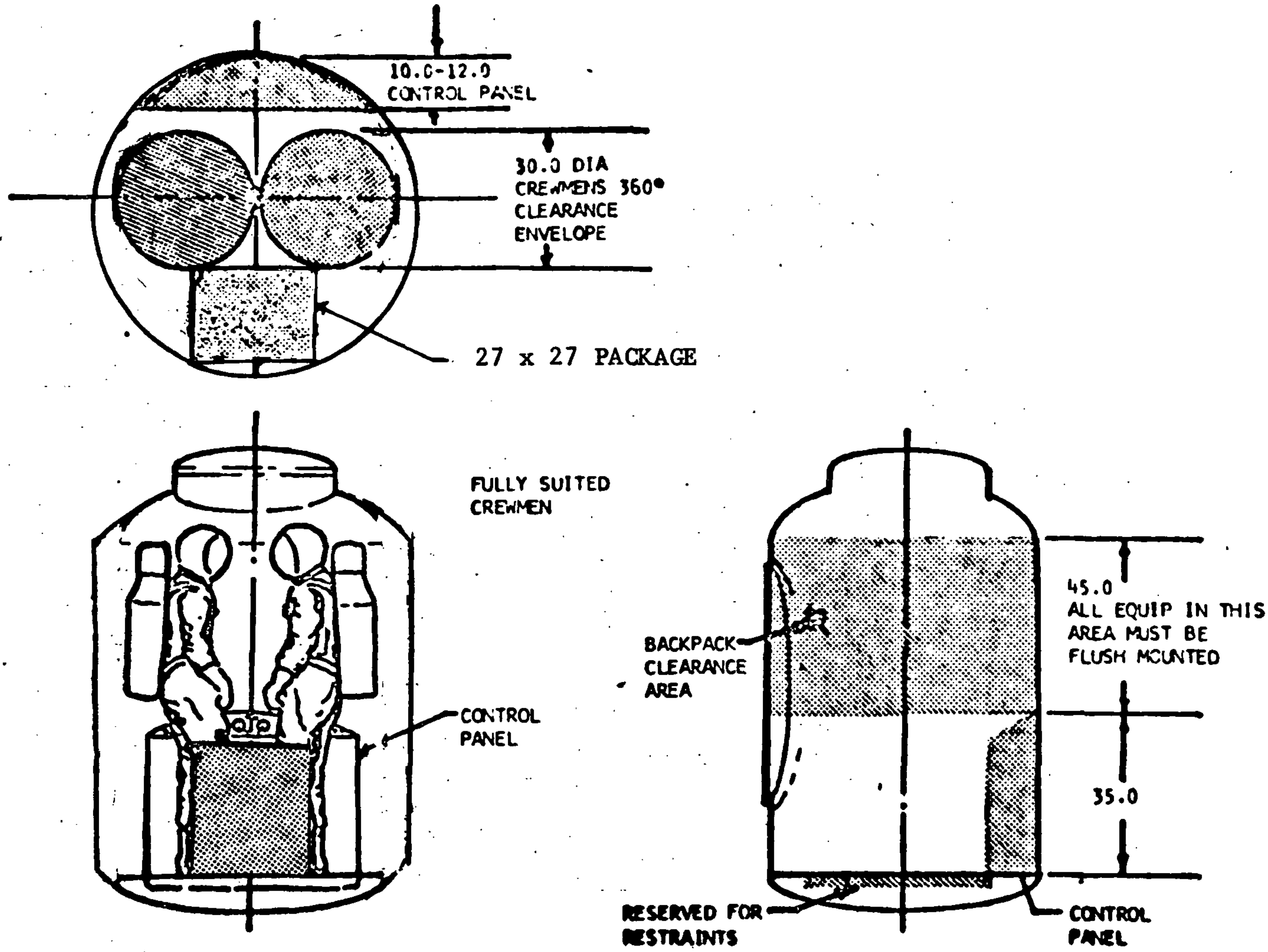


Figure 2-12. Airlock Volumetric Allotment Crew - Equipment

Related Procedure				
Man Unaided - SS	Man Unaided - IVA	Man Unaided - EVA	Man Aided/Auto-SS	Fluid - SS
4-1	4-2	4-3	4-4	4-5
X	X	X	X	X

25. Passageways/aisles shall be capable of accommodating cargo transfer operational requirements. Section 1.0 presents primary passageway criteria for crew transfer only. Sizing of cargo passageways is a function of cargo items plus crew envelope or mechanical device plus clearance. Some passages, especially in space stations, may be discriminatory between primary cargo routes and secondary routes (such as crew quarters aisles). Table 2-3 reflects a survey of largest package sizes from element studies, and Figure 2-13 presents overall envelope considerations and dimensions. These data are summarized in Table 2-4.

Table 2-3. Cargo Package Survey

Package Size Survey Data	Area (in.)	Dia. (in.)
MSC guidelines and constraints for MSS	40x40(x50)	57
Maximum for hand maneuvering	30x30	43
Maximum for pushing directly in front of crewman	20x25	32
EOS maximum cargo package	20x20	28
RAM maximum cargo package	25x25	35
MSS maximum cargo package	27x27	38
Note: Data do not include clearance		

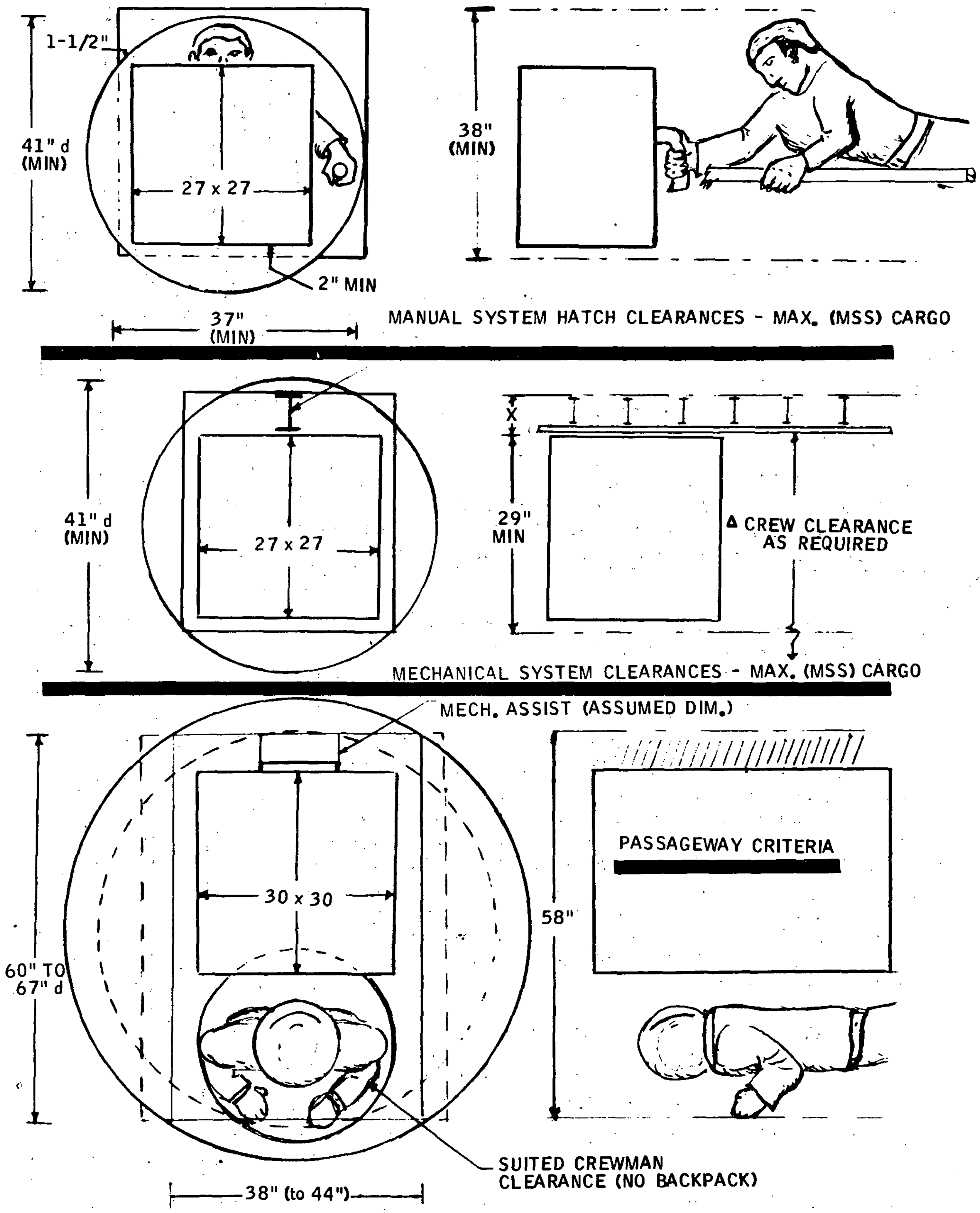


Figure 2-13. Cargo Transfer Sizing

Table 2-4. Summary of Cargo Clearances

Hatch Size	Diameter-inches (minimum)	Area-inches (minimum)
Manually unaided	41	37x38
Manually aided (plus mechanical system clearance)	(41)	(29x30)
Primary Passageway	60	38x58

Note: Dimensions include 3-inch circumferential minimum clearance, and are for largest package (MSS and MSS interfaces). Other elements may be reduced for package sizes on Table 2-3.

Requirement	Man Unaided - SS (4-1)	Man Unaided - IVA (4-2)	Man Unaided - EVA (4-3)	Man Aided/Auto-SS (4-4)	Fluid - SS (4-5)
26. Verification of habitable atmosphere prior to shirtsleeve entry into mated elements for cargo transfer shall meet crew transfer requirements (Section 1.0).	X	X	X	X	X
27. Audio and visual alarms shall be provided for cargo transfer devices. This shall include warning to prevent inadvertent collision with crew members along passages, and in the event of hazardous failure modes the device shall be designed to fail safe. Audio alarms shall be of flashing light type and used primarily to alert the crew to the presence of a dangerous or potentially dangerous situation. Included is automatic initiation of fault isolation and independent redundant sensors.	X	X	X	X	X
28. The capability shall be provided to insure that passageways (hatchways of normally uninhabited element) are free of obstructions so that cargo movement will not be inhibited. Crew must also be able to achieve access to cargo which might be obstructing the passage.	X	X	X	X	X
29. Vent connections shall be provided for use with fluid containers on each side of the element interface.	X	X	X	X	

Requirement	Related Procedure				
	Man Unaided - SS	Man Unaided - IVA	Man Unaided - EVA	Man Aided/Auto-SS	Fluid - SS
	4-1	4-2	4-3	4-4	4-5
30. All Fluid lines shall be secured to the requirements of the fluids being transferred.					X
31. Hazardous fluid lines shall be double-walled and isolated from power wires and each other (see Appendix C, DS-208). Damage to one line will not cause propagation to another.					X
32. GH_2 and GO_2 lines shall be barriered or isolated from each other or transfer of fluids shall not be done simultaneously (reference Appendix C, DS-208).					X
33. A method shall be provided whereby fluid interfaces can be verified to be free of liquids that may contaminate the surrounding environment prior to disconnect.					X
34. Fluid couplings shall be operable by a crewman in a pressurized suit.					X
35. Leak-detection sensors shall be provided when transferring any contaminable fluid. Vent systems may be required to protect against contamination for plumbed transfer.	X	X	X	X	X

Functional Requirements Applicability

Table 2-5 summarizes the functional requirements for packaged cargo transfers and identifies their applicability by categories of element pairs. All of the functional requirements pertaining to fluid transfer are applicable for each approach for all the applicable element pair. A listing of the element pairs in each category follows.

Manned-to-Unmanned, Manual Unaided - SS and IVA
Manned-to-Unmanned, Manual Aided/Auto - SS and IVA

EOS/space-based tug
EOS/RAM attached EOS
EOS/RAM detached EOS
EOS/retrievable resupply satellite
EOS/EO resupply modules
EOS/low EO MSS
EOS/CPS CLS
EOS/RNS CLS
EOS/OLS
EOS/OPD
Space-based tug/space-based tug
Space-based tug/retrievable resupply satellite
Space-based tug/EO resupply modules
Space-based tug/low EO MSS
Space-based tug/CPS CLS
Space-based tug/RNS CLS
Space-based tug/OLS

Manned-to-Unmanned, Manual Unaided - SS
Manned-to-Unmanned, Manual Aided/Auto - SS

Low EO MSS/RAM attached MSS
Low EO MSS/RAM detached MSS
Low EO MSS/EO resupply modules
Low EO MSS/low EO MSS
OLS/OLS
OPD/OPD

Manned-to-Unmanned, Manual Unaided EVA
Manned-to-Unmanned, Manual Aided/Auto EVA

EOS/Retrievable Resupply Satellite
Space Based Tug/Retrievable Resupply Satellite

Table 2-5. Functional Requirements Applicability

Functional Requirements	Element Pairs							
	Manned-to-Unmanned						Manned-to-Manned	
	Manual Unaided SS	Manual Unaided IVA	Manual Unaided EVA	Manual Aided/ Auto SS	Manual Aided/ Auto IVA	Manual Aided/ Auto EVA	Manual Unaided SS	Manual Aided/ Auto SS
1. Two crewmembers for IVA, EVA and hazardous shirtsleeve operations	X	X	X	X	X	X	X	X
2. Backup crewman's duties	X	X	X	X	X	X	X	X
3. Crew mobility aids and restraint devices	X	X	X	X	X	X	X	X
4. Equipment installation capable of crew push-off or impact loads	X	X	X	X	X	X	X	X
5. Equipment susceptible to damage to be color-coded or placarded	X	X	X	X	X	X	X	X
6. Lighting along all transfer routes	X	X	X	X	X	X	X	X
7. Hatch operations	X	X	X	X	X	X	X	X
8. Windows in hatches	X	X	X	X	X	X	X	X
9. Noise levels	X	X	X	X	X	X	X	X
10. Airlock capabilities		X	X		X	X		
11. Communication capabilities	X	X	X	X	X	X	X	X
12. Space suit integrity verified		X	X		X	X		
13. Passageways/aisles	X	X	X	X	X	X	X	X
14. Atmospheric monitoring	X	X	X	X	X	X	X	X
15. Alarms	X	X	X	X	X	X	X	X
16. Ensure passageway/access is unobstructed	X	X	X	X	X	X	X	X
17. Acceptable weight (mass) and dimension of cargo items for manual handling	X	X	X	X	X	X	X	X
18. Cargo transfer devices maintain full control				X	X	X		X
19. Cargo items packed to prevent damage	X	X	X	X	X	X	X	X
20. Transfer systems not compromise on undocking operations				X	X	X		X
21. Containers enclosing pressure vessels to be vented	X	X	X	X	X	X	X	X
22. Transfer systems capable of checkout prior to usage				X	X	X		X
23. Transfer systems not limit performance of transfer operations				X	X	X		X
24. Handles and handholds on all cargo requiring handling	X	X	X	X	X	X	X	X

Manned-to-Manned, Manual Unaided - SS
Manned-to-Manned, Manual Aided/Auto - SS

EOS/EOS
EOS/space-based tug
EOS/RAM attached EOS
EOS/EO resupply modules
EOS/low EO MSS
EOS/OLS
Space-based tug/space-based tug
Space-based tug/low EO MSS
Space-based tug/OLS
Low EO MSS/RAM attached MSS
Low EO MSS/low EO MSS
OLS/OLS

Current resupply requirements for the modular space station indicate that the control moment gyros (CMG's), 38 inches diameter, are the largest resupply item. Therefore, a hatch opening greater than 41 inches will accommodate both this and the crew transfer requirement of 30-inch diameter. This and other significant element requirements are presented in Table 2-6. It should be noted that the attached element operations activity discusses the cargo items that would need to pass through interfacing element hatches. The table refers to these requirements and adds a 3-inch minimum for a transfer system clearance. This does not include any additional clearance for packaging or ease of clearance.

Table 2-6. Significant Vehicle Requirements Model

Cargo Transfer Requirement	Rationale	Other Activity Impact
GENERAL (EOS, RAM, TUG, MSS)		
View windows in pressure hatches	Shirtsleeve viewing of IVA/EVA operations, and viewing for checkout prior to ingress	Satisfies attached element operations requirement for checkout
Interface hatchways, controls and displays	Interface tunnel pressure and checkout. Unmanned element checkout and/or subsystem activation	Satisfies attached element operations requirement for checkout
EOS AND TUG (MANNED)		
IVA/EVA capability, IVA/EVA pressure suits and support for at least two crew members	Current analyses indicate satellite resupply/maintenance will require IVA/EVA	None
HATCH SIZING (MIN. DIA.)*		
Crew and cargo - EOS - 30 in. dia.	Standard cargo container 22 x 22 x 18 is largest item	Crew transfer - crew only requires 30-in. dia. (minimum)
Crew and cargo - MSS - 41 in. dia.	38 in. dia. for cargo plus 3 in. minimum for transfer system	41 in. min. (attached element operations)
Crew and cargo - RAM - 38 in. dia.	35 in. dia. for cargo plus 3 in. minimum for transfer system	35 in. min. (attached element operations)
Crew and cargo - Tug - 41 in. dia.	Same as MSS	Same as MSS

* Ground operations not considered in this study. See Figure 2-13 and Table 2-4.

2.7 DESIGN INFLUENCES AND PREFERRED APPROACH SELECTION

Packaged cargo transfer and the fluid cargo transfer must be treated separately for preferred approach selection. The process for selection of a preferred approach for both of the cargo transfer activities begins with a relative comparison of the approaches, disregarding any element pair unique considerations. This relative comparison involves the analysis of advantages and disadvantages of each approach on a factor by factor basis as shown in Tables 2-7 and 2-8. This comparison then leads to a definition of element pair selection factors and a preferred approach for each of these selection factors. The selection factors and their preferred approaches are described in Tables 2-9 and 2-10.

COMPARISON FACTORS

Bulk Cargo Transfer

For packaged cargo transfer, the crew operational modes are shirtsleeve and IVA, as in crew transfer. EVA is considered a possible alternate for those element pairs where IVA was selected, but was not evaluated. For IVA modes, the size of the airlock would be severely impacted by the need to include the cargo in the airlock with the crew. Including just one (maximum manual-unaided size) package in the airlock requires about a 25 percent increase in volume over the minimum for two crew.

The cargo size and weight also has considerable impact on the approach selection as a direct relationship with human capabilities. Figure 2-14 summarizes human performance capabilities for cargo handling. The package volumes and masses indicated as being capable of manual handling would apply to the manual unaided approach, and those which are definitely outside the range of handling capability of a man apply to the manual aided or automated approaches.

The quantity of cargo items to be transferred also impact the selection of an approach. The larger the quantity of items, the more one is driven to an automated system. It is only logical that men traversing back and forth across a transfer route consume more time than an automated transfer system. The time consumed is, of course, longer as the travel distance increases, as discussed below. The quantity of cargo transferred also is a factor in time consumed.

The distance involved in the transport of the cargo impacts the selection of the approach in that a large transfer distance drives to a manual aided or an automated system. This is especially true if large quantities of cargo are involved.

The travel distance and the quantity of cargo items are more flexible parameters than that of cargo size/weight of the cargo. All three depend somewhat on one another but need to be singled out for evaluation purposes.

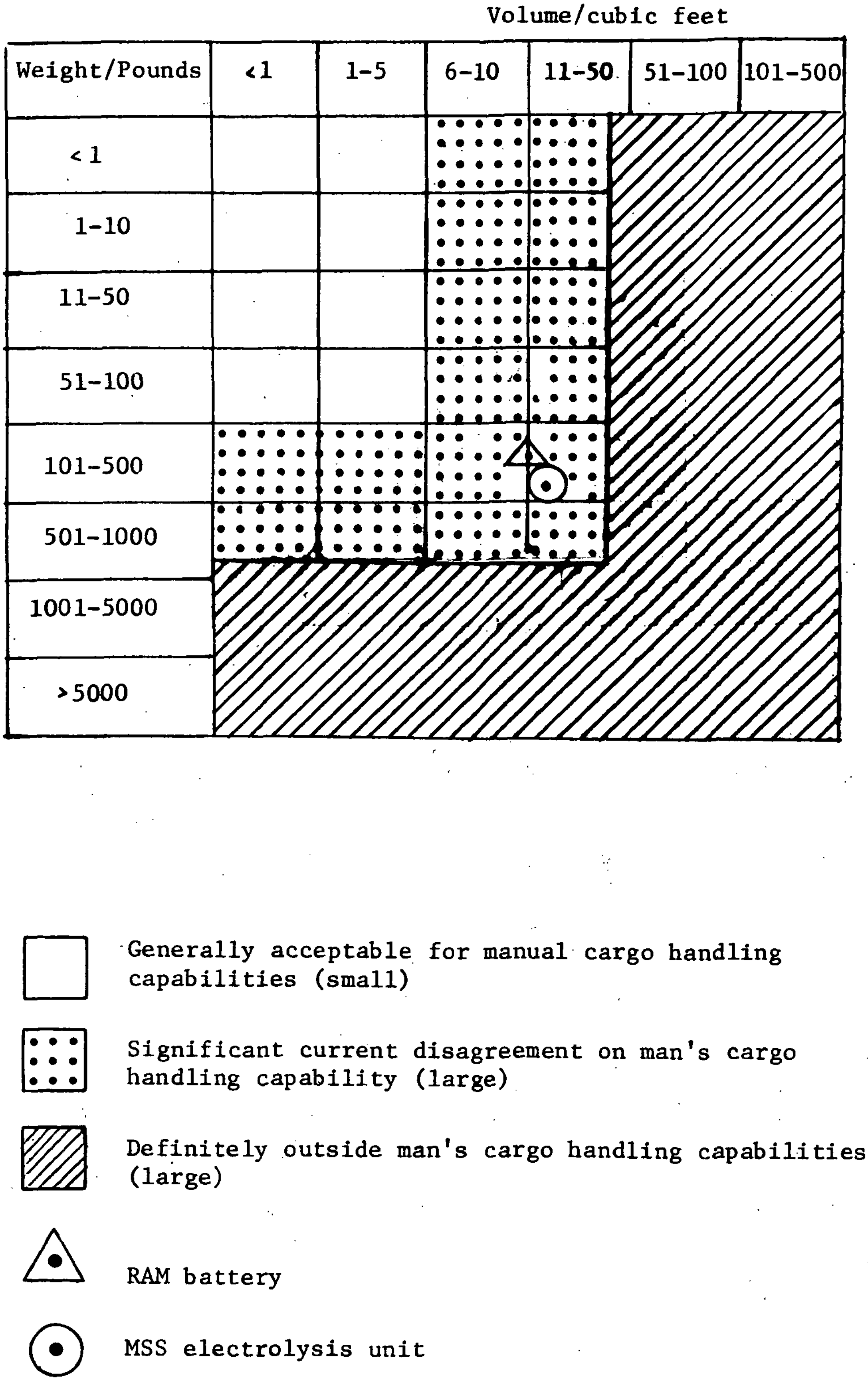


Figure 2-14. Human Cargo Handling Capabilities

With evaluation criteria one cannot say when there are too many manual unaided transfer trips and when manual aided methods must begin. Similarly, it is difficult to define when the manual aided system is too slow and an automated system must be used. It appears clear that for small cargo items, small quantities, and a short distance for transfer, the optimum cost effective approach is manual unaided. However, cost comparisons are more difficult after this level. The time differences between systems become more important as travel distances and quantities increase. Then time becomes a cost evaluation parameter as it impacts other mission requirements.

Fluid Cargo Transfer

For fluid cargo transfer an evaluation of the number of fluids to be transferred per element pair has concluded that few, at most, will be transferred. This indicates that the driving factor, namely flexibility, for the manual temporary approach becomes an insignificant driver. Therefore, this approach has been eliminated for subsequent approach selections. The main comparison factor which eliminates this approach are the safety considerations involved in transferring hazardous fluids and the obstruction of the interface hatchway. This obstruction could cause difficulty in hatch closing in emergency conditions, both with respect to interference with hatches and the amount of fluid/gas which would be vented to the habitable environment. Figure 2-15 shows a method for which the manual plumbed lines and connects would accommodate shirtsleeve access and space environment venting. It should be noted that the automatic plumbed interconnect concept does not involve plumbed lines or connection interfaces in a habitable environment.

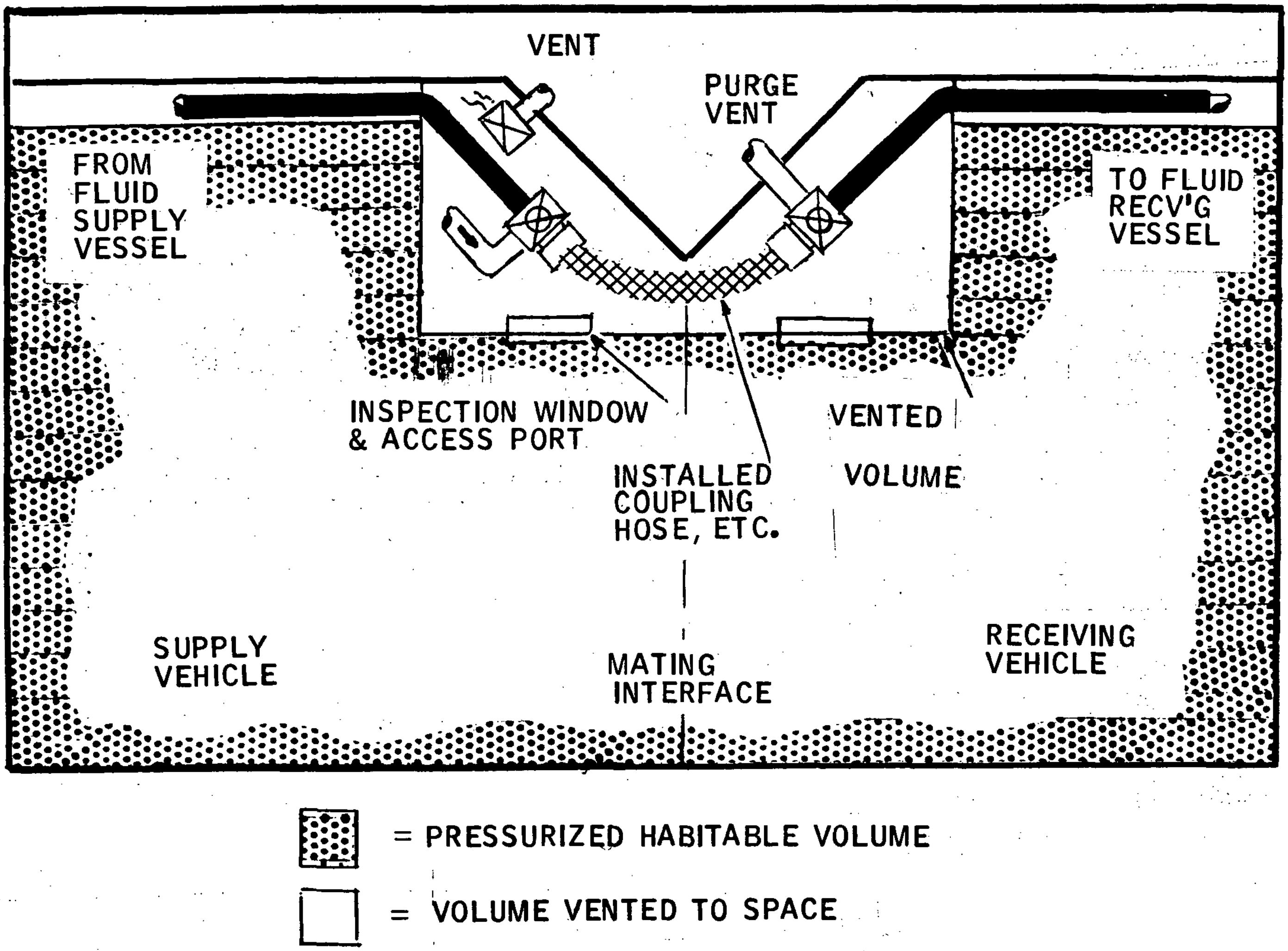


Figure 2-15. Manual Plumbed Fluid Connection

Table 2-7. Packaged Transfer Approach Comparison

COMPARISON FACTORS	MANUAL UNAIDED	MANUAL AIDED	AUTOMATED
Technology Status	Present	Present	Present
Checkout and Maintenance	Maintenance Free, Minimum Checkout	Some	Specialized Maintenance Checkout Required Redundant Method Required
Commonality			
. Accommodating to Crew Transfer	Good	Good	Poor
. Adaptability/Sensitivity	Good	Fair	Fair
Relative Cost	Low	Medium	High
Safety			
. Transfer in Hazardous Environment (Unpress., High Radiation)	Poor	Poor	Good
. Normal Environment	Good	Good	Good
Additional Factors			
. Electrical Power	Not Required	Not Required	Required
. Reliability	High	Medium	Low
. Cargo Control	Positive	Variable	Positive
. Mobility Range	Wide	Restricted	Restricted
. Operational Complexity	Simple	Complex	Simple
. Weight	Low	Medium	High
. Human Effort	High	Medium	Low
. Cargo Size Accommodated	Small	Large	Large
. Two Way Simultaneous Transfer	Yes	Requires Parallel System	Requires Parallel System
. Interface Obstruction	No	Yes	Yes
. Speed of Transfer	Low	Medium	High

Table 2-8. Fluid Transfer Approach Comparison

COMPARISON FACTORS	MANUAL TEMPORARY	MANUAL PLUMBED	AUTOMATIC PLUMBED
Technology Status	Present	Present	Advanced
Relative Cost	Medium	Medium	High
Checkout and Maintenance	Low	Low	High
Commonality/Flexibility	Good	Acceptable	Poor
Safety			
. Use in Hazardous Environment	Poor	Poor	Good
. Interface Obstruction	Poor	Good	Good
. Hazardous Fluids	Bad	Good	Good
Additional Factors			
. Human Effort	High	Low	None

PREDOMINANT FACTORS

Bulk Cargo Transfer

The characteristics of the bulk cargo transfer operation that influence the preferred approach selection most are (1) cargo size, (2) quantity of cargo, (3) travel distance, and (4) crew accessibility/operating mode. Table 2-9 indicates the preferred approach for these key factors.

Cargo Size

Obviously if the size of the cargo is small the simplest, least expensive, and least costly is manual unaided. However, as the cargo size approaches or exceeds safe manual transfer an aided system is preferred. Only in the extreme case would an automated concept be selected. Analyses of cargo to be transferred indicate that all cargo can be transferred without resorting to an automated concept.

Cargo Quantity

If the quantity of transfer item is small and the size is also within mans capability the manual-unaided approach is preferred. As the traffic increases, regardless of the cargo size the trend is to aided and ultimately automatic. The preference is based strictly on the crew work load required for the transfer.

Travel Distance

This factor is also related to the resultant work load on the crew. For short distances manual is preferred. As the distance increases an aided system is preferred. For example, cargo transfer from a resupply module to the MSS could entail significant distance through multiple modules. An aided system would definitely be preferred.

Crew Mode

If the transfer operation can be accomplished in a shirtsleeve environment then the other factors govern the preferred approach. If either EVA or IVA is required then an aided or automatic approach is preferred. The aided concept is compatible with EVA restraint requirements and IVA crewman flexibility/dexterity limitations.

Fluid Transfer

The predominant factor in determining the preferred concept for fluid transfer is the interface configuration and the crew accessibility and is summarized in Table 2-10.

Shirtsleeve Accessibility

If the mating geometry provides a shirtsleeve environment the manual-plumbed mode is preferred. It offers maximum accessibility to the hardware for maintenance and checkout and can be made the most reliable and safe.

Table 2-9. Cargo Transfer

Packaged Transfer Approach Selection Factors

COMMONALITY INFLUENCE (ACROSS ACTIVITIES)

- o Crew Transfer - Major Influence
- o Attached Element Operations - Major Influence
- o Other Activities - No Significant Influence

SELECTION FACTOR	APPROACH PER FACTOR	RATIONALE (APP. COMPARISON FACTORS)
Cargo Size - Small	Manual Unaided	Cost, Checkout and Maintenance, Reliability, Etc.
- Large	Manual Aided	Required for Large Cargo, Cost, Checkout and Maintenance
Cargo Quantity - Small	Manual Unaided	
- Medium	Manual Aided	Human Effort
- Large	Automated	
Travel Distance - Short	Manual Unaided	Cost, Checkout and Maintenance, Reliability, Etc.
- Long	Manual Aided, Automated	Human Effort
Crew Mode - Shirtsleeve	Either	-------------------
- IVA	Man Aided, Automated	Small Cargo, Safety
- EVA	Man Aided, Automated	Small Cargo, Safety

Table 2-10. Cargo Transfer

Fluid Transfer Approach Selection Factors

NOTES:

1. Manual temporary rejected for approach selection - safety is a major driver, flexibility not a significant driver (few fluids). (See approach comparison)

2. Commonality influence (across activities)

   - Crew transfer, attached element operations and mating - significant influence

   - Other activities - no significant influence

SELECTION FACTOR	APPROACH PER FACTOR	RATIONALE
Mating Geometry		
- Shirtsleeve Mode	Manual Plumbed	Checkout, Maintenance, Cost, Technology
- IVA/EVA Mode	Manual Plumbed, Automated	Hazardous Environments

Temporary plumbing would result in a hazardous situation and is not compatible with the safety requirement for quick emergency separation or element to element isolation.

IVA Accessibility

Either the manual-plumbed or automated approaches are applicable. Automated plumbing interconnects are discussed in the propellant transfer section, 3.0, and are feasible. However, they are complex mechanisms and could require significant maintenance. Unless the element pair interface involves two non-mannable elements, e.g., tug and satellite, manual plumbed is preferred.

PREFERRED APPROACH SELECTION

Bulk Cargo Transfer

Each element pair involved in cargo transfer operations was analyzed to determine the preferred approach. Table 2-11 presents the detailed evaluation for the element pairs for bulk or packaged cargo transfer. The analysis of cargo/resupply items included in Appendix A indicates that most of the cargo items can be transferred by manual unaided means. The quantitized information presented there is of essential value for determining the selected approach and the associated requirements. For example, the size of cargo items that must be transferred through a hatch will dictate the size of that hatch if the items are larger than the requirements dictated by crew transfer. Additionally, if a transfer system must be put across the hatchway, then its envelope must not interfere with that required for crew transfer.

The inclusion of resupply modules in the space program directly affects the selections. It is assumed that this element will be used to resupply orbital facilities such as the MSS, OPD, CPS, RNS, and OLS. Thus, the cargo transfer interface between these facilities and the logistics vehicles is simplified. Tug cargo transfer interfaces are reduced only to replenishment of their own consumables.

The one cargo interface that requires unique handling is the satellite with its logistics vehicles. The EOS to satellite interface requires some type of capture device to initially "mate" with the satellite. Either a second device (manipulator) could be used to interchange modules automatically or the first device (manipulator) position it at a pressure hatch and the interchange be accomplished manually in an IVA/EVA mode. The same options apply in the case of a manned tug servicing a satellite. However, unmanned tug servicing of a satellite will require remote controlled manipulator operations. From a commonality standpoint an automatic resupply concept would appear to be favored for satellites. However, satellites are usually unique, dedicated configurations for specific reasons. Therefore, each satellite must be individually evaluated and design trades as well as operational trades must be conducted to define the preferred approach.

Table 2-12 summarizes the selections for bulk cargo transfer. Only the MSS, OLS and resupply modules require manual and cargo transfer provisions.

Table 2-11. Cargo Transfer

Packaged Transfer Approach Selection

	FACTORS				APPROACH PER FACTOR					
ELEMENT PAIRS	CREW MODE	CARGO SIZE	CARGO QTY	DISTANCE	CREW MODE	CARGO SIZE	CARGO QTY	DISTANCE	SELECTED APPROACH	RATIONALE
EOS/EOS	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capability
EOS/S.B. Tug	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capability
EOS/RAM Att. EOS	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capability
EOS/RAM Det. EOS	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capability
EOS/Satel.	IVA or Re-mote	S	S	S	MA Auto	MU MA	MU MA	MU	MA Auto	Approach is determined by satellite configuration
EOS/EO Resup. Mods.	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capability
EOS/Low EO MSS	SS	S	S	L	-	MU	MU	MA	MU	Cargo within man's capability and transfer time is not a significant driver
EOS/CPS-CLS	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capability
EOS/RNS-CLS	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capability
EOS/OLS	SS	S	S	L	-	MU	MU	MA	MU	Cargo within man's capability and time is not a significant driver
EOS/OPD	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capability
S.B. Tug/S.B. Tug	SS	L	S	S	-	MA	MA	MU	MA	Cargo within man's capability
S.B. Tug/Satel.	IVA EVA	S	S	S	MA Auto	MU MA	MU	MU		Approach is determined by satellite configuration
S.B. Tug/EO Resup. Mods.	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capabilities

Table 2-11. Cargo Transfer

Packaged Transfer Approach Selection (Continued)

	FACTORS				APPROACH PER FACTOR					
ELEMENT PAIRS	CREW MODE	CARGO SIZE	CARGO QTY	DISTANCE	CREW MODE	CARGO SIZE	CARGO QTY	DISTANCE	SELECTED APPROACH	RATIONALE
S.B. Tug/Low EO MSS	SS	S	S	L	-	MU	MU	MA	MU	Cargo within man's capabilities. Time and human effort saved by an automated system is not a significant driver
S.B. Tug/CPS-CLS	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capability
S.B. Tug/RNS-CLS	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capability
S.B. Tug/OLS	SS	S	S	L	-	MU	MU	MA	MU	Cargo within man's capability. Time not a significant driver
S.B. Tug/OPD	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capability
EO MSS/RAM Att. MSS	SS	L	MS	L	-	MA	MA	MA	MA	Cargo beyond man's capability and rapid
EO MSS/RAM Det. MSS	SS	L	S	L	-	MA	MA	MA	MA	cargo transfer not required; complexity
MSS/EO Resup. Mods.	SS	L	L	L	-	MA	Auto	MA	MA	of automation not warranted
Low EO MSS/Low EO MSS	SS	L	L	L	-	MA	Auto	MA	MA	Same as MSS/EO Resup. Mods. (Rapid transfer not needed)
OLS/OLS	SS	L	L	L	-	MA	Auto	MA	MA	Same as MSS/EO Resup. Mods. (Rapid transfer not needed)
EOS/G.B. Tug	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capability
EOS/G.S. MSS	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capability
EOS/EO Shuttle CPS	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capability
EOS/Tug Man LPS	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capability

Table 2-11. Cargo Transfer

Packaged Transfer Approach Selection (Continued)

ELEMENT PAIRS	FACTORS: CREW MODE	FACTORS: CARGO SIZE	FACTORS: CARGO QTY	FACTORS: DISTANCE	APPROACH PER FACTORS: CREW MODE	APPROACH PER FACTORS: CARGO SIZE	APPROACH PER FACTORS: CARGO QTY	APPROACH PER FACTORS: DISTANCE	SELECTED APPROACH	RATIONALE
G.B. Tug/G.B. Tug	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capability
G.B. Tug/S.B. Tug	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capability
G.B. Tug/R.R. Sate.	IVA EVA	S	S	S	MA	MA	MU	MU	MA Auto	Approach is determined by satellite configuration
G.B. Tug/EO Resup. Mods.	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capability
G.B. Tug/G.S. MSS	SS	S	S	L	-	MA	MU	MA Auto	MU	Cargo within man's capability; rapid cargo transfer not required
G.S. MSS/EO Resup. Mods.	SS	L	L	L	-	MA	MA	MA	MA	Cargo beyond man's capability; heavy traffic
Tug Unmanned LPS/EO Resup. Mods.	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capability
Tug Manned LPS/EO Resup. Mods.	SS	S	S S	S	-	MU	MU	MU	MU	Cargo within man's capability
S.B. Tug/G.S. MSS	SS	S	S	L	-	MU	MU	MA	MU	Cargo within man's capability; rapid cargo transfer not required
S.B. Tug/EO Shuttle CPS	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capability
S.B. Tug/Tug Man LPS	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capability
RAM Att. MSS/G.S. MSS	SS	L	M	L	-	MA	MA	MA	MA	Same as RAM Att. MSS/Low EO MSS

Table 2-11. Cargo Transfer

Packaged Transfer Approach Selection (Continued)

ELEMENT PAIRS	FACTORS: CREW MODE	FACTORS: CARGO SIZE	FACTORS: CARGO QTY	FACTORS: DISTANCE	APPROACH PER FACTOR: CREW MODE	APPROACH PER FACTOR: CARGO SIZE	APPROACH PER FACTOR: CARGO QTY	APPROACH PER FACTOR: DISTANCE	APPROACH PER FACTOR: SELECTED APPROACH	RATIONALE
RAM Det. MSS/G.S. MSS	SS	L	S	L	-	MA	MA	MA	MA	Same as RAM Att. MSS/Low EO MSS
G.S. MSS/G.S. MSS	SS	L	L	L	-	MA	Auto	MA	MA	Same as Low EO MSS/Low EO MSS
OLS/Tug Unmanned-LPS	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capability
OLS/Tug Manned-LPS	SS	S	S	S	-	MU	MU	MU	MU	Cargo within man's capability

NOTES:

SS = Shirtsleeve
L = Large, Long
S = Small, Short
MA = Manually Aided
MU = Manually Unaided

Table 2-12. Bulk Cargo Transfer Summary

Approach	Applicable Element Interfaces
Manual Unaided	• All EOS interfaces except some satellites* • All Tug interfaces except some satellites*
Manual Aided	• MSS Internal • MSS - RAM's • MSS - Resupply Modules • OLS - Resupply Modules • OLS Internal • Some satellite interfaces*
Automated	• Some satellite interfaces*
*Preferred approach is dependent upon satellite configuration	

Fluid Transfer

As pointed out previously the manual-temporary approach is undesirable. In this approach fluid transfer lines occupy crew transfer space, the lines are exposed to collisions with either cargo or crew, emergency separation is not feasible, element isolation during an emergency requires disconnects, and purge and vent procedures are complex. The automatic plumbed approach, though feasible, is complex and costly, limits flexibility, and requires more complex maintenance. Therefore, the preferred approach for fluid transfer was manual plumbed where feasible. Manual plumbed was not feasible in some satellite interfaces and obviously between two unmanned elements. Table 2-13 summarizes the applicability of the preferred approaches.

Figure 2-12 illustrated a concept for manual plumbed interconnect. Adequate space between the pressure bulkheads of mated vehicles (assuming any of the four docking concepts evaluated in Appendix A is used) is available for installation of this concept. The rigid lines on both elements are outside the pressure shell of both elements. These lines are terminated in valves and connectors between the end hatch of a module and the docking port mating interface. A coupling is manually installed between the two stubbed lines for fluid transfer. A pressure sealed cover is installed over the interconnection.

Table 2-13. Fluid Transfer Preferred Approach

Approach	Applicable Element Interfaces
Manual Temporary	None
Manual Plumbed	• All EOS interfaces except some satellites[1] • All MSS interfaces • All manned Tug interfaces except some satellites[1] • All resupply modules[2] • All OLS interfaces • Some satellite interfaces[1]
Automated	• Some EOS--satellite interfaces[1] • All unmanned tug to unmanned element interfaces • Some tug to satellite interfaces[1] • Some satellite interfaces[1]
1. Satellite interface preferred approach is dependent upon the satellite configuration and the bulk cargo transfer concept 2. Does not include propellant resupply modules which are discussed in section 3.0 and are automated dedicated interconnects	

This concept does not prohibit element isolation in the event of an emergency because the interconnect is between the hatches of the two elements. Crew passage is not hampered because the interconnect is intentionally installed at the outer periphery of the docking device to facilitate venting upon the completion of the fluid transfer. During the transfer the miniature compartment can be vented to space thus providing an additional margin of safety in the event of a failure in the interconnect.

Alignments are not critical and multiple fluid interconnects can readily be accommodated. Standardization is also not required in all elements because the coupling can be varied for different fluids and fluid lines. Note that only one element must be manned. The receiver element need not even be mannable.

DESIGN INFLUENCES

Except for staellite and unmanned-to-unmanned element interfaces the impact on the various elements to accommodate bulk cargo transfer is minimal. Manual-aided provisions should be included in the MSS, OLS, RAM and resupply modules. All other transfers can be handled manual unaided. However, cargo transfer operations are the primary influence on interface hatch design. The docking/berthing port inside diameter must be large enough to accommodate all objects that are anticipated to pass through this opening. With regard to the earth orbit resupply module (cargo module) the largest items for each subsystem expected to be delivered to an MSS is presented below.

MSS Large-Dimension Items Summary

Subsystems	Comment
G&C	CMG's 38-inch diameter
Crew provisions	All items are small
EPS	Electrolysis unit 24-inch by 24-inch by 48-inch. Solar panels replaced on a special orbiter flight not using the cargo module.
ECLSS	Electrolysis unit 30-inch by 30-inch by 26-inch. If radiator panels need replacement the module is removed and returned to earth.
Communications	All items are small assemblies except high-gain antenna. If antenna needs replacement either the entire module will be returned or the antenna package will be replaced with the aid of the manipulator.

The largest item is the ECLSS electrolysis unit. However, further investigation reveals that this unit can be "broken down" into subassemblies thus removing it as a driver for hatch opening clearance. The next largest item is a CMG, 38 inches in diameter. At 38 inches, the CMG is substantially reduced is size from its optimal size to enable it to fit in the space available in the MSS. Although there is still some potential for reduction in size, this amounts to only one or two inches and severely compromises performance. Therefore a hatch opening of at least 38 inches, plus clearance of 3 inches minimum, is required. This requirement applies to the MSS and, since the MSS is resupplied by an earth orbit resupply module, the hatch opening of the resupply module must also be 41 inches.

An examination of the RAM hatch opening shows that nearly all items anticipated to pass through the hatch opening are of a small dimension. One item that appears to be the largest single assembly needing replacement would be a CMG. Its dimensions are approximately 2 feet by 2 feet by 3 feet. This dimension would drive the diameter of a circular hatch opening to 38 inches including clearance. Consideration was given to experiment equipment and assemblies that would need to be replaced. The largest experiment items either belonged to an attached RAM, wherein a failed unit would not be replaced (the RAM would be returned to ground), or the items were so large as to rule them out as practical units to drive the tunnel opening dimension.

Addressing the issue of the RAM-to-MSS interface and the attached RAM-to-EOS interface, the largest item expected to pass through the tunnel is a standardized cargo container. This container size (from DS 209) is 22 inches by 22 inches by 18 inches. The hatch opening to accommodate this size is, required to be at least 31 inches (including 3 inches for clearance).

In consideration of the close correlation of these dimensions, and in the interests of standardization for EOS-RAM, RAM-MSS, and Cargo Module interfaces, all elements are influenced toward the 41 inch diameter (37 inch by 38 inch rectangular) opening. Further compatibility in this standard exists with respect to the alternate approaches--manual, manual-aided or automatic, as shown in Figure 2-13, where 41 inches meets all minimum criteria.

Automated interchanges between unmanned elements and with some satellites will be required. However, these operations will be very infrequent and the device(s) should be a kit installation on the logistics vehicle.

The manual-plumbed concept is a significant design influence on all elements and their docking concept. In the section on mating it was pointed out that a common docking system was feasible. Similarly the generic fluid interconnect concept discussed above illustrates that commonality across elements is feasible. Future studies on docking system optimization/standardization should incorporate a common fluid interconnect concept with at least the operational characteristics of the one developed in this study.

Major design influences are summarized in Table 2-14. All of these requirements are compatible with the crew transfer activity. Hatch sizes are based upon the unique cargo transfer requirements. It is quite significant that all four of the docking concepts evaluated in the mating activity analysis can accommodate various hatch sizes. It is the utilities interconnect and the mating interface that requires standardization. Also, those elements that require mechanical aided cargo transfer equipment must have matching hardware interconnects.

Table 2-14. Significant Element Requirements

Cargo Transfer Requirement	EOS	RAM	TUG	MSS	Rationale	Other Activity Impact
Hatch view windows	X	X	X	X	SS viewing of EVA/ EVA operations & Inspection	Compatible with crew & attached element operations
Interface hatchway controls & displays	X	X	X	X	Habitable environment verification	Compatible with crew & attached element operations
IVA/EVA capability	X (1)		X (2)		Some satellites & RAM's will require IVA/EVA maintenance	Compatible with crew & attached element operations; 30" minimum for crew transfer
Manual aid equipment		Some		X	Cargo size & traffic	Requires compatible provisions in mating design concepts
Automatic equipment	X (3)		X (3)		Some satellite servicing requires remote operations	Compatible with mating concepts with satellites
Plumbed fluid, manual interconnect	X	X	X	X	Flexible, safe, fluid transfer technique	Gross standardization of utilities inter-connections required
41-inch hatch	X	X	X	X	Standardization & cargo transfer	Crew operations

1. Kit installation of airlock
2. Depressurize crew compartment
3. Kit installation

3.0 PROPELLANT TRANSFER

The propellant transfer interfacing activity pertains to the transfer of large quantities of liquid oxygen and liquid hydrogen propellants in orbit for use by vehicle main propulsion engines. The transfer of relatively small quantities of propellants for attitude control systems, and the transfer of other liquids and gases is included in the cargo transfer interfacing activity.

3.1 SUMMARY

Following is a summary of the results of the evaluations conducted in connection with the propellant transfer interfacing activity. The detailed results are included in paragraphs 3.2 through 3.7, and in Appendix A9 of this report. The data included in Appendix A9 supplements and supports the analyses in this section (section 3.0), and are frequently referenced herein. For convenience this summary is divided into six subsections corresponding to each major paragraph.

ELEMENT INTERFACE AND MISSION MODEL MATRICES

A total of 117 potential interfacing element pairs have been identified in the Orbital Operations Study, involving the 25 orbital elements in the study inventory. At least one of the 14 interfacing activities (i.e., mating, separation, orbital assembly, propellant transfer, etc.) will occur between each of the 117 element pairs. Of these 117 element pairs, propellant transfer can occur between 38 pairs. The potential type of propellant transfer and the function or role of each involved element is identified in paragraph 3.2.

A total of 11 mission models have been developed and documented in Volume 1. These mission models, or mission sequences of events, encompass all 14 of the interfacing activities and all 25 of the space elements. Of the 11 mission models, seven include propellant transfer involving a total of 38 element pairs as mentioned in the previous paragraph. A matrix included in paragraph 3.2 identifies the inter-relationships between mission models and element pairs for propellant transfer.

ALTERNATE APPROACHES

There are two basic approaches identified for performing propellant transfer to the user vehicle in earth orbit, i.e., fluid transfer and modular transfer. Fluid transfer to the user involves the transfer of liquid propellants from a supplying element to the user vehicle's permanently - attached tanks. Modular transfer to the user vehicle involves the exchange of a full tank(s) for an empty tank(s) and requires that the user vehicle be designed to accommodate this exchange (the tank-set concept).

The refueling of an element in earth orbit may involve a sequential combination of both fluid and modular transfer, two fluid transfer operations, or two modular transfer operations. The refueling of a user may involve an intermediate element such as an OPD or a transport tug. These various combinations of approaches and elements are referred to herein as propellant transfer logistics options, 11 of which are identified and described in paragraph 3.3.

In order to make possible a more in-depth analysis of the more viable logistics options, the least attractive options were dropped from further study. The remaining four options include direct fluid transfer to the user, direct modular transfer to the user, and two cases utilizing a mini-depot as an intermediate element. In all four options the orbiter delivers a propellant logistics tank (which may be a tank-set) to earth orbit, attaches that tank to another element, followed by orbiter separation from the tank.

DESIGN CONCEPT MODELS

In order to validate each of the four propellant transfer logistics options, at least one viable design concept for performing each option has been identified and described in paragraph 3.4. The direct fluid transfer option utilizes a dual-propellant logistics tank delivery by the orbiter to the user vehicle. The tank design incorporates fluid transfer pumps, interconnect extention mechanisms, and small thrusters for providing continuous thrusting during the propellant transfer operation. The placing of these hardware items in the logistics tank, minimizes the adverse impact of weight on the mass fraction of the user vehicle. The thrusters provide a low acceleration force (10^{-4} to 10^{-5} g's) to settle the propellant for liquid/vapor interface control. The tank is sized for a total "propellant plus tank" weight of 65,000 pounds, resulting in a tank weight of approximately 4,400 pounds and length of 38 feet.

The direct modular transfer option utilizes tank-sets which are optimized for each user vehicle to maximize mass fraction since the tanks accompany the vehicle on its mission. These tanks could be similar in design to the direct fluid transfer logistics tanks, but need not necessarily incorporate the transfer pumps and the extention mechanisms. These items could be designed into the user vehicle.

Two of the four logistics options utilize a mini-depot as an intermediate element. Although the two mini-depots are not the same in all respects, they both incorporate transfer pumps, interconnect extension mechanisms and thrusters for liquid/vapor interface control (i.e., linear acceleration). These weight items need to be delivered to orbit only once. Hence the logistics tank that supports either of the mini-depots can be significantly lighter than the tank used for the direct fluid transfer option. The mini-depot concept for one of the logistics options remains attached to both the logistics tank and the user vehicle during fluid transfer, and does not incorporate permanent tanks of its own. The other mini-depot concept utilizes integral tanks which are refilled from a logistics tank.

In this concept the mini-depot then transfers propellant to the user vehicle subsequent to separating from the logistics tank. This concept allows the orbiter to return to earth with the logistics tank prior to the actual transfer of propellants to the user vehicle.

OPERATIONAL PROCEDURES

Operational procedures have been developed for each of the two alternate approaches, fluid transfer (procedure No. 6-1) and modular transfer (procedure No. 6-2). These two procedures are presented in detail in Appendix B, and have been summarized in paragraph 3.5. The two operational procedures can be made applicable to the various propellant transfer logistics options by combining them sequentially as appropriate for a particular logistics option. Each of the procedures presents a sequence of operations, the rationale for performing each options, and the functional requirement associated with each operation.

FUNCTIONAL REQUIREMENTS

The functional requirements determined for propellant transfer have been grouped into two categories in paragraph 3.6. The first category consists of general requirements that are applicable to functions or operations that must be performed in the accomplishment of propellant transfer. The second category are requirements which have been related to element pairs and to vehicles. The primary functional requirements relate to docking ports, alignments and interlock, control and monitoring of transfer operations, propellant expulsion, thermodynamic control, and maintenance of safe transfer conditions. The number of orbiter flights required to refill the Space-Based Tug, CPS, and RNS is 1.4, 19.2 and 9.2 by fluid transfer. The corresponding values for modular transfer are 4-to-5 percent lower.

DESIGN INFLUENCES AND PREFERRED APPROACH SELECTION

Comparisons between the remaining four propellant transfer logistics options identified in paragraph 3.3, the selection of a preferred option for refueling each of the user vehicles, the rationale for the selections, and identification of design influences are documented in paragraph 3.7. Various evaluation factors were used in the selection process including safety impact, maintenance impact, technology status, relative cost, operational complexity, commonality, design influence on the user vehicle, and number of orbiter flights. One of the four logistics options received a good rating against each of the evaluation factors, with the qualified exception of the number of orbiter flights. This logistics option is direct fluid transfer to the user with no intermediate element involved. The direct modular transfer logistics option is 4 to 5 percent more efficient relative to number of orbiter flights, due to the relatively low propellant losses involved. However, the assumption was made that the modular tanks (tank-set concept) would always be returned to earth empty of propellant. This would not be completely true because of user vehicle propellant reserve requirements. The direct fluid transfer logistics option is preferred primarily because of reduced costs (no mini-depot required), favorable commonality rating, and minimum design influence on the user vehicle.

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3.2 ELEMENT INTERFACE AND MISSION MODEL MATRICES

Of the 25 elements listed in the space vehicle inventory, at least 9 are possible recipients or suppliers of large quantities of propellants. Any of the space-based propulsive vehicles (space tug, CPS, RNS, or lunar tugs), the lunar program resupply module, and the OPD are potential recipients of large quantities of propellant. The orbiter, both the ground-based and space-based tugs, the earth orbit resupply module, and the OPD represent the supplier side of the interface. It should be noted that it may be necessary to transfer propellant both to and from such elements as depots or the space-based tug.

The matrix shown in Figure 3-1 lists the 38 element-to-element interactions identified with propellant transfer. These interactions are categorized by source of refill. Twenty-four interactions can be associated with tanker delivery, eight with refill from modules, and seven with refill from a depot. Because the space-based tug may operate as a tanker as well as a user element, there are two possible interactions shown between the space-based tug and the OPD.

The Orbital Operations Study contract included baseline performance and vehicle characteristics data for the 25 elements in the study inventory. These data are documented in Appendix C of this report. Table 3-1 presents data extracted from this source that is especially pertinent to propellant transfer. (Figure 3-1) In addition, Table 3-1 includes a brief definition of the OPD and the mini-depot in order that a clear distinction can be drawn between the two. This distinction is adhered to in the frequent references made to these elements in the following subsections.

Figure 3-2 presents in similar matrix format the mission models that identify propellant transfer activities. As stated previously, only 9 of the 25 elements in the space vehicle inventory are involved in bulk transfer of propellants. In the 11 mission models, there are 14 occasions when the orbiter could be transferring propellant, 13 occasions when the ground-based tug could be, and 23 when the space tug could be delivering or receiving fuel. Also, there are 29 occasions involving earth orbital resupply modules and 23 involving depots.

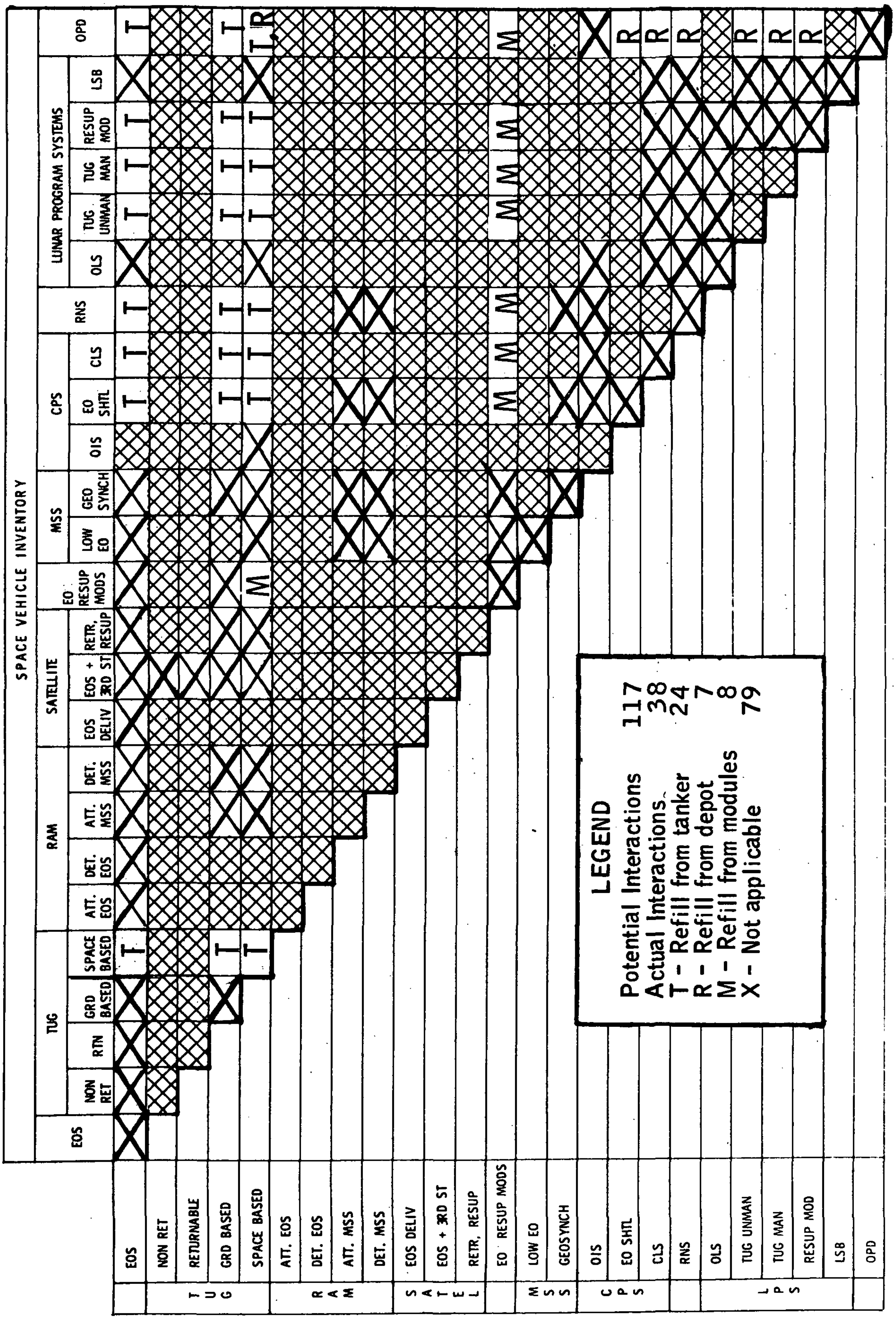


Figure 3-1. Propellant Transfer Interactions

Table 3-1. Vehicle Models and Definitions

EOS ORBITER

- PAYLOAD CAPAB. 25000 LB TO 270 N.M./55°
  40000 100 N.M./Polar
  65000 100 N.M./28.5°
- CARGO BAY 15 Ft x 60 Ft

ORBITAL PROPELLANT DEPOT (OPD)

- FOR ORBITAL STORAGE OF LARGE QUANTITIES OF PROPEL, i.e., RNS OR CPS

MINI-DEPOT

- FOR SHORT TERM STORAGE - UP TO 80,000 LB
- PERMANENT OR EXCHANGEABLE TANKS

RNS - 300 K LBS LH_2

CPS - 1,080,000 LBS LH_2/LO_2

S.B. TUG - 78,945 LBS LH_2/LO_2

		SPACE VEHICLE INVENTORY																								
		EOS	TUG				RAM				SATELLITE			EO RESUP MODS	MSS		CPS			RNS	LUNAR PROGRAM SYSTEMS					OPD
			NON RET	RTN	GRD BASED	SPACE BASED	ATT. EOS	DET. EOS	ATT. MSS	DET. MSS	EOS DELIV	EOS + 3RD ST	RETR, RESUP		LOW EO	GEO SYNCH	OIS	EO SHTL	CLS		OLS	TUG UNMAN	TUG MAN	RESUP MOD	LSB	
	EOS				2,5	2,5												2,10,11	2,10,11	2,11		2	2	2		2
TUG	NON RET																									
	RETURNABLE																									
	GRD BASED					8												8,10,11	8,10,11	8,11		8	8	8		8
	SPACE BASED					5								2,5,8				5,10,11	5,10,11	5,11		5	5	5		4,5,6
RAM	ATT. EOS																									
	DET. EOS																									
	ATT. MSS																									
	DET. MSS																									
SATEL	EOS DELIV																									
	EOS + 3RD ST																									
	RETR, RESUP																									
	EO. RESUP MODS																	2,5,8, 10,11	2,5,8, 10,11	2,5,8,11		2,5,8	2,5,8	2,5,8		2,5,8
MSS	LOW EO																									
	GEOSYNCH																									
CPS	OIS																									
	EO SHTL																									4,10,11
	CLS																									4,10,11
	RNS																									4,11
LPS	OLS																									
	TUG UNMAN																									2,5
	TUG MAN																									2,5
	RESUP MOD																									5
	LSB																									
	OPD																									

Figure 3-2. Applicable Mission Models for Propellant Transfer

3.3 ALTERNATE APPROACHES

The transfer of propellants from an element to the user vehicle in earth orbit can be accomplished in either of two basic ways, i.e., by fluid transfer and by modular transfer. Figure 3-3 shows these two approaches pictorially and illustrates one possible logistics option for one element pair.

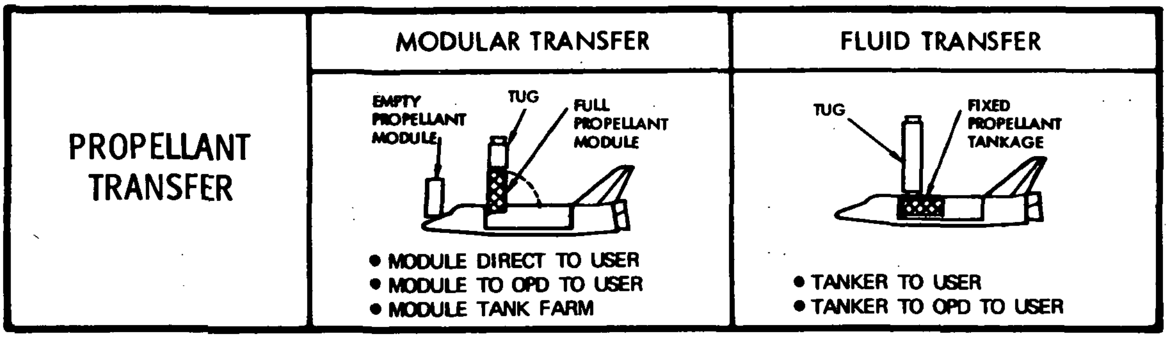


Figure 3-3. Propellant Transfer Alternate Approaches

The modular transfer illustration shows a tug being refueled by an exchange of propellant tanks, i.e., an empty tank being exchanged for a full tank. This is sometimes referred to as the tank-set concept when the user vehicle does not incorporate permanent tanks. The fluid transfer illustration shows a tug (which incorporates integral tanks that are installed during tug assembly on earth) being refueled from a propellant logistics tank which remains stowed in the orbiter cargo bay. In this particular case the orbiter might be thought of as a tanker. The fluid transfer approach would also involve the deployment of the logistics tank from the orbiter, followed by the fluid transfer operation. Still another delivery mode would be the separation of the logistics tank from the orbiter, followed by the fluid transfer operation.

The refueling of a CPS by either modular or fluid transfer might utilize a tug as an intermediate transport vehicle between the orbiter and the CPS.

As the previous paragraph suggests, there are many options or subapproaches for refueling a user vehicle, some of which involve both fluid and modular transfer. In order to identify all potentially viable logistics options for refueling a user vehicle, the sequence block diagram of Figure 3-4 was constructed. The vertical columns alternate between the orbiting element involved and the mode of transfer. For each of the eleven logistics options the sequence starts with the delivery of the propellant logistics tank to earth orbit in the orbiter; and ends with the transfer of propellant to the ultimate user.

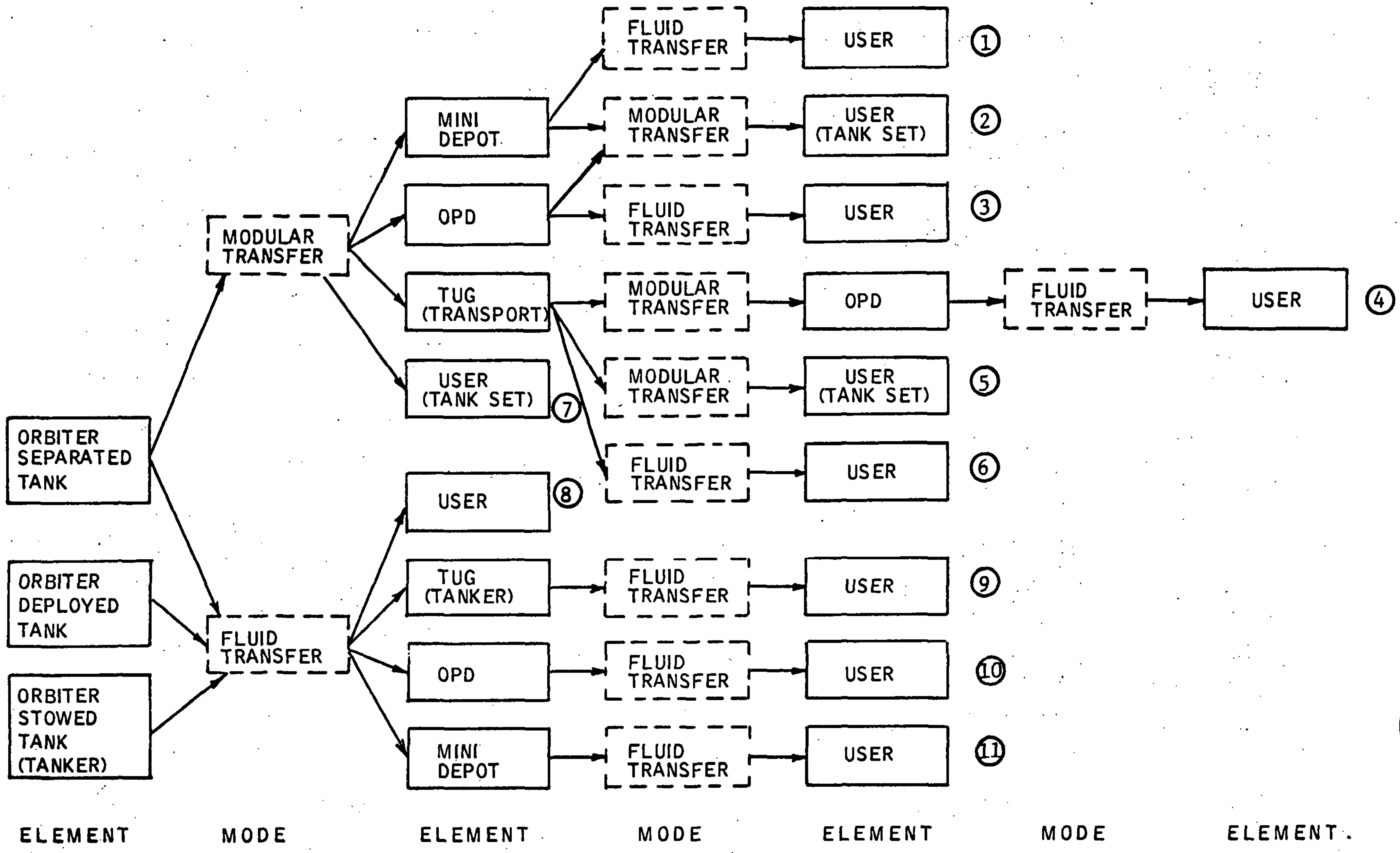


Figure 3-4. Propellent Transfer Logistics Options

Nine of the eleven logistics options include more than one propellant transfer operation. Option No. 4 includes three transfer operations. As can be seen, a modular transfer operation can be followed by either modular or fluid transfer. Fluid transfer is never followed by modular transfer in a given logistics option.

EOS ORBITER PROPELLANT DELIVERY CONCEPTS

Eight concepts for propellant delivery in orbit from the EOS orbiter to the user vehicle have been evaluated and discussed in Appendix A9. The three concepts which showed the most promise are shown in the left-hand column of Figure 3-4, and illustrated in Figure 3-5 for tug resupply. Configuration A is the stowed tank concept with propellant settled by radial acceleration, and the resupply tank retained in the cargo bay during fluid transfer. Configuration B is the deployed tank concept with propellant settled during fluid transfer by either radial or linear acceleration, and the logistics tank deployed and supported from the cargo bay by stabilizer struts. Configuration C is the orbiter-separated tank concept where the tank is detached from the orbiter during fluid transfer, and propellant settling is provided by linear acceleration. Table 3-2 briefly presents some of the advantages and disadvantages derived from a comparative evaluation. No single factor was identified as a strong driver. Configuration C appears to be at least as attractive as the other two for tug refueling, and is compatible with refueling of the CPS and RNS. For purposes of the Orbital Operations Study, Configuration C is baselined for orbiter propellant delivery, and becomes a part of the total sequence in each of the eleven logistics options shown in Figure 3-4 (see block entitled "Orbiter-Separated Tank").

The orbiter separated tank configuration (Configuration C) requires that the propellant logistic tank be deployed and separated from the orbiter prior to propellant transfer. Figure 3-6 presents a viable method of logistics tank deployment and separation from the orbiter. The sequence of events shown on the Figure assumes a swing-out ring for tank deployment at the aft end of the cargo bay. This appears best to minimize the length of the manipulator arms. The manipulator arm is used to provide a controlled soft docking between the tank and the user vehicle.

DESCRIPTION OF PROPELLANT LOGISTICS OPTIONS

The terms modular and fluid transfer as used herein are defined as follows:

Modular Transfer - The transfer of a propellant module from one vehicle to another. Modular transfer may be followed by fluid transfer, and may involve the user vehicle tank-set concept.

Fluid Transfer - The transfer of liquid propellant from one tank to another. The receiving tank may be an intermediate orbiting element or an integral (permanently fixed) tank in the user vehicle.

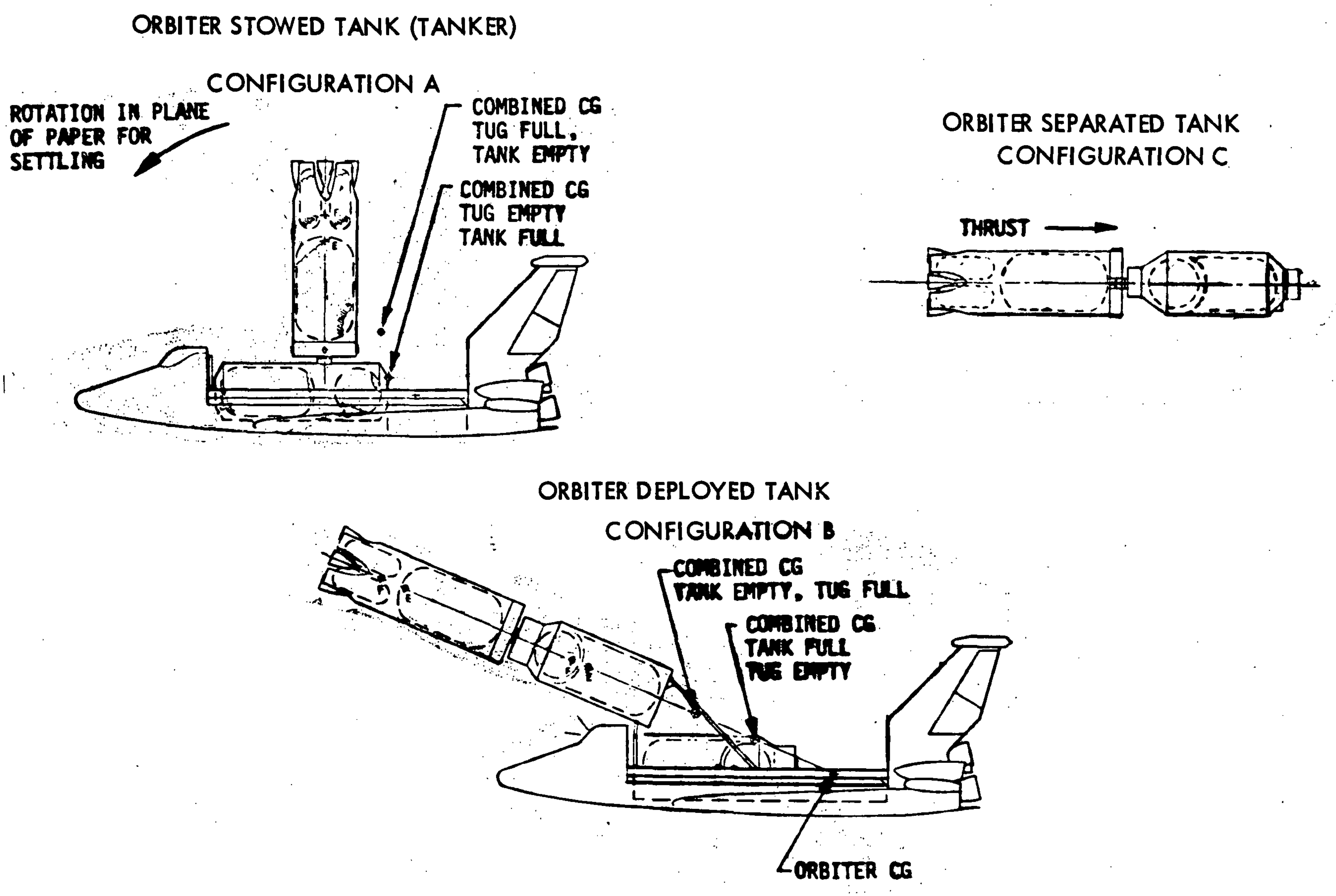


Figure 3-5. Potential Propellant Delivery Concepts

Table 3-2. Advantages and Disadvantages of Three Delivery Concepts

Advantages	Disadvantages
Configuration A	
Low propellant loss (rotat. accel.)	Orbiter required during transfer
No in-space handling of logistic tank	Inverted ground fill and vent configuration
No in-space orbiter/tank interface disconnect	C.G. migration not on tug/tank longitudinal axis
One rendezvous/docking per transfer	Special side tank vent
Configuration B	
Low propellant loss (rotational accel.)	Orbiter required during transfer
One rendezvous/docking per transfer	In-space tank deployment
Normal ground fill and vent configuration	Flexible in-space orbiter/tank interface
C.G. migration along longitudinal axis	Complex structural dynamics
Standard tug fill and vent locations	Manipulator reach requirement extended
	High propellant loss (linear accel.)
Configuration C	
Orbiter free for other operations during transfer	Moderately high propellant loss
Improved attitude control system	In-space tank deployment
Dynamic stability due to symmetry	In-space orbiter/tank interface disconnect
	Two rendezvous/dockings per transfer

1 RENDEZVOUS WITHIN REACH OF MANIPULATOR ARM

2 CARGO BAY DOORS OPENED

3 TANK MODULE ROTATED AND SUPPORTED BY SWING OUT RING

4 MANIPULATOR ARM GRASPS USER

5 USER DRAWN TO DOCKING WITH TANK

6 TANK DETACHED FROM SUPPORT RING

7 TANK/USER MOVED AWAY BY MANIPULATOR ARM

8 ARM RELEASES TANK/USER

9 ORBITER MOVES TO SAFE DISTANCE

10 TRANSFER INITIATED

11 TRANSFER COMPLETE

12 TANK/USER RENDEZVOUS WITH ORBITER WITHIN REACH OF MANIPULATOR ARMS

13 ARM GRASPS TANK/USER

14 TANK DRAWN TO SUPPORT RING

15 TANK DOCKING FIXTURE RELEASES USER

16 MANIPULATOR ARM MOVES USER AWAY FROM TANK MODULE

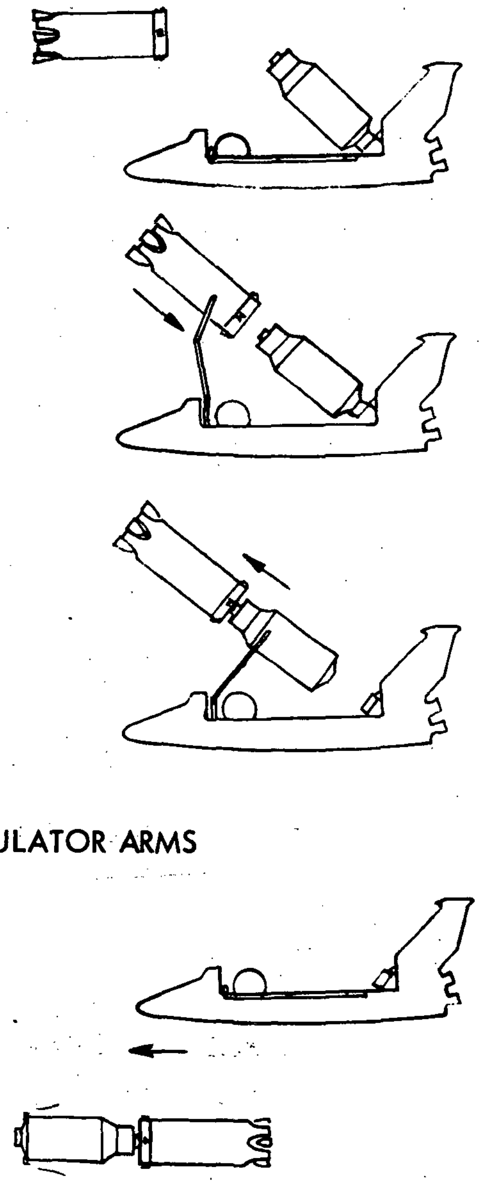


FIGURE 3-6. TYPICAL TANK DEPLOYMENT SEQUENCE

The following is a brief description of each logistics option shown in Figure 3-4.

Option 1 - A logistics tank is delivered to a mini-depot by the orbiter. The orbiter separates from the tank. The user vehicle mates to the mini-depot and is refueled by fluid transfer from the logistics tank which is attached to the mini-depot.

Option 2 - A logistics tank (tank set) is delivered to the mini-depot or OPD. The user vehicle (designed for tank set concept) exchanges empty tanks for full tanks at the mini-depot or OPD.

Option 3 - A logistics tank is delivered to the OPD. The user vehicle mates with the OPD and is refueled by fluid transfer.

Option 4 - A logistics tanks is delivered to a tug "transport" by the orbiter. The tug transports the tank to the OPD, where the propellant is transferred by fluid transfer to the user.

Option 5 - Similar to Option 4 except that the tug transports the logistics tank (tank set) to the user vehicle (designed to accommodate tank-sets) where the empty user tank is exchanged for a full tank.

Option 6 - Similar to Option 4 except that the tug transports the logistics tank to the user which is refueled by fluid transfer.

Option 7 - A logistics tank (tank set) is delivered to the user vehicle by the orbiter. The empty tank from the user vehicle (designed to accommodate tank sets) is exchanged for the full tank.

Option 8 - A logistics tank is delivered directly to the user, followed by fluid transfer to the user integral tanks.

Option 9 - A logistics tank is delivered to a tug "tanker". Fluid transfer takes place to the tug integral tanks. The tug then separates from the logistics tank and flies to the user vehicle, where fluid transfer takes place to the user integral tanks.

Option 10 - A logistics tank is delivered to the OPD where fluid transfer occurs. Subsequently fluid transfer occurs to the user vehicle integral tanks.

Option 11 - A logistics tank is delivered to the mini-depot where fluid transfer occurs. Subsequently fluid transfer occurs to the user vehicle integral tanks.

Although the above defined options are all potentially viable, some are considerably more attractive than others. Due to the large number of options (or sub-approaches) identified, it was deemed desirable to delete the least attractive options from further detailed analyses in the Orbital Operations Study.

DELETION OF TUG TRANSPORT RELATED OPTIONS

An analysis of the role of the space-based tug as an intermediate delivery vehicle indicates no advantage if the orbiter is capable of delivering the propellant directly to the user without reducing the orbiter payload delivery capability. The orbiter payload delivery capability baselined for the Orbital Operations Study is shown on Figure A9-57 of Appendix A9, Section 5.0. This figure is compatible with the specification performance values included in the Orbital Operations Study vehicle performance guidelines presented in Appendix C, and is based upon the EOS orbiter 161C configuration. The figure shows a 65,000 pound payload delivery capability to altitudes greater than 300 n.mi. at inclinations of 28.5 to 31.5 degrees. This capability assumes the use of OMS abort propellant above 100 n.mi. altitude. Based on these performance data, the orbiter is more than capable of delivering a 65,000 pound payload to the altitudes and inclinations which have been considered for the earth orbital parking orbits of the OPD, CPS, and RNS.

Figure 3-7, presents the rationale for deletion from further in-depth study of all propellant logistics options utilizing the tug as a tanker or intermediate transport vehicle.

Figure 3-7. Rationale for Deletion of Tug Tanker/Transport Propellant Logistics Options

- Potential Tug Use
  - Tanker or transport between orbiter and OPD, CPS, or RNS
- Baseline Model EOS performance

  65,000 up to >300 n.mi., 31.5°
- Impact of Tug as intermediate vehicle
  - Not required for delivery
  - Requires dedicated tug or complicates mission planning
  - Increased operational complexity
  - Increased propel. losses for tanker concept
  - Requires additional propel for tug delta-V
- Conclusions

  Delete logistics options involving tug transport/tanker

As Figure 3-7 indicates their are some significant disadvantages to the use of the tug as an intermediate vehicle including increased operational complexity and increased propellant requirements, both of which reflect in higher costs. Since the tug is not required as an intermediate vehicle for delivery of payloads to the OPD, CPS, or RNS, there appears to be no significant advantage to retaining for further study those logistics options which utilize the tug in this capacity. Hence logistics options numbers 4, 5, 6, and 9 are deleted from further study.

Payload delivery predictions have been made for EOS configurations which are more recent than the Orbital Operations Study baseline configuration. These estimates indicate a possible maximum altitude of 200 to 250 n.mi. (31.5 degrees inclination) for a 65,000 pound payload. This is based upon the use of OMS abort propellant (currently hypergolics, formerly cryogenics) to increase delivery altitude. This capability is still adequate for direct delivery to the CPS which currently has an earth parking orbit below 200 n.mi. Orbiter payload delivery capability could become a programmatic sensitivity item. If the maximum altitude for delivery of a 65,000 pound payload (using OMS abort propellant) should turn out to be less than currently predicted, or if the earth parking orbit selected for the CPS should be significantly higher than currently envisioned, the potential role of the space-based tug as an intermediate transport element would have to be re-evaluated. Since the orbiter is volume limited for delivery of LH_2, resulting in a weight maximum of approximately 34,000 pounds of LH_2, direct orbiter delivery of propellant to the RNS is not a potential problem.

DELETION OF OPD RELATED OPTIONS

The advantages and disadvantages of using an OPD (as compared to other alternatives) for storage of large quantities of propellant in earth orbit have been investigated and evaluated. Figure 3-8 summarizes the major considerations related to the viability of the OPD concept.

Figure 3-8. Rationale for Deletion of OPD Related Propellant Logistics Options

- Potential OPD Use
  - Storage of large quantities of propellants in orbit -- support RNS or CPS
- Major Considerations
  - CPS/RNS can store own propellant

    May require additional CPS/RNS
    May require additional orbiter
  - High cost for development, delivery to orbit, and assembly of OPD
  - Orbiter OMS propellant (hypergolics, formerly cryogenics) no longer compatible with a cryogenic storage facility
- Conclusion
  - Delete logistics options involving OPD

The refueling of a CLS (either CPS or RNS) in earth orbit requires the storage of large quantities of propellant in earth orbit. This requirements is imposed by the large propellant capacity of a CLS (refer to Table 3-1) requiring many EOS orbiter flights to deliver sufficient propellant to earth orbit for one complete refueling. There are two potential concepts for providing this storage capability. The CLS can be refueled directly from the EOS orbiter, requiring a relatively long total elapsed time to completely refuel a CLS. In this concept the CLS serves as its own storage facility. The second concept involves the use of an orbital propellant depot (OPD) to serve as a propellant storage facility of propellants received from the EOS orbiter. In this concept the CLS is refueled from the OPD, and refueling does not commence until the OPD has sufficient propellant on board to completely refuel the CLS in one continuous operation.

Relative cost effectiveness becomes the ultimate criteria for determining which of these two storage concepts is preferred since both are feasible concepts. The major trade is between the cost associated with the development, design, construction and assembly in earth orbit of an OPD versus the cost of an additional orbiter and/or an additional CLS, if required. Several factors are involved in the tradeoff including the cost of an OPD, the duration of a CLS mission, time in earth orbit (per CLS mission) when the CLS is not available for refueling operations, CLS flight frequency, cost of an additional CLS vehicle, number of shuttles used for refueling, frequency of shuttle flights, and cost of an additional shuttle. This trade has been conducted for the CPS and is documented in DS-457. Based on a five-year operation period, the trade study indicates that for mission durations (including non-available time in earth orbit) of 45 days, that the OPD is not cost effective when CPS flight intervals are greater than approximately 125 days. This is based on operation with one CPS. The tradeoff is between the cost of the OPD and the cost of delivery shuttles. Without an OPD, more shuttles are required to refuel the CPS in the time interval available. It is also indicated that a second CPS would be used, rather than an OPD, at the higher flight frequencies (flight intervals less than 125 days) where an OPD is cost effective with one CPS operation. In other words, the OPD is never cost effective compared to the available alternatives, i.e., either additional shuttles or an additional CPS. For purposes of the Orbital Operations Study, it is concluded that all propellant logistics options involving the use of an OPD do not warrant additional consideration. This results in the deletion of Options 2 (OPD portion), 3, and 10 (see Figure 3-4).

DELETION OF OPTION NO. 2 (USING MINI-DEPOT)

Option number 2 utilizes modular transfer to the mini-depot, followed by modular transfer to the user vehicle. This option, of course, requires that the user vehicle be designed to accommodate modular tank exchange, i.e., tank set concept. A much simpler approach, operationally, is utilized in Option number 7 which involves one less transfer operation. In addition, option 7 does not entail the additional costs of a mini-depot to serve as an intermediate tank holding station. Consequently option number 2 is deleted from further study and consideration.

LOGISTICS OPTIONS REMAINING FOR FURTHER STUDY

As a result of the deletion of options discussed in the previous three subsections, there are four remaining logistics options, i.e., options numbers 1, 7, 8, and 11 (See figure 3-9). Options Numbers 1 and 11 utilize mini-depot concepts. Option number 7 only requires that the user vehicle be designed to accommodate tank sets. Options 7 and 8 utilize no intermediate element between the orbiter and the user vehicle other than the propellant logistics tank.

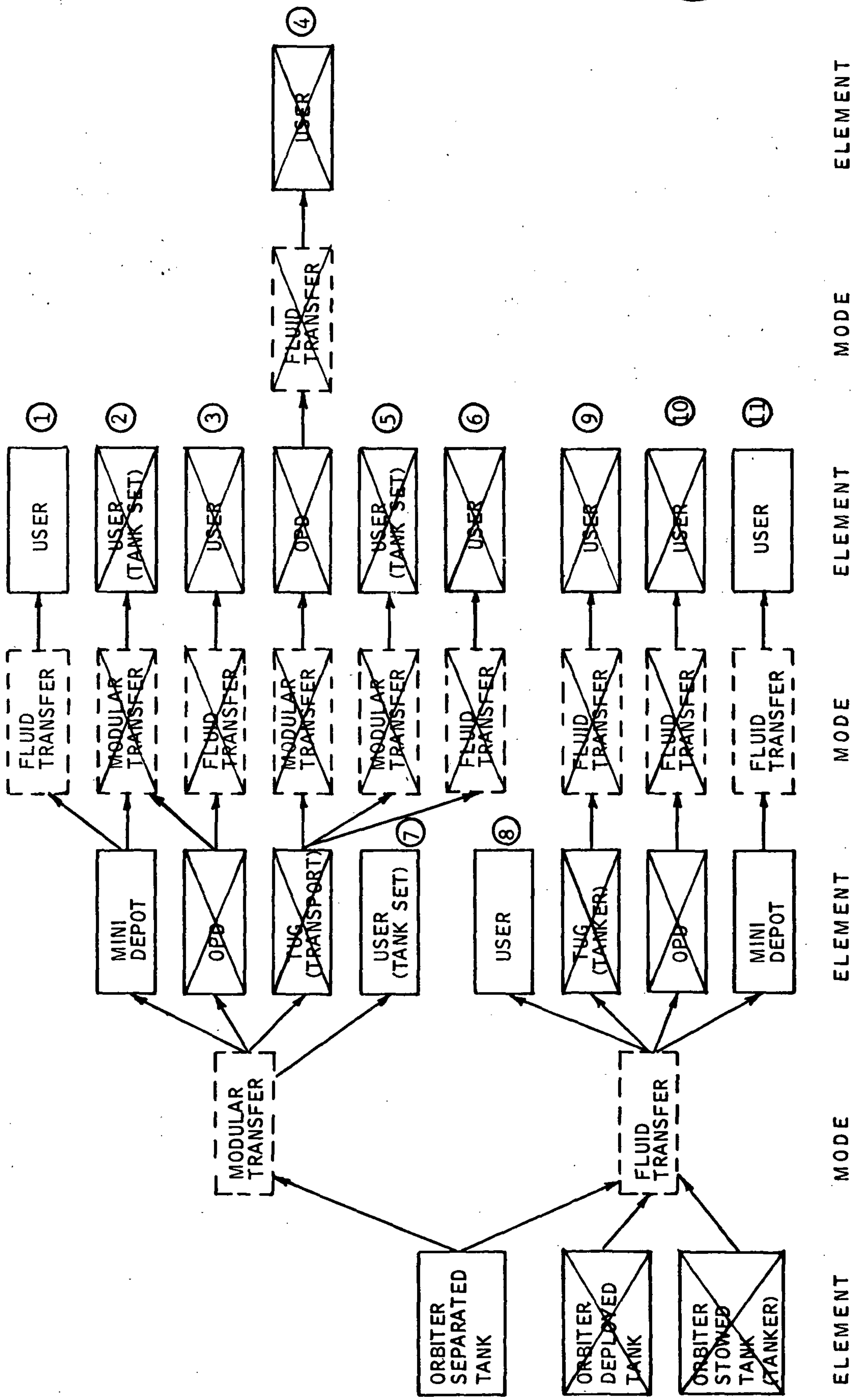


Figure 3-9. Propellent Transfer Logistics Options

3.4 DESIGN CONCEPT MODELS

This section presents sketches and narrative briefly describing design concept models for specific propellant transfer hardware elements. These elements include propellant logistics tanks and mini-depots, and their related subsystems. The intent herein is to present a viable design concept for each element of the four propellant logistics options (Options Nos. 1, 7, 8, and 11) selected for further study in Section 3.3. Design trade studies are involved only to the extent necessary to assure the selection of a viable concept, as opposed to an optimum concept. A detailed presentation of design concepts is included in Appendix A9 in support of the summary data included in this section. Appendix A9, in some cases, goes to a depth greater than necessary to assure selection of a viable design concept, and also includes data related to logistics options which were deleted from in-depth study in Section 3.3. The inclusion, however, of these additional data in Appendix A9 was felt to enhance the overall understanding of the many potential facets of propellant transfer as related to hardware design, operational complexity, and subsystem functions.

In order to transfer propellant from one element to another (fluid transfer) some means of liquid/vapor interface control must be provided in order to assure transfer of liquid only through the transfer plumbing. This can be accomplished in many ways three of which, illustrated on Figure 3-10, are radial acceleration, linear acceleration, and capillary action. All three are viable concepts, although capillary action requires more advanced technology in its application. Radial acceleration requires that the combined c.g. of the attached elements always remain outside of both the supplier and the receiver tanks during transfer. From a physical standpoint this may require a long boom between the supplier tank and the user vehicle. This is particularly true when the user vehicle is a heavy element like the CPS or RNS. The linear acceleration method requires continuous thrusting during the transfer operation to maintain liquid/vapor interface control (a period of 10 to 15 hours). The radial acceleration method requires thrusting to establish the desired rotation rate, followed 10 to 15 hours later by another short thrusting period to null out the rotation. During the transfer period, minimal thrusting is required to maintain attitude stability. (Refer to Appendix A9 for further discussion.)

Logistics Option No. 1 utilizes a mini-depot as an intermediate propellant resupply element, involving fluid transfer from the depot to the user vehicle. Linear acceleration has been selected as a viable means of liquid-vapor interface control during propellant transfer to all three user vehicles, i.e., CPS, RNS, and tug. In the case of the CPS and RNS, radial acceleration does not appear desirable at this time due to the large boom length required (see Appendix A9). Figure 3-11 illustrates a mini-depot design concept utilizing linear acceleration for liquid/vapor interface control. The mini-depot includes the capability for attitude control and orbital make-up, the transfer system compressors and pumps, the transfer interconnect extension mechanisms, and the thrusters for providing linear acceleration. The logistics tank used in conjunction with this mini-depot would be a minimum weight tank because it would not be required to include the compressors, extension mechanisms, and

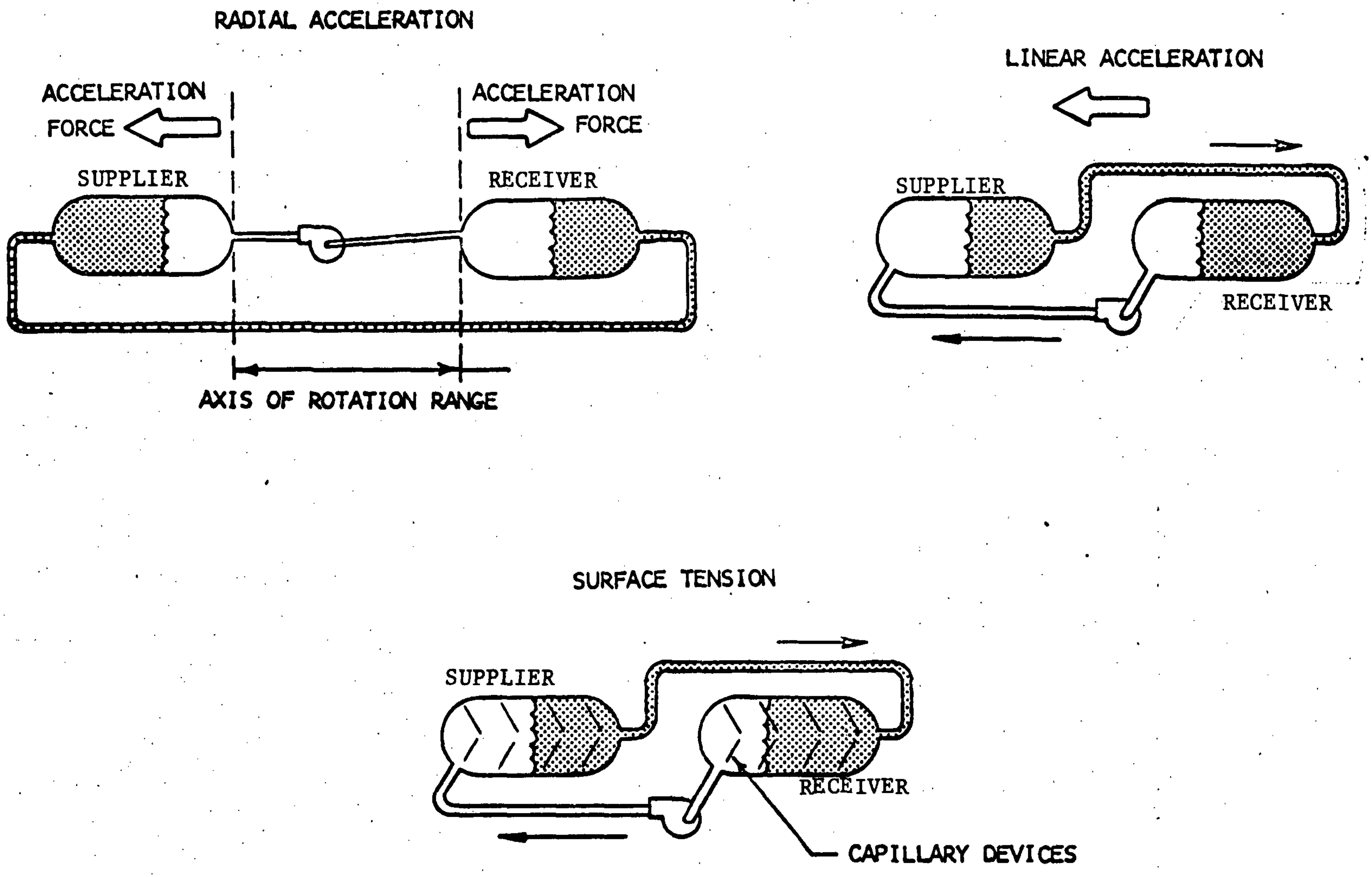


FIGURE 3-10. LIQUID/VAPOR INTERFACE CONTROL CONCEPTS

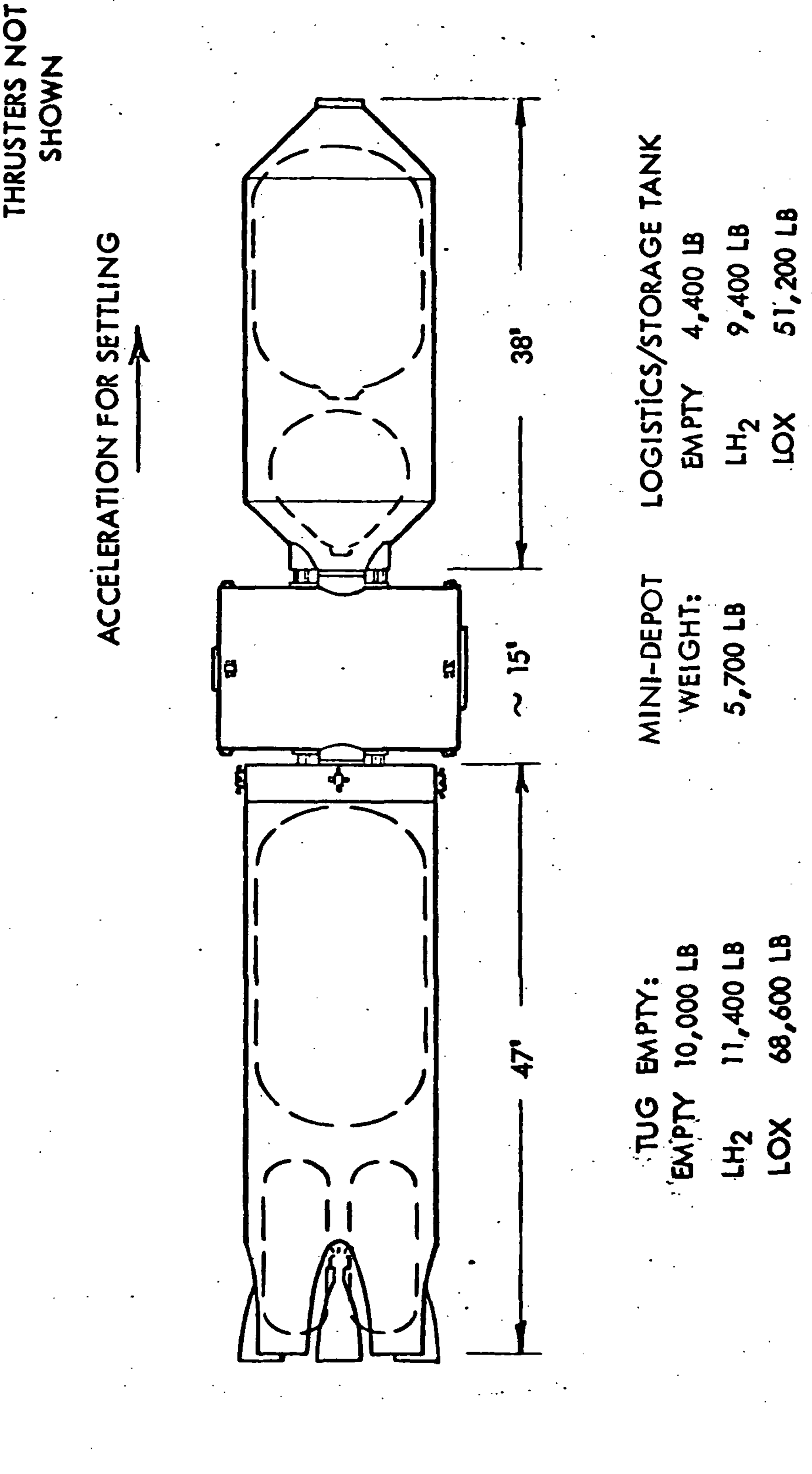


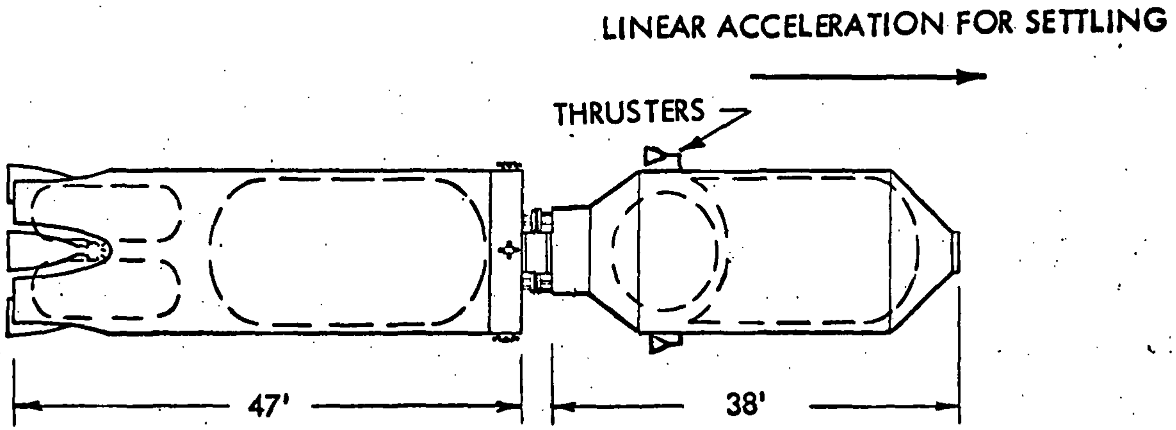
Figure 3-11. Modular, Linear Mini-Depot

thrusters. Based on an orbiter total payload delivery weight of 65,000 pounds, it is estimated that this logistics tank would weigh approximately 4400 pounds for a propellant capacity of 60,600 pounds. The tank would be approximately 38 feet long, leaving approximately 20 feet in the cargo bay for payload sharing. Refer to Appendix A9 for a more detailed discussion of this mini-depot, including the extension mechanism design concept and the associated logistics tank.

Logistics Option No. 7 (refer to Figure 3-9) involves a modular transfer of a tank-set directly to a user vehicle. This tank would serve a dual purpose, i.e., that of a logistics tank in transit, followed by attachment to the user vehicle where it would become the propellant tank (or tanks) for the main propulsion engines. This logistics option involves an exchange of full for empty tanks at the user vehicle. The fluid transfer interface between this tank and the user engines would be similar to the interface between the logistics tank (described for logistics Option No. 1) and the mini-depot. These similarities and some of the potential differences are discussed in Appendix A9.

Logistics Option No. 8 incorporates a single fluid transfer directly to the user vehicle from the logistics tank delivered by the EOS orbiter. Since no mini-depot is involved, either the user vehicle or the logistics tank must incorporate the propellant transfer compressors, interconnect extension mechanisms, and the thrusters for liquid/vapor interface control. To minimize the weight impact on the user vehicle, these features are incorporated into the logistics tank. As shown in Figure 3-12 and Figure 3-13, this tank is approximately 400 pounds heavier than the tank which interfaces with the mini-depot. The interconnects between the tank and the CPS or tug would include as a minimum: two propellant transfer lines; two propellant return lines; electrical power; hazard monitoring; and propellant transfer control. This same tank design can be used for refueling both the tug and the CPS. Due to the increased boil-off of LH_2 in the CPS (because of the relatively long time duration to refill a CPS, i.e., nine EOS flights) the CPS logistics tank would require a somewhat higher ratio of LH_2 to LO_2. Common thrusters could be used for the CPS and tug supportive logistics tanks if the system were designed with multiple thrusters sized for the higher mass CPS case. Some of the thrusters would then be inoperative during fluid transfer to the tug. The logistics tank for refueling the RNS could be the same design concept but much longer (approximately 58 feet) and incorporating one large LH_2 tank. Due to the low density of LH_2, a tank sized to completely fill the orbiter cargo bay would contain only 34,000 pounds of LH_2.

Logistics Option No. 11 utilizes the mini-depot as an intermediate propellant resupply element, somewhat similar to the mini-depot described for logistics Option No. 1. The mini-depot for Option No. 11, however, would have integral tanks requiring fluid transfer into them from a logistics tank, followed by fluid transfer from the mini-depot to the user vehicle. This concept is illustrated in Figure 3-14. The logistics tank used with this concept could be essentially the same as that described for logistics Option No. 1. With this concept, the orbiter could return to earth after the depot is refueled and before the propellant is transferred to the user vehicle.



	TUG	TRANSFER CAPABILITY	LOGISTICS TANK
EMPTY	10,000 LB	EMPTY	4,800 LB
LH_2	11,400 LB	LH_2	9,300 LB
LOX	68,600 LB	LOX	50,900 LB

(Including pumps, ext. mech., etc.)

Figure 3-12. Fluid Transfer, Linear Acceleration

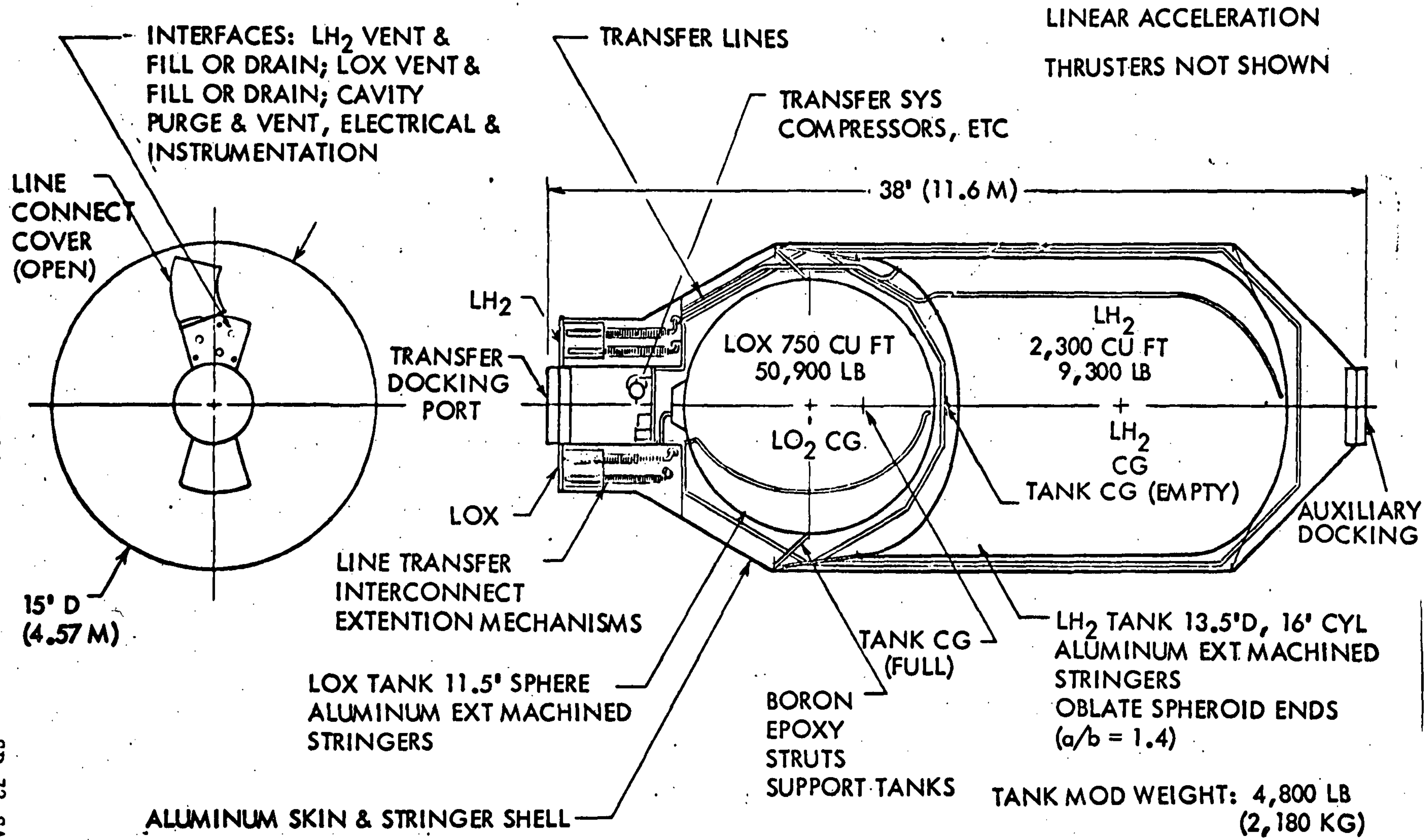


Figure 3-13. Transfer Capability Logistics Tank

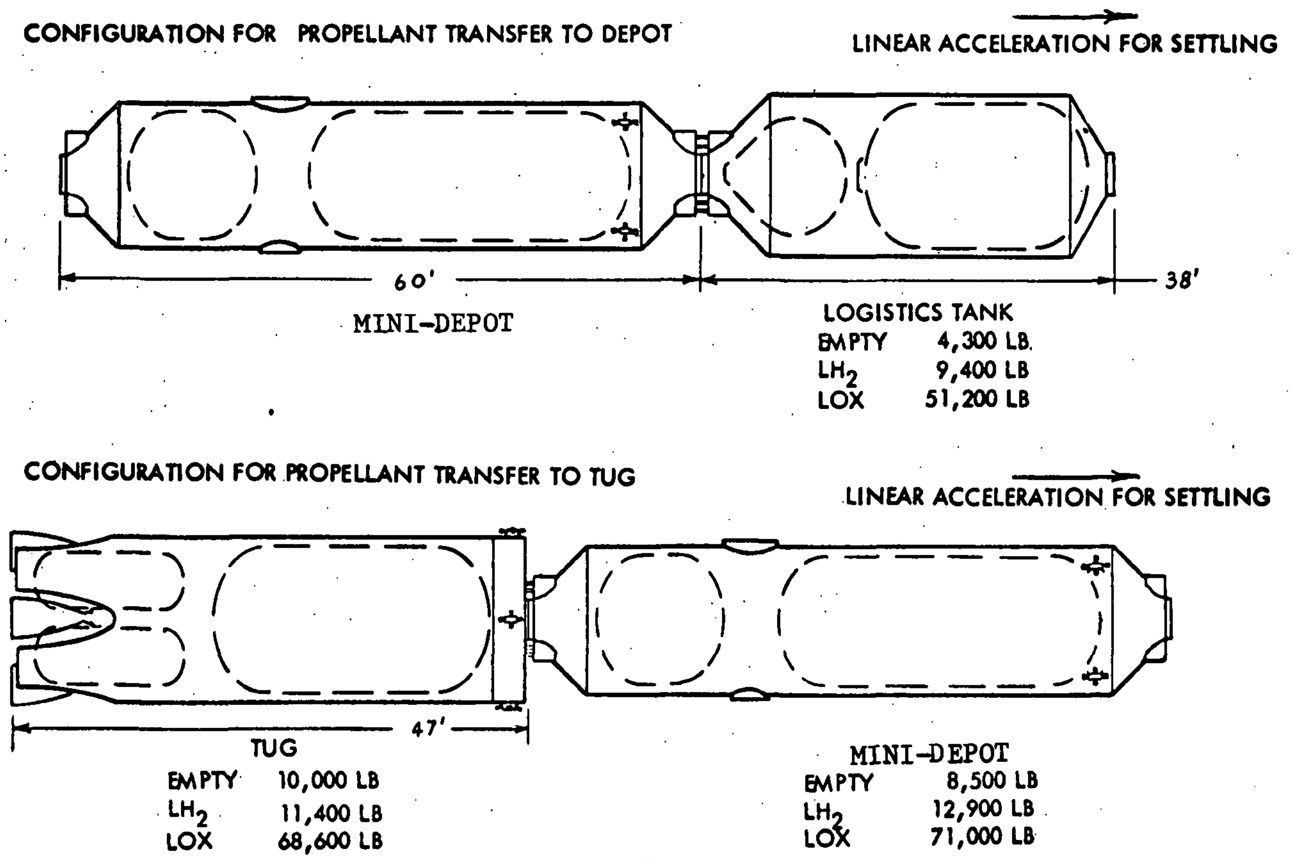


Figure 3-14. Permanent Tankage, Linear Mini-Depot

3.5 OPERATIONAL PROCEDURES

Detailed operational procedures have been developed for each of the two alternate approaches, i.e., fluid transfer (Procedure No. 6-1) and modular transfer (Procedure No. 6-2) to the user vehicle. These procedures, and a detailed discussion of the procedures and their applicability to interfacing element pairs, are documented in Appendix B. Included in this section is a brief summary of the procedures and their applicability to element pairs.

In Section 3.3 four propellant transfer logistics options were selected from a total list of eleven for further study and analysis. One of the four options (Option No. 1) utilizes modular transfer followed by fluid transfer. A second option (Option No. 11) involves two fluid transfer operations. Option No. 7 utilizes one modular transfer only, and Option No. 8 includes one fluid transfer only. The operational procedures in Appendix B are somewhat generic in their wording and application, and can be pieced together to provide the propellant transfer operations portion of the four propellant logistics options. It should be noted that the logistics options defined are actually large segments of total missions and encompass more than just propellant transfer. The logistics options also include rendezvous, stationkeeping, mating, separation, attached element transport, EOS payload deployment, and EOS payload retraction and stowage. The operations associated with these other interfacing activities may be found in the appropriate sections of Appendix B.

Figure 3-15 presents a summary of each of the two procedures for propellant transfer, and indicate little similarity between the two. In fluid transfer (subsequent to mating of the elements), propellant and system lines are extended through the interconnect interface, connections are made and verified, and controlled flow is implemented through propellant settling, pumping, pressurization, and filling operations. Modular transfer involves matings and separations, interspersed with deployment mechanism operations and the use of a temporary holding port on one of the vehicles.

The procedures applicability matrix in Appendix B identifies all potential element pairs between which propellant transfer can occur, and identifies which procedure(s) is applicable to each element pair. The matrix includes the 17 space program elements remaining for in-depth study from the original element inventory of 25, as explained in Section 4.0 of Volume I and Section 1.0 of Appendix A. There are a total of 14 interfacing element pairs identified for propellant transfer, 10 of which may utilize either of the two procedures. The remaining four element pairs, i.e., those involving the EO Resupply Module (defined in this activity as a logistics tank for fluid transfer), utilize the fluid transfer Procedure No. 6-1 only. The supplier elements include the EOS orbiter, space-based tug, and the OPD. The receiver elements include the space-based tug, CPS, RNS, and OPD. The EO Resupply Module is an intermediate element used for fluid transfer only.

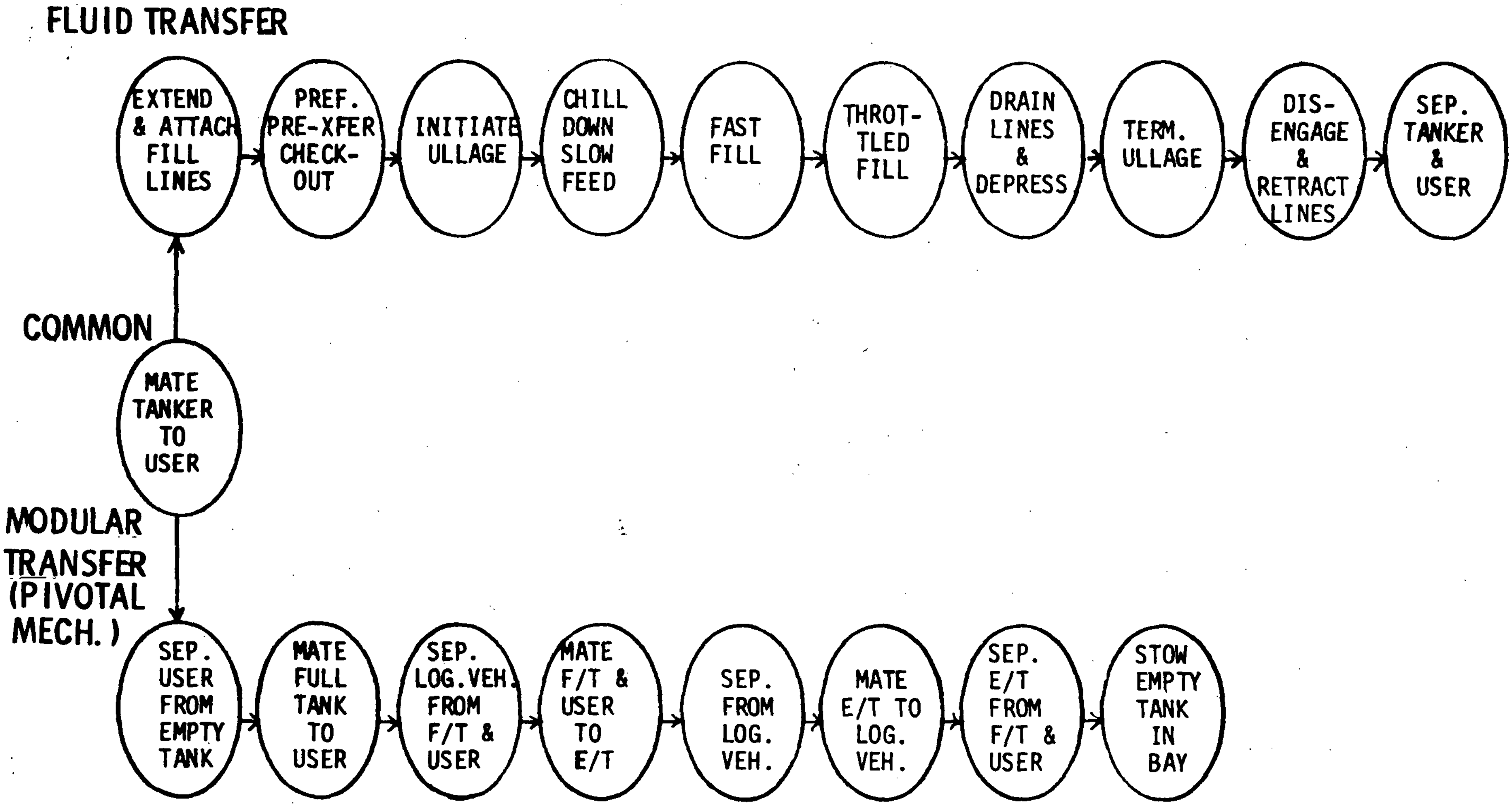


Figure 3-15. Propellant Transfer Procedural Comparison

3.6 FUNCTIONAL REQUIREMENTS

This section presents functional requirements for performing propellant transfer in earth orbit by either of two approaches, i.e., modular transfer or fluid transfer to the user. Presented first are the general requirements that are applicable to functions or operations that must be performed in the accomplishment of propellant transfer. This group of requirements is not tied to specific orbital elements. Following the general requirements are the requirements that can be related to specific element pairs and are unique, in some cases, to certain elements. Requirements pertaining to deployment of propellant modules (i.e., propellant logistics tanks) from the EOS orbiter are similar to those related to the deployment of other types of payloads and are covered in Section 4.0, Part 2 of Volume II, "EOS Payload Deployment." Requirements associated with the initial mating of elements for the purpose of propellant transfer are included in Section 1.0, Part 2 of Volume II, "Mating."

GENERAL FUNCTIONAL REQUIREMENTS

Included in this subsection are the general functional requirements applicable to modular and/or fluid transfer of propellants in earth orbit. The format used consists of a statement of the requirement followed by a discussion, rationale, and quantitative data where appropriate. In each case the requirement is cross-referenced to the operational procedure in which the related function or operation occurs. In some cases the generation of the operational procedures helped to identify and define the requirement. Operational Procedure No. 6-1 is applicable to fluid transfer of propellants to the user vehicle, and Procedure No. 6-2 applies to modular transfer of propellants to the user.

Requirement	Related Procedure Number 6-1	Related Procedure Number 6-2
1. Propellant transfer subsystem shall incorporate a means for expulsion of propellants from the supplying module or tank.	X	X
Because gravity feed is not possible in space, the propellant must be forced out of a tank to another tank or to point of use. Principal methods for forced expulsion are pumps, bladders, stored gas, liquid-gas conversion, and acceleration (liquid head) expulsion. Operating pressures range from 15 to 40 psia, depending on type of propellant, method of expulsion, and desired flow rate.		

	Related Procedure Number 6-1	Related Procedure Number 6-2
2. Propellant transfer subsystem shall incorporate a means for ullage or liquid-gas interface control.	X	X
Propellant in a partially empty module or tank must be kept available to the tank outlet in order to empty that module or tank. The principal methods for accomplishing this are the use of capillary devices, dielectrophoresis, linear acceleration, and centrifugal acceleration.		
Use of the last method requires that the center of gravity of the combined elements being rotated always remains outside the source and receiver tanks. This is necessary to prevent liquid from venting from the receiver tank and to completely drain the source tank. For linear or centrifugal acceleration the forces needed for ullage control can range from 2×10^{-2}g to 2×10^{-5} g.		
Figures 3-16, 3-17, and 3-18 present parametric data showing propellant and thrust requirements for centrifugal and linear acceleration as a function of mass, g level, moment arm, etc.		
3. Propellant transfer pressures and temperatures shall be maintained at appropriate levels during and after transfer.	X	X
Pressure and temperature of the propellants need to be maintained at those levels specified for normal transfer to the engines of user vehicles, temperatures compatible with the pump net pressure suction head for the propulsion subsystem and pressures determined by the pressure/temperature curve for efficient transfer. Compatibility of propellant transfer subsystems and reduction of inert weight form the basis for this requirement. Operation of equipment and propellant movement through the lines generate heat that increases evaporation rates which slows the flow rate and increases the ullage problem. Maintenance of temperature below some threshold level also is essential to prevention of gas-lock of certain types of expulsion equipment. Temperature levels for control are 37°R for LH_2 and 162°R for LO_2. Pressure levels for control are nominally about 20 psia, although operating expulsion pressures may vary between 15 and 40 psia.		

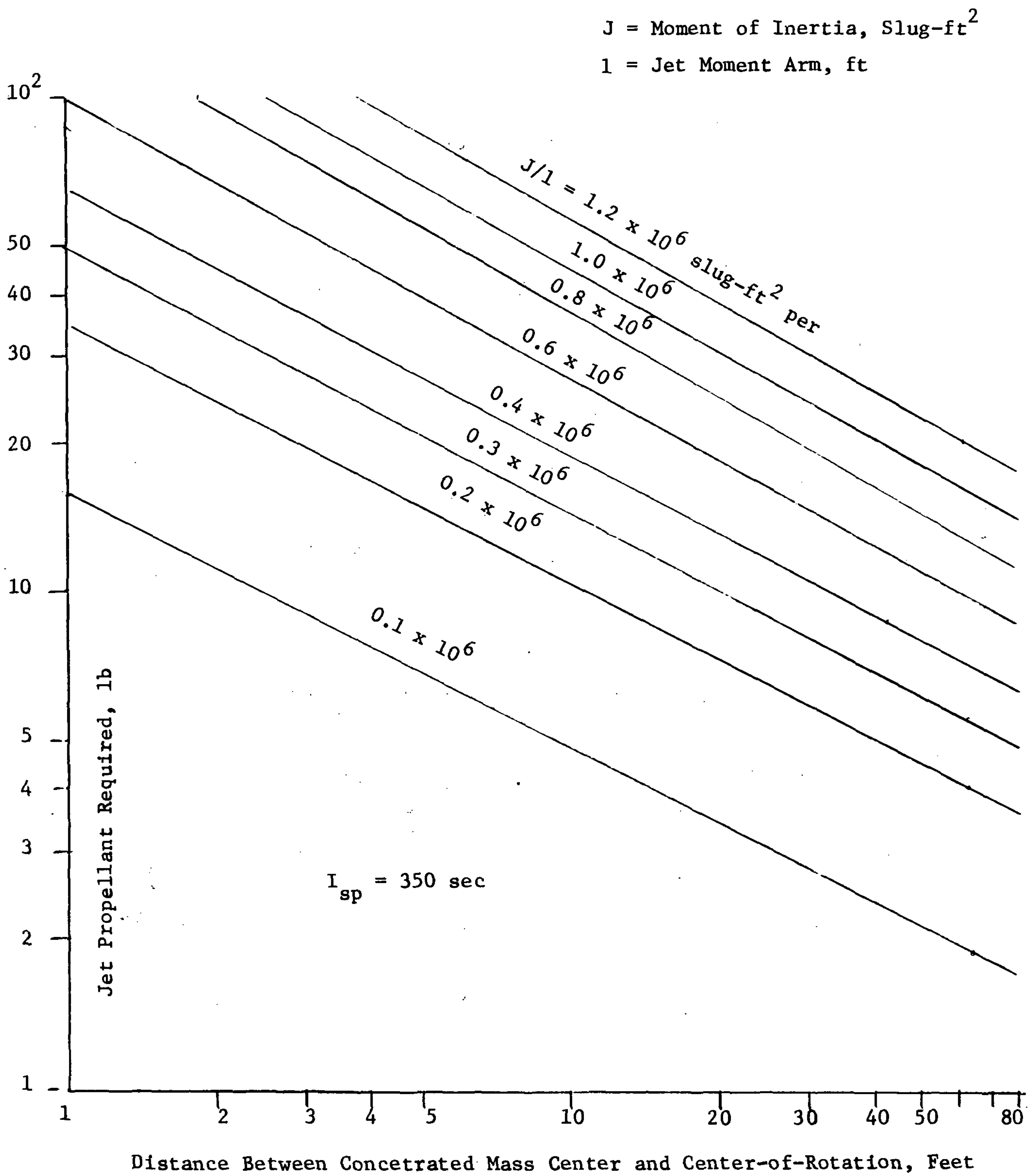


Figure 3-16. Jet Propellant Required to Achieve 10^{-4} g by Rotation During Either Spin-Up or Spin-Down

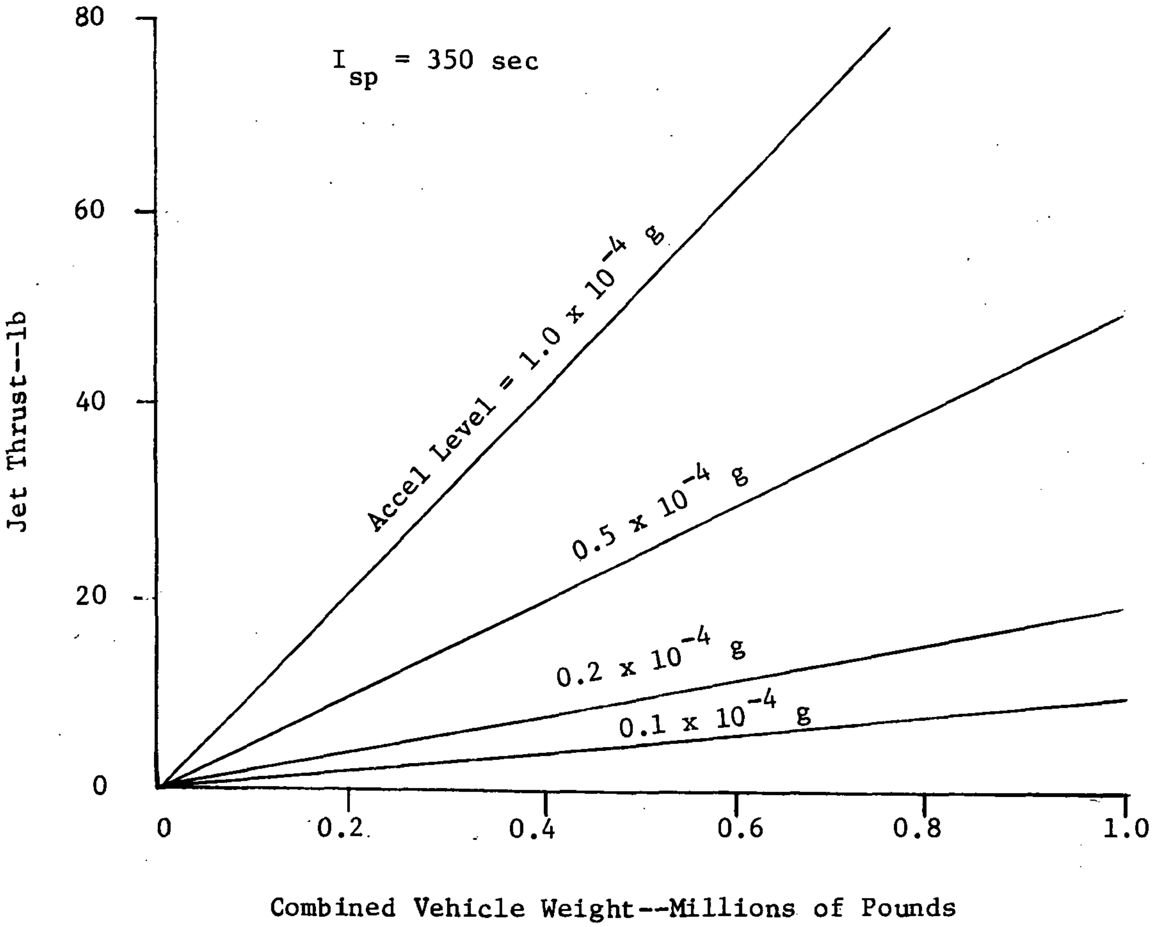


Figure 3-17. Thrust Level Required to Maintain Vehicle Linear Acceleration Level

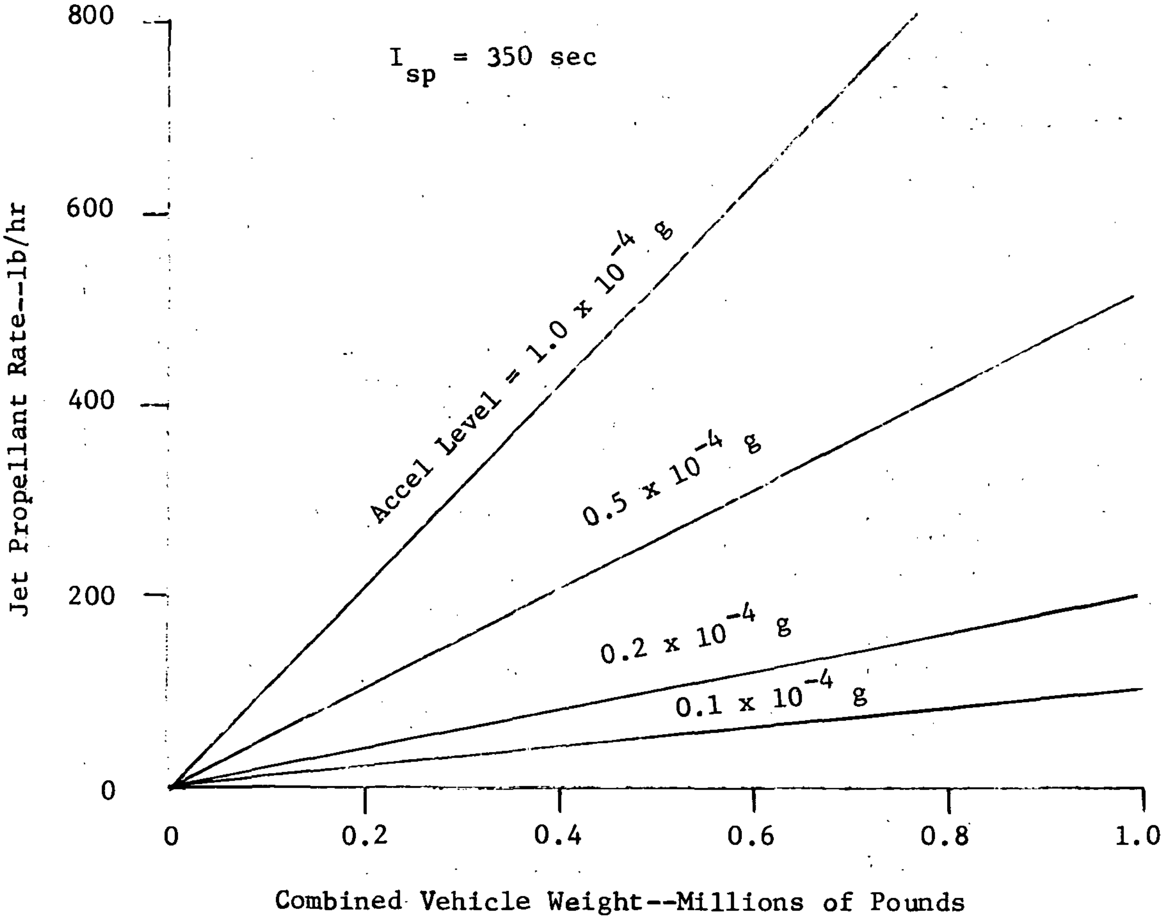


Figure 3-18. Propellant Consumption Rate Required to Maintain Vehicle Linear Acceleration Level

	Related Procedure Number	
	6-1	6-2
During cryogenic propellant transfer some form of thermodynamic control of the receiver tank is required, to avoid exceeding receiver tank pressure limits and to control propellant temperature within the required range. The receiver tank will normally contain some propellant residual in a gaseous state. Also, gas is generated in the receiver tank when the warm tank walls give up heat to the incoming cryogenic propellant. This residual and generated gas must be displaced, compressed, or condensed as propellant enters the tank.		
The resultant temperature of the propellant transferred will depend on the initial conditions and the performance of the thermodynamic control concept employed.		
4. Elements in contact with propellants shall be capable of operating effectively at the specified temperature levels.	X	X
Freezing of pumps or other expulsion devices could reduce the propellant flow rate or even cause a complete stoppage. Freezing of vent control valves could cause a hazardous rise in pressure in the tank and transfer lines. Freezing of flow meters could result in inaccurate control of the transfer, wastage of propellant, or even failure to transfer enough propellant for completion of the planned mission. Specified contact temperature levels will be required and monitored to prevent hazards.		
5. A means shall be provided for verifying the alignment, interlock, and seal integrity of propellant transfer lines at the physical interface between the two mated elements or between tank set and element prior to initiating fluid flow.	X	X
Alignment inaccuracy could restrict the flow of propellant, disrupt control of either the means for fluid expulsion or the liquid/gas interface, or cause the interconnect mechanism to malfunction. Failure to interlock the transfer lines could result in wasteful leaks, in contamination of nearby equipment and structures, and possible in the generation of combustible mixtures inside the mated elements. Because undesirable changes may occur during reduction of temperature to cryogenic levels, verification should be made both before and after chilldown.		

	Related Procedure Number 6-1	Related Procedure Number 6-2
6. Each type of propellant shall be transferred through lines, valves, and pumps dedicated to handling that type of propellant, using isolation and barriers between the lines to allow for parallel fluid flow.	X	X
It is necessary to prevent a failure in one line from inducing a failure in a second line carrying another type of propellant and thus creating a very hazardous condition. Mixing of gases is to be avoided as well as mixing of the cryogens. A method of accomplishing both dedication and isolation is to have all docking interfaces provide a line interconnect fixture, adjacent and external to the docking fixture, in addition to the docking fixture even though there may be only two propellant transfer ports. Space inside the fixture or rack can be compartmentalized using insulated panels to separate LH_2 lines, LO_2 lines, and nonpropellant lines.		
7. A means shall be provided for safe purging or clearing of transfer lines across a physical interface prior to use and separation.	X	X
This requirement is designed to prevent contamination of the attachment mechanism and other equipment near the interface and to reduce potential hazards to safe separation upon completion of propellant transfer. A number of means are possible for purging the lines (and tank) as described for expulsion in (1) above, with the pump expulsion method selected as best for a baseline system. This system will consist of a pump located in the extreme exit portion of the propellant tank or in the propellant transfer line between the vehicles and is driven by some power system such as a gas generator and turbine or fuel cell and electric motor.		
8. Control of propellant transfer shall be established in one of the interfacing elements as a control center and exercised on both sides of the interface.	X	X
Control of propellant transfer may be manned or automated but must reside at only one point to prevent indecision and interference. To operate properly the control center must receive information and send commands to all operating components at any location. Unified control over all parts of the sub-		

Related Procedure Number	
6-1	6-2

systems is essential to safe, effective transfer. The communications system links the related elements of the propellant transfer system with the integrated space program. It provides data for monitoring subsystems status and event occurrence as well as providing means for commanding control. It provides these data to ground an in-flight monitors and support vehicles (such as shuttle and tug) through MSFN. It provides a backup to the GNC system by recording positions in space and rate of change of position. TV cameras assist in remote monitoring of maneuvers and inspection of vital propellant transfer and docking connections. Data from these sources will be telemetered to control locations and transmitted in real time. Voice communications are provided as required. The communication system can be divided into three functional areas: intercommunication equipment; data equipment; and RF equipment, all interfacing to perform the mission. (See communications activity (9) for detailed discussions of communications requirements and operations and procedures.)

9. A means shall be provided for measuring or gauging the amount of propellant transferred or stored at any time. — 6-1: X; 6-2: X

To meet the objectives of propellant transfer with appropriate operational control and flexibility, the mass of LH_2 or LO_2 in all tanks under low-g conditions must be measured by a suitable propellant gauging subsystem. The amounts transferred must also be measured and known at all times. The system output will have to be compatible with the ground control systems and the on-board communications subsystem. An accuracy of approximately one percent of full tank is desirable in order to determine such problems as excessive boil-off or gross leaks. Candidate propellant gauging concepts include Radiation Sensor System, Radio Frequency Sensor System, Capacitance Sensor System, Ultrasonic Sensor System, and Discrete Sensor System. Table 3-3 presents design description and capability data that were developed in the OPSS study (DS-451) to satisfy the particular needs for fluid transfer for the OPD.

Related Procedure Number	
6-1	6-2

Table 3-3. Typical Propellant Gauging Subsystem Characteristics

Item	Requirement
Accuracy	±1% of full tank
Power	100 watts max at 28 vdc input
Response	10 seconds max for full-scale change
Output	0-5 vdc for full-scale change
Stability	750 hours minimum between service and calibration
Linearity of Electronics	±0.25% of full scale
Warmup	20 minutes maximum
Checkout	Capability to simulate various propellant tank modes for automatic c/o purposes

10. Provision shall be made for determining and reducing or eliminating hazards and non-safe conditions in the transfer of propellants and providing appropriate equipment and systems for monitoring and maintaining safety. (6-1: X; 6-2: X)

System safety in propellant transfer activities in space is a mandatory requirement for such activities and operations to continue. The proximity of LH_2 and LO_2 propellants in the transfer procedure imposes hazardous implications for which protective means are required.

11. Propellant modules shall be capable of being utilized as propellant tank sets by the space-based propulsive vehicle. (6-2: X)

Propellant modular transfer includes their use as interchangeable tanks for propulsive elements, even though they may also have integral tanks for reserve and emergency operations.

	Related Procedure Number 6-1	Related Procedure Number 6-2
Large vehicles, like CPS, may carry 20 or more such modules and switch from an empty to a full module during its mission. Refill is accomplished by exchange of the empty module for a full one. Use of a module as a tank set requires an assembly and disassembly operation for each mission.		
12. Propellant modules utilized with nuclear propulsive vehicles shall be single tanks that carry only LH_2 fuel.	X	X
The RNS does not use an oxidizer. Elimination of dual tanks for this vehicle would reduce the structural weight required throughout each mission.		
13. Propellant modules utilized with chemical propulsive vehicles shall be capable of being configured into tank sets containing the two propellants in the ratio to be used by the vehicle's engines.		X
A tank set could have two modules each with only one propellant or a single module with dual tanks. The number of sets depend on the propellant needed for the mission. Loading only the type of propellant in a module would (a) minimize heat transfer between tanks, (b) simplify fuel line connections to the engines, and (c) reduce chance of forming combustive mixtures near the interconnect points.		
14. Alignment aids and propellant line interconnectors shall remain sealed until initiation of feed to the engines.		X
This is needed to prevent leaks and malfunctions of the interconnectors. To accomplish this the attaching and handling points used for transport and storage of the propellant module could be well removed from the interconnector assembly. If the attachment mechanism contained the alignment aids and propellant line interconnectors, these could be recessed and protected to prevent inadvertent damage.		

FUNCTIONAL REQUIREMENTS BY VEHICLE

Included in this subsection are those propellant-transfer requirements which can be related to specific element pairs and/or to specific orbital elements. All element pairs identified in the operational procedures applicability matrix (see Section 3.5) for which a propellant transfer logistics option remains (see Section 3.3 where four logistics options have been retained for further study out of a total list of eleven) are included. The space-based tug, as an intermediate transport vehicle, has been deleted from additional study in Section 3.3. Also deleted from additional study were the OPD and the EOS orbiter as a tanker. The interface between the EOS and the user vehicle (RNS, CPS, or tug) always involves an additional element, i.e., a propellant module. This module may be purely a logistics tank, or may be a combination of logistics tank and a tank-set. In the latter case, the tank-set would remain attached to the user vehicle when it conducts its mission.

Table 3-4 presents propellant quantity and EOS flight requirements imposed by each of the three user vehicles, i.e., CPS, RNS, and tug.

Table 3-4. Propellant Quantity and Orbiter Flight Requirements

	Supplier/Receiver					
	EOS/Tug		EOS/CPS		EOS/RNS	
Requirement/Parameter	EOS	Tug	EOS	CPS	EOS	RNS
Propel. Quantity - 1 Refill						
LH_2 - (lb)	-	12,570	-	170K	-	300K
LO_2 - (lb)	-	66,375	-	910K	-	-
Total (lb)	-	78,945	-	1,080K	-	300K
Number of EOS Flts - 1 Refill						
Fluid Transfer	1.4	-	19.2	-	9.2	-
Modular Transfer	1.4	-	18.1	-	8.9	-

Number of EOS flights is shown for both fluid and modular transfer to the user, and are based on logistics Options Nos. 8 and 7, respectively (see Section 3.3). The supporting data for the determination of the number of flights are presented in Appendix A9.

Table 3-5 presents requirements imposed by fluid transfer operations on the orbiter, the propellant logistics tank, and the user vehicle. The requirement for thrusters (for liquid/vapor interface control), pumps and compressors, and interconnect extension mechanisms have been imposed on the logistics tank rather than the user. This was done in order to minimize the weight impact on the user vehicle - weight which would otherwise have to be carried on the user vehicle mission. Since it is anticipated that the orbiter would be separated from the logistics tank/user at the time actual fluid transfer takes place (see Section 3.3), the EOS orbiter requirements would be limited to those relating to status monitoring during delivery, handling, and propellant dumping. The propellant dumping capability would be utilized in the event of an aborted mission requiring the orbiter to return to earth prior to the accomplishment of the propellant transfer operation. The orbiter performance capability probably will not permit return to earth with a full load of propellant (approximately 60,000 pounds) in the cargo bay.

Table 3-5. Vehicle Requirements for Fluid Transfer to User Vehicle

Element / Function or Design Feature	EOS/User*		
	EOS Orbiter	Logistics Tank	User Vehicle
Docking Ports			
Fluid Transfer	No	1	1
Handling/Holding	Optional	1	Optional
Align & Interlock Verification Capab.	No	-	Yes
Thrusters for Liquid/Vapor Interface Control	No	Yes	No
On/Off Control of Thrusters for L/V Interf. Control	No	-	Yes
Propel. P/L Dumping Capab.	Yes	Yes	No
Control of Transfer Ops	No	No	Yes
Instrum - Status Monit.	Yes	-	Yes
Pumps, Compressors, etc.	No	Yes	No
Interconnect Extension Mechan.	No	Yes	No

*Requirements are applicable to CPS, RNS, and S.B. tug as user vehicle.

Table 3-6 presents requirements imposed by modular transfer on the EOS orbiter, the modular propellant tank (tank-set concept) and the user vehicle (CPS, RNS, or tug). The requirements apply only if the user vehicle is designed to the tank-set concept. Since the modular tank would be accompanying the user vehicle on its mission, it is optional whether certain hardware items should be placed on the tank or the user. No unique thrusters are required for liquid/vapor interface control since no fluid is transferred until required by the main engines of the user in performance of the user vehicle mission.

Table 3-6. Vehicle Requirements for Modular Transfer to User Vehicle

Function or Design Feature \ Element	EOS/User*		
	EOS Orbiter	Modular Tank**	User Vehicle**
Docking Ports			
Fluid Transfer	-	1	1
Handling/Holding	Optional	1	Optional
Align & Interlock Verification Capab.	No	-	Yes
Thrusters for Liquid/Vapor Interface Control	No	No	No
Propel. P/L Dumping Capab.	Yes	Yes	Yes
Control of Transfer Ops	Prime	No	Backup
Instrum.-Status Monit.	Yes	-	Yes
Pumps, Compressors, etc.	No	Optional	Optional
Interconnect Extension Mechan.	No	Optional	Optional

*Requirements are applicable to CPS, RNS, and S.B. tug as user vehicle.

**User vehicle is assumed designed to accept the modular tank, i.e., the tank-set concept.

3.7 DESIGN INFLUENCES AND PREFERRED APPROACH SELECTION

This paragraph presents comparisons between the various approaches for performing propellant transfer in earth orbit, selects the preferred approach for refueling each user vehicle, and identifies design influences. Although there are only two basic approaches for refueling a vehicle, i.e., modular and fluid transfer, there are many variations or combinations of these approaches which can be utilized. These combinations are referred to as propellant logistics options, and have been described in Paragraph 3.3. Of the total of eleven logistics options which were originally identified in this study, four were selected for detailed study and analysis (see Paragraph 3.3 for the selection rationale). Figure 3-]9 presents all eleven logistics options and identifies the four options to be compared and to be included in the selection process.

Options Nos. 1, 7, 8, and 11 are the most viable options identified in this study for performing propellant transfer. Options Nos. 1, 8, and 11 involve fluid transfer to the user vehicle. Options Nos. 1 and 11 require a mini-depot as an intermediate element (see Paragraph 3.2 for a definition of this element and Appendix A9 for a physical description). Only Option No. 7 involves the tank-set concept, and requires that the user vehicle be designed to accommodate main-engine tanks which can be exchanged in orbit. The tank-set doubles as a logistics tank for propellant delivery from earth. In all four cases the logistics tank is separated from the orbiter in earth orbit subsequent to delivery, and in all four cases an empty logistics tank is returned to earth by the orbiter. In Options Nos. 1 and 8 the orbiter remains in earth orbit while the propellant is being transferred to the user, then returning to earth with the same tank after it has been emptied. In Option No. 11 the orbiter also returns to earth with the same tank; however, the orbiter is not required to remain in orbit while the user is being refueled because the mini-depot has permanently installed integral tanks which are filled from the logistics tank.

For Options 1 and 11, linear acceleration for liquid/vapor interface control is selected as a viable concept. Although rotational acceleration might be equally viable for refueling a tug, it would be very impractical for the RNS or CPS due to the required mini-depot boom length for c.g. control (see Appendix A9). Linear acceleration has also been selected for Option No. 8, as discussed in Paragraph 3.3.

The selection of the preferred logistics option for refueling each of the user vehicles (RNS, CPS, and tug) is based upon the evaluation of eight factors. One of these factors is the design influence or impact on the user vehicle. The design influence on the user is essentially the same for all options except Option No. 7, the tank-set concept. The design influence of fluid transfer on the user is presented in Paragraph 3.6 and in Appendix A9. Figure 3-20 summarizes the penalties on the user vehicle if the modular interchange (tank-set) concept is used.

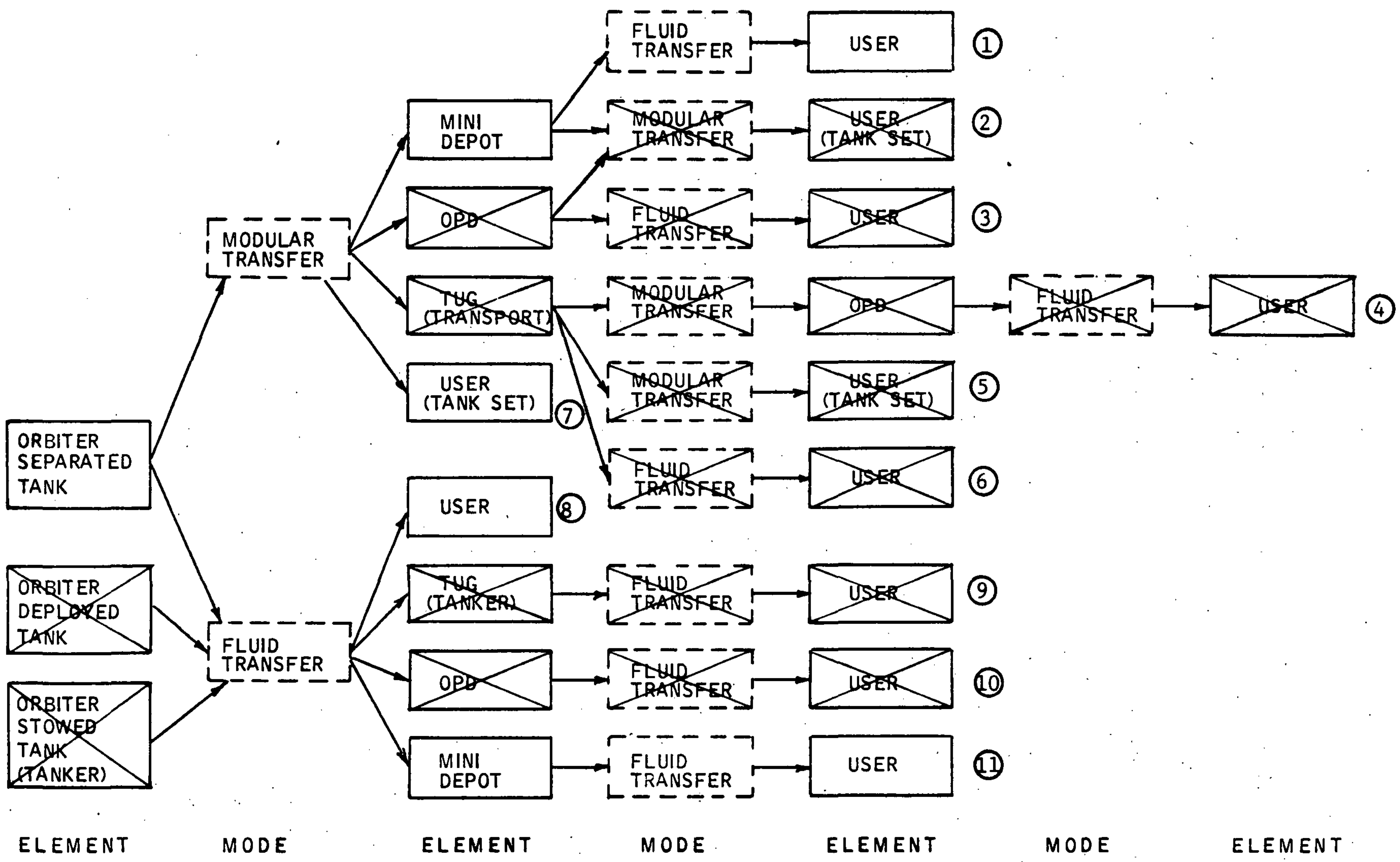


Figure 3-19. PROPELLENT TRANSFER LOGISTICS OPTIONS

User Vehicle Design Configuration	Non-Mod.	Modular	
Vehicle Tank Concept	Perman.	Perman.	Tank-Set
Vehicle Weight Penalty Items:			
- Ground Insulation System			√
- Additional Handling Require.			√
- Additional Boiloff Capacity			√
- Additional Interf. Isol. Equip.		√	√
- Additional Struct. for Rigidity		√	√
- Additional Docking Port		√	√

Figure 3-20. Weight Impact of Tank-Set Concept on User Vehicle

The use of the fluid transfer mode allows the user vehicle to have tanks which remain permanently attached to the user and which can be delivered to orbit empty. These permanent tanks, as indicated on Figure 3-20, can be of two types: (1) tanks which are integral to the basic vehicle design and which would be installed in the vehicle on the ground (non-modular vehicle design); and (2) tanks which are delivered to orbit separately, and assembled permanently to the vehicle cluster in orbit (modular vehicle design). In addition, the modular vehicle design is also amenable to the propellant tank-set concept which involves the exchange of full tanks for empty tanks in earth orbit, i.e., the modular propellant transfer mode. Figure 3-20 uses the non-modular vehicle design configuration as a baseline for comparison purposes. The check marks identify the applicability of vehicle weight penalty items to vehicle tank concepts. For the modular vehicle design configuration, the tank-set concept results in higher tank weights than does the permanent tank concept due to the first three weight penalty items listed on Figure 3-20.

Table 3-7 presents a comparison of the four options, and the rationale for the ratings applied for each evaluation factor, and the final selection of a preferred logistics option. Due to the utilization of the mini-depot as an additional element. Options No. 1 and 11 received relatively unfavorable ratings against the following evaluation factors: safety impact; maintenance impact; relative cost; and operational complexity. From a commonality standpoint Option No. 7 rates lowest because each user vehicle (with the tank-set concept) would require tanks which are optimized for the user vehicle and its mission.

A considerable degree of commonality in tank design for refueling of the tug and CPS by Options No. 1, 8, and 9 could exist. The external dimensions, docking ports, and much of the internal design of the logistics tanks could be the same (see Section 3.4 for design concepts). Due to the additional boil-off of LH_2 in the CPS (as compared to the tug) because of

Table 3-7. Comparison/Selection of Logistics Options

Evaluation Factor \ Logistics Option	(1) * MT → M. DEP, FT → USER	(7) MT → USER	(8) FT → USER	(11) FT → M. DEP, FT → USER	RATIONALE FOR RATINGS.
Safety impact	High	Medium	[Low]	High	Greater impact with additional element
Maintenance impact	*High*	[Low]	[Low]	*High*	*Mini-depot requires additional* maintenance
Technology status	Advanced	Advanced	Advanced	Advanced	Technology development approximately equal
Relative cost	High	[Low]	[Low]	High	High cost of additional element
Operational complexity	High	Medium	[Low]	High	High with additional element medium with tank set
Commonality	[Medium]	Low	[Medium]	[Medium]	Low with tank set. Very similar logistics tank for tug and CPS
Design influence on user	[Low]	High	[Low]	[Low]	Integral tanks can minimize weight of user vehicle
Number of orbiter flights: Tug	1.36	1.32	1.35	1.38	Option (11) losses highest due to two fluid transfers
CPS	19.20	18.10	19.19	20.44	
RNS	9.16	8.90	9.16	9.46	

NOTES:
- [ ] Denotes favorable rating
- See Figure 3-19 for logistic options flow chart
- * MT = Modular Transfer; FT = Fluid Transfer

PREFERRED OPTION: No. (8) Fluid transfer to user from a logistics tank. The logistics tank is delivered directly to user by orbiter.

RATIONALE FOR SELECTION: Lowest cost and operational complexity. Good commonality and relative low design impact on user the longer time period required to refill a CPS, the ratio of LH_2 to LO_2 in the logistics tank would be higher for the CPS. Since the RNS requires only LH_2 and because the orbiter cargo bay imposes a volume limitation on transport of LH_2, the RNS logistics tank will be approximately 60 feet long. The tug/CPS logistics tank would be approximately 40 feet long.

The number of orbiter flights required to refill each of the user vehicles is a minimum with Option No. 7 since the only propellant losses involved are boil-off losses. Option No. 11 requires the most number of orbiter flights primarily because of the propellant losses associated with an additional fluid transfer operation. The supporting data for the determination of the number of flights are documented in Appendix A9.

The preferred logistics option selection for propellant resupply of all user elements is Option No. 8. The primary drivers are cost and operational complexity. Secondary drivers are commonality and relatively low design impact on the user vehicles.

UTILIZATION OF EOS PAYLOAD DELIVERY CAPABILITY

The following is a discussion of mission planning considerations for maximizing utilization of EOS orbiter payload delivery capability, primarily in conjunction with the preferred propellant transfer logistics option (i.e., Option No. 8, direct fluid transfer).

As discussed in Section 3.4 and illustrated in Figure 3-13, a possible propellant transfer logistics tank for refueling the tug and the CPS would be approximately 40 feet long, weigh approximately 4800 pounds, and have a propellant capacity of 60,200 pounds. This results in a total weight of 65,000 pounds, which is equal to the maximum delivery capability of the orbiter to 200-250 nautical mile altitude and 28.5-31.5 degrees inclination (refer to pages 3-16 and 3-17). The propellant logistics tank for refueling the RNS, which requires LH_2 only, would be sized to occupy the total available volume in the orbiter cargo bay (i.e., 60 feet long by 15 feet diameter). This LH_2 tank would weigh approximately 7000 pounds with a capacity of approximately 34,000 pounds of LH_2.

A total of 20 EOS flights are required to refuel the CPS (refer to Table 3-7), of which the first 19 flights would be made with a full-up propellant logistics tank with a total weight of 65,000 pounds each. Additional EOS flights would be required to deliver the CPS payload in modular form. Providing high utilization of the EOS payload delivery capability presents no problem. Refueling the RNS would require ten EOS flights (refer to Table 3-7), nine of which would involve full utilization of the orbiter delivery capability as limited by cargo-bay size. The space-based tug with a propellant capacity of 78,900 pounds (refer to Appendix C for description of the tug baseline model used for this study) would require considerably less than the total amount of propellant that could be delivered to orbit in two EOS flights with full-up propellant logistics tanks (i.e., 120,400 pounds). Hence, consideration must be given to mission planning methods for maximizing utilization of the orbiter for resupply of the tug with propellant and with tug payload.

The requirements for delivery of propellants and payloads to earth orbit in support of space-based tug missions will vary considerably from one tug mission to the next. Tug propellants required for a given mission may range from 10,000 or 20,000 pounds up to a maximum of perhaps 80,000 pounds, depending upon the tug mission delta-V requirements and the weight of tug payload to be delivered. The tug payload weight for a given mission may range from a few hundred pounds up to 10,000 pounds or more. This imposes a considerable challenge to the mission planner relative to planning of the sequence of tug missions and the supporting orbiter missions so as to maximize utilization of the EOS payload delivery capability. With the preferred propellant transfer logistics option (direct fluid transfer), there are at least four basic methods that can be used in various sequences to increase EOS utilization as listed below:

1. EOS delivery of a full-up propellant logistics tank to orbit followed by transfer of the total propellant quantity to the tug.

2. EOS delivery of a full-up propellant logistics tank to orbit, transfer of a portion of the propellant to the tug prior to the tug mission, and transfer of the remaining propellant to the tug after completion of the tug mission. This requires that the orbiter remain in orbit while the tug mission is being conducted.

3. EOS combined delivery of a partially loaded propellant logistics tank and the tug payload, i.e., payload sharing.

4. Same as "3" with an additional payload emplaced in orbit by the orbiter. This delivery method may impose a requirement for an additional shorter propellant logistics tank for smaller propellant quantity deliveries in conjunction with multiple payloads.

It is believed that the application of the above methods to mission planning can result in acceptably high utilization of EOS payload delivery capability in support of tug missions and in conjunction with the direct fluid transfer logistics option.

Although the direct fluid transfer logistics option has been selected in this study as the preferred method for refueling of the CPS, RNS, and the tug; it cannot be categorically stated at this time that a mini-depot propellant storage facility will not prove ultimately to be a desirable means for supporting a space-based tug. This type of facility has potential advantages from the standpoint of providing increased flexibility in mission planning pertaining to both EOS missions and tug missions. The EOS could possibly deliver full propellant loads on most propellant delivery missions, storing excess propellants at the mini-depot. This would also permit greater flexibility in the selection of time at which tug refueling occurs and the amount of propellant transferred for each tug mission. Total space programmatic considerations (including a detailed traffic model) and detailed cost estimates of various mini-depot configurations are required to conduct the necessary mini-depot evaluation trades. The major trades would be cost of mini-depot versus delta costs associated with utilization of EOS payload delivery capability with and without a mini-depot.

DESIRABLE TECHNOLOGY ITEM

Linear acceleration has been selected in this study as a viable concept for liquid/vapor interface control for fluid transfer. The other two identified alternatives are rotational acceleration and capillary devices for surface tension. All three concepts are discussed in paragraph 3.4 and in Appendix A9. The primary reasons for not selecting a capillary system are the development problems and associated development risk. If future development efforts related to capillary systems should prove this concept feasible, a re-evaluation of its application to fluid transfer might result in the selection of this concept over the other two alternatives.

4.0 ATTACHED ELEMENT OPERATIONS

Attached element operations designate that interfacing activity in which one element provides operations support to another attached element while the latter element is stored, operating, or being serviced or checked out. The support may take different forms. It may be as simple as monitoring the attached element while it is in quiescent storage. It may involve removal of exposed film and supply of expendables during periodic servicing; or it may be a provision of some service such as orientation or pointing of the attached element while it is operating. Other examples of operational support considered under attached element operations are pressurization of an attached element to permit crew visitation, data transfer and analysis, supply of electric power, and thermal control.

4.1 SUMMARY

The attached element operations activity is involved with 51 of the potential 117 element-to-element pairs. These 51 interactions are divided into any one of three modes of operations: (1) RAM operations, (2) service and checkout, and (3) quiescent storage. Relating to the mode of RAM operations are three alternate approaches: (1) independent, (2) dependent, and (3) modular dependent. These approaches apply to the subsystem level of activity and, as a result, a given mode may involve more than one alternate approach.

Paragraph 4.4 defines the design concept models applicable to attached element operations. Essentially, those functions relating to RAM operations and experiment program requirements are defined for the EOS, MSS, and RAM. In addition, mission performance data (payload, altitude) for the EOS are defined.

Paragraph 4.5 presents a summary of the operational procedures which are presented in detail in Appendix B of this report. A total of three operational procedures has been developed for the attached element operations activity; one each for RAM operations, service and checkout, and quiescent storage.

The functional requirements determined for attached element operations have been grouped into two main categories in paragraph 4.6. The first category consists of general requirements that are applicable to functions or operations that must be performed in the accomplishment of attached element operations. These requirements have been cross-referenced to applicable operational procedures. The second category is more specific requirements which are presented in matrix form for each of the three modes of operation and related to each applicable element pair. Requirements for support of RAM operations are related to vehicle orientation, electrical power, and orbital maintenance; while those for servicing and checkout are concerned with monitoring, calibrating, and routine servicing.

Paragraph 4.7 presents the analyses associated with the selection of the preferred alternate approaches. In general, the dependent approach (the supported element completely dependent on the supporting element) is selected for providing support for the service and checkout mode, and for the quiescent mode. For the RAM operations mode while attached to the MSS, most support required by the RAM is within the basic design capabilities of the MSS. One exception to this is imposed by three RAM payloads requiring attitude pointing to less than ±0.25 degree. The following is a brief summary of the alternate approach selections for the MSS-supported RAM operations mode, and the rationale for these selections.

Function	Approach			Rationale
	Dependent	Independent	Mod. Depend.	
Communications	X			Avail. on MSS
Data management	X			Avail. on MSS
Environmental control	X	X		Certain functions avail. on MSS
Thermal control	X			Avail. on MSS
Attitude control				
$> 0.25^{\circ}, 0.05^{\circ}/sec$	X			Within MSS capab.
$< 0.25^{\circ}, 0.05^{\circ}/sec$			X	Augment MSS cap.
Electrical power	X			Avail. on MSS

Throughout the analyses of alternate approach selection for EOS-supported RAM operations there was the intent to utilize as much of the EOS capability as possible without imposing additional requirements on the EOS subsystems. For example, RAM's generating less than 1 Mbps data may utilize the existing EOS capability. RAM's generating data at a greater rate would need to provide the additional hardware to meet the higher requirement rather than impose an additional requirement on the EOS. The following briefly summarizes the approach selections for the EOS-supported RAM operations mode, and the rationale for these selections.

Function	Approach			Rationale
	Dependent	Independ.	Mod. Depend.	
Communications				
Tracking and voice	X			Avail. on EOS
data				
< 1 Mbps	X			Avail. on EOS
1 to 10 Mbps*			X	RAM transmitter and EOS antenna
Up to 50 Mbps		X		Tape storage up to 6 cubic feet plus equipment
Data management		X		Minimize EOS scar and sensitivity to crew size
Environmental control		X		
Thermal control		X		EOS limited to sustaining itself
Attitude control				
$> 0.5°$, $0.05°$/sec	X			Within EOS capab.
$< 0.5°$, $0.05°$/sec			X	Augment EOS cap.
Electrical power				
< 500 watts avg. & 20 kw-hr	X			Within EOS capab.
> 500 watts avg. & 20 kw-hr		X	X	Augment EOS capab.

*Ground network model is limited to 1 Mbps data transfer rate

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4.2 ELEMENT INTERFACE AND MISSION MODULE MATRICES

Most of the propulsive elements, the space stations, and the depots have the capability to support other elements in some manner. Only the CPS employed as an orbital injection stage (OIS) would not provide operational support to any other element. Such support is not required for initial earth orbit injection. Figure 4-1 displays the particular element-to-element interactions identified with attached element operations. The interactions are categorized by type of modes of operation. Of the 51 actual interactions, three involve support to attached RAM's, 30 involve servicing and/or support during quiescent storage, and 18 involve checkout without servicing or other support.

The EOS orbiter would provide operational support to attached RAM's during sortie missions. Both the low earth orbit and geosynchronous space stations would provide similar support to RAM's attached to them. The orbiter could service another orbiter, a space-based tug, a free-flying RAM, a retrievable satellite, a low earth orbit MSS, or an OPD. A ground-based tug might be used to service a space-based tug, a RAM when detached from a geosynchronous MSS, a retrievable satellite in an orbit beyond that which the orbiter could reach, a geosynchronous orbit space station, and an OPD. The space-based tug could perform the servicing missions enumerated for the ground-based tug plus similar missions to service the large chemical (CPS) or nuclear shuttles (RNS). On the other hand, the space-based tug could be stored and serviced at either of the space stations or at an OPD. Besides the space-based tug, the space stations would service detached RAM's assigned to them and store or service earth orbit resupply modules as required. Either the CPS or the RNS might service an MSS in geosynchronous orbit or a supportive OPD. A depot could provide both storage and servicing support to space-based tugs, and propellant resupply modules.

The mission models relating to particular element-to-element interactions are shown on the face of the matrix in Figure 4-2. All of the models except MM-9 identify at least one attached element operations interaction. As might be expected, the elements most frequently involved in this interface activity are the EOS orbiter (26) times and the space-based tug (25) times. The earth orbital resupply modules and the OPD's are involved on 19 occasions each. The geosynchronous space station is either a supporting or a supported element 15 times, and the low earth orbit MSS is involved on 10 occasions. In the matrix, the blocks representing the interactions between the space-based tug and the two space stations and that between the space-based tug and an OPD, all show two sets of mission model numbers separated by a slash. In each case, MM-4 identified opportunities for the space-based tug to service space stations or depots. On the other hand, MM-4, MM-5 and MM-6 provided occasions where the tug might be stored and serviced at an MSS or an OPD. Reference Volume 1 for the definition of mission models.

		SPACE VEHICLE INVENTORY																								
			TUG				RAM				SATELLITE				MSS		CPS				LUNAR PROGRAM SYSTEMS					
		EOS	NON RET	RTN	GRD BASED	SPACE BASED	ATT. EOS	DET. EOS	ATT. MSS	DET. MSS	EOS DELIV	EOS + 3RD ST	RETR, RESUP	EO RESUP MODS	LOW EO	GEO SYNCH	OIS	EO SHTL	CLS	RNS	OLS	TUG UNMAN	TUG MAN	RESUP MOD	LSB	OPD
	EOS	S	C	X	C	S	O	S	X	X	C	C	S	C	S	X		C	C	C	C	C	C	C	C	S
TUG	NON RET											X														
	RETURNABLE											C														
	GRD BASED				X	S			X	S		C	S	C		S		X	X	X		X	X	X		S
	SPACE BASED					S			X	S		C	S	C	S,Q	S,Q	X	S	S	S	X	X	X	X	X	S,Q
RAM	ATT. EOS																									
	DET. EOS																									
	ATT. MSS														O	O		X		X						
	DET. MSS														S	S		X		X						
SATEL	EOS DELIV																									
	EOS + 3RD ST																									
	RETR, RESUP																									
	EO RESUP MODS													X	S,Q	S,Q		X	X	X		X	X	X		S,Q
MSS	LOW EO														X											
	GEOSYNCH															X		S		S						
CPS	OIS																	X	X	X	X					X
	EO SHTL																	X								S
	CLS																		X		X	X	X	X	X	S
	RNS																			X	X	X	X	X	X	S
LPS	OLS																				X	X	X	X		
	TUG UNMAN																							X	X	X
	TUG MAN																							X	X	X
	RESUP MOD																							X	X	X
	LSB																								X	
	OPD																									X

LEGEND

Potential Interactions	117
Actual Interactions	51
O - RAM Operations	3
S - Servicing & Checkout	30
C - Checkout Only	18
Q - Quiescent Storage	6
X - Not Applicable	66

Figure 4-1. Attached Element Operations Interactions

		SPACE VEHICLE INVENTORY																								
		EOS	TUG				RAM				SATELLITE			EO RESUP MODS	MSS		CPS			RNS	LUNAR PROGRAM SYSTEMS					OPD
			NON RET	RTN	GRD BASED	SPACE BASED	ATT. EOS	DET. EOS	ATT. MSS	DET. MSS	EOS DELIV	EOS + 3RD ST	RETR, RESUP		LOW EO	GEO SYNCH	OIS	EO SHTL	CLS		OLS	TUG UNMAN	TUG MAN	RESUP MOD	LSB	
	EOS	2	1		7,8	2,4	3	2			1	1	2,4	2,5,8, 10,11	2			2	2	2	2	2	2	2	2	2
TUG	NON RET																									
TUG	RETURNABLE											7														
TUG	GRD BASED					8				8		7	8	8		8										8
TUG	SPACE BASED					4				4		4	5	5,10,11	4/4,5,6	4/4,5		4	4	4						4/4,5,6
RAM	ATT. EOS																									
RAM	DET. EOS																									
RAM	ATT. MSS														2,5	5,8										
RAM	DET. MSS														2,4	4,8										
SATEL	EOS DELIV																									
SATEL	EOS + 3RD ST																									
SATEL	RETR, RESUP																									
	EO. RESUP MODS														2	5,8, 10,11										2,5,8, 10,11
MSS	LOW EO																									
MSS	GEOSYNCH																	10,11		11						
CPS	OIS																									
CPS	EO SHTL																									4,10,11
CPS	CLS																									4,10,11
	RNS																									4,11
LPS	OLS																									
LPS	TUG UNMAN																									
LPS	TUG MAN																									
LPS	RESUP MOD																									
LPS	LSB																									
	OPD																									

Figure 4-2. Applicable Mission Models for Attached Element Operations

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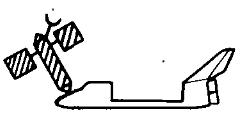
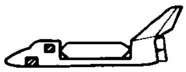
4.3 ALTERNATE APPROACHES

There are three alternate approaches defined for attached element operations; independent, dependent, and modular dependent. In most cases the approaches are not appropriately defined at the element or vehicle level of activity. As a result one must penetrate to a greater depth, such as the system or subsystem level of activity, in selecting alternate approaches.

Pictorially, the three alternate approaches for attached element operations are as follows:

	INDEPENDENT	DEPENDENT	MODULAR DEPENDENT
ATTACHED ELEMENT OPS			

A definition of the alternate approaches follows.

INDEPENDENT

The independent approach is applicable to those functions that are performed by an element (such as a RAM) completely independent of the attached supporting element (such as an EOS). A typical independent function might be atmospheric temperature control and circulation being provided solely by the RAM.

DEPENDENT

The dependent approach is applicable to those functions where the supported element (such as a RAM) is completely dependent upon the attached supporting element (such as an EOS). An example might be the dependency of the RAM on the EOS for transmission of voice and telemetry data (less than 1 Mbps) from the orbiting pair to ground stations.

MODULAR DEPENDENT

The modular dependent approach is applicable to those functions that are performed through support obtained from supplemental modules (such as a RAM support module) or kits that are add-on to the basic design configuration of either the supported element (such as a RAM) or the supporting element (such as an EOS). Communications and environmental control provide good examples of this alternate approach. If communications data rates are generated in excess of 1 Mbps and need to be delivered from orbit to ground in real time, then the RAM will need to provide its own processing and transmission by means of add-on equipment. (In conjunction with this equipment, the RAM would utilize the EOS S-band omni antenna and RF distribution components, which is illustrative of the dependent approach.) Environmental control for life support within a payload module will draw upon a separate module for provision of the habitable environmental control support.

ALTERNATIVES APPLICABILITY

Because the alternate approaches are defined at the functional level of activity, there exist opportunities where more than one approach may be selected for a given element pair. This selection will, of course, depend on the function being considered. In addition, for a given function there may exist more than one alternative, this being dependent upon the performance requirements and mission requirements. For example, consider communication data requirements for a RAM while operating in the EOS attached sortie mode. If data rates greater than 10 Mbps are generated and there is no mission requirement to transmit these data in real time to the ground, then the data may be stored on the RAM, independent of the EOS. On the other hand, if data rates are less than 10 Mbps but greater than 1 Mbps and real time transmission were required, then the RAM would provide the processing and transmitter but rely upon the EOS for modular dependency in the form of antennas and RF distribution. Finally, if data rates were less than 1 Mbps and real time transmission were required, then the RAM would be dependent on the EOS for full utilization of its communications system. Thus, a hybrid alternative selection exists not only for this element pair but also for this particular function.

The alternate approaches described in this paragraph and later utilized in the approach selection process in paragraph 4.7, are more appropriately applied to the RAM operations mode and are less applicable to the other two modes, service and checkout and quiescent. This will be more apparent from the analysis and discussion in paragraph 4.7; however, an observation at this point may clarify this statement. RAM operations encompass an "active" operation - experiments being performed, life support, communications, attitude orientation and stabilization are being called upon for support. Service and checkout and quiescent storage imply "passive" and dormant-type operations. That is, no experiments are being operated, little crew activity is required within the supported module, and much less sophisticated support is required from the supporting element. Because of the closer relationship of RAM operations with the mission objectives and their inherent more complex requirements, there exists a wide range of alternate approaches for RAM operations. On the other hand, because service and checkout and quiescent storage involve relatively less complex operations and support, nearly all alternate approaches become dependent on the supporting element or vehicle and are of little value in an alternate approach selection process.

4.4 DESIGN CONCEPT MODELS

This section addresses itself to the various design concept models utilized as a basis in the attached element operations activity. These design models are defined at a level of detail sufficient to aid in the analysis documented in the three subsequent sections; operational procedures, functional requirements, and preferred approach selection. The three design concept models presented herein are for the (1) modular space station, (2) earth orbit shuttle, and (3) research and applications module (RAM).

Attached element operations activity is involved with each of the 25 elements defined in the Orbital Operations Study vehicle inventory. Some of these vehicles are generically defined and as such represent a large number of individual vehicles that need to be considered in this activity. For example, the earth orbit cargo resupply module is definable as one baseline design concept, whereas an EOS attached RAM (sortie) represents some 37 different payloads (vehicles), all of which need to be examined in this study.

The ultimate result of examining each of the vehicles in the study inventory is to serve as a foundation for the selection of alternate approaches. For example, a sortie RAM experiment may require a data rate transmission requirement far in excess of the EOS capability. As a result, a choice exists as to the means of satisfying this requirement; kit the shuttle or the RAM for this one special requirement, redefine shuttle requirements, or redefine operations (record/store data for return to earth rather than transmit to ground). Thus, for this example, the design concept models for the shuttle and the sortie RAM provided a basis for the subsequent analysis and preferred approach selection.

Although there are 25 generic elements defined in the orbital operations inventory, only the MSS, the EOS, and the RAM's require the development of a design concept model for this activity. As defined in paragraph 4.3, the preferred approach for service and checkout and quiescent storage modes has essentially been selected and is defined as dependent on the supporting vehicle. As a result, alternate approach selections do not encompass these two modes. The RAM operations mode, on the other hand, involves all three alternatives (dependent, independent, modular support) and therefore requires a design concept model for the elements associated with this mode; namely, MSS, EOS, and RAM's. A definition of the design concept models is now presented for each of the three elements.

MODULAR SPACE STATION DESIGN CONCEPT MODEL

There are several significant characteristics of the modular space station that will have a direct influence on the alternate approach selection in paragraph 4.7. These characteristics encompass communications, attitude control, thermal, electrical power, crew, environmental control, and orbit maintenance and collectively constitute the MSS design concept model. The MSS itself represents an iterative design process wherein its design is directed by the basic mission objectives; namely, the experiment program objectives. As a result, it is likely that there already exists a strong compatibility between RAM operations and the MSS. However, because objectives of the space program are constantly changing, it is appropriate that there exists a design concept upon which the experiment programs can be evaluated and this is presented below.

Table 4-1 defines the MSS characteristics that are pertinent to RAM operations.

Table 4-1. MSS Design Concept Model

Characteristic	Interface	
	Initial	Growth Station
Electrical power available		
Average	4.8 kw	12.1 kw
Peak	7.2 kw	18.1 kw
Thermal	Dissipates metabolic heat	
Environmental control	MSS provided	
Orbit	240 to 270 n mi/55 degrees incl.	
Crew size (for experiment operations)	35 man-hr/day	90 man-hr/day
Attitude requirements		
Pointing accuracy	±0.25 degree	±0.25 degree
Stabilization	0.05 deg/sec	0.05 deg/sec
Communications	See Figure 4-3 and Table 4-2	

In addition to the previously defined characteristics, the following characteristics are also an integral part of the MSS design concept model.

1. The MSS has capability to maintain both inertially fixed and locally oriented attitude hold modes, X-axis perpendicular to the orbit plane or X-axis along the velocity vector.

2. The following ECS interfaces are available: heat transfer, air ducting, water, O_2, N_2 pressure equalization valve, airlock pumpdown, and external coolant freon loop.

3. Hardline wiring exists for provision of the following functions: timing, data transfer, caution and warning and subsystem monitoring.

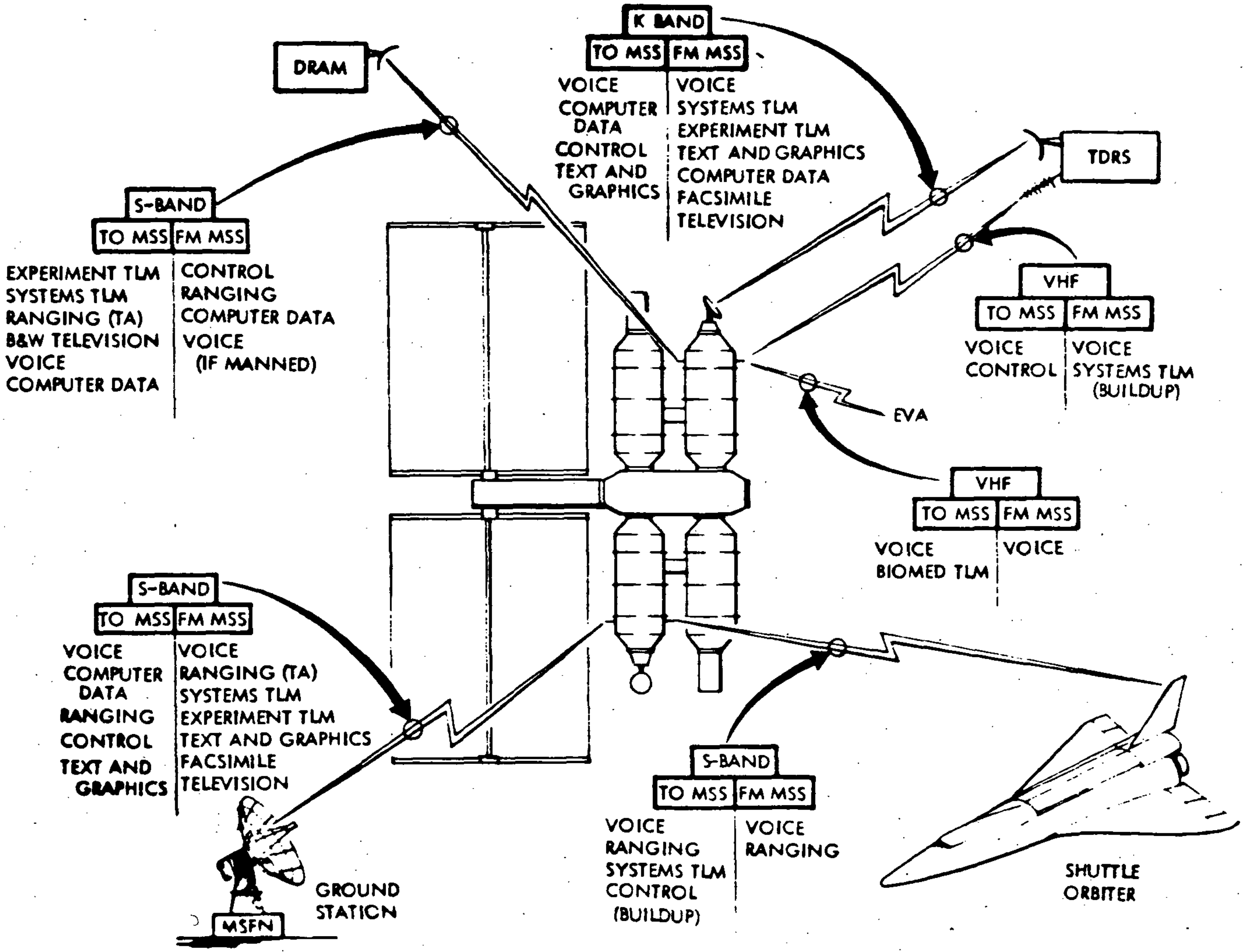


Figure 4-3 External Communication Link Requirements

Table 4-2. **External Communication Data Characteristics**

		RF Channel	Voice	Television	System TLM	Computer Data	Experiment Data	Text/Graphics	Command Data	EVA TLM	Facsimile	Ranging Measure	Ranging Respond
From Space Station To	Detached RAM	S-band	(1) 300-4000 Hz						10 kbps			0.5 mbps	
	Shuttle orbiter	S-band	(1) 300-4000 Hz		50 kbps							0.5 mbps	0.5 mbps
	MSFN ground terminal direct	S-band	(3) 300-4000 Hz	4.5 MHz	500 kbps	500 kbps	2.0 mbps	1.0 kbps		200 bps			0.5 mbps
	Ground terminal via TDRS	VHF	(1) 300-4000 Hz		10 kbps								
	Ground terminal via TDRS	K-band	(3) 300-4000 Hz	4.5 MHz	500 kbps	500 kbps	2.0 mbps	1.0 kbps		200 bps	0.5 MHz		0.5 mbps
	EVA	VHF	(1) 300-4000 Hz										
To Space Station From	Detached RAM	S-band	(1) 300-4000 Hz	2.9 MHz	50 kbps	500 kbps	Part of system TLM						0.5 mbps
	Shuttle orbiter	S-band	(1) 300-4000 Hz						1.0 kbps			0.5 mbps	0.5 mbps
	MSFN Ground Terminal Direct	S-band	(4)* 300-4000 Hz			500 kbps		1.0 kbps	1.0 kbps			0.5 mbps	
	Ground Terminal via TDRS	VHF	(1) 300-4000 Hz						1.0 kbps				
	Ground Terminal via TDRS	K-band	(4)* 300-4000 Hz			500 kbps		1.0 kbps	1.0 kbps				
	EVA	VHF	(1) 300-4000 Hz							200 bps			

*One of the four voice channels - ground to MSS - is a high-fidelity channel 30-10,000 Hz for entertainment.

EARTH ORBIT SHUTTLE DESIGN CONCEPT MODEL

The earth orbit shuttle (EOS), like the MSS, serves as the supporting vehicle during attached element operations and, as a result, a design concept model needs definition in order to proceed with the subsequent analyses of this activity. Early program planning envisioned the EOS as primarily a transportation vehicle. Now, the EOS is being thrust into a role wherein it serves as the supporting element (for a short period of time, approximately 7 to 30 days) much like the MSS. As a result of this, the compatibility of the EOS to the various payload (experiment) objectives is not as obvious as that existing with the MSS.

Table 4-3 defines the EOS interface characteristics and represents the design concept model.

Table 4-3. EOS Design Concept Model

Characteristic	Interface
Electrical power available	
Average	500 watts
Peak	800 watts
Energy	20 kwh
Maximum cargo bay size	15 ft diameter, 60 ft length
Crew provision	28 man-days
Pointing accuracy	±0.5 degree
Stability	
Combined jet	0.05 deg/sec
Single jet	0.025 deg/sec
Mission duration	7 days, nominal
Orbit/payload	25,000 lb to 275 n mi x 55 degrees incl. (Reference discussion in this paragraph)
Communications	Reference discussion in this section

Communications

The EOS communications interfaces of interest to attached element operations activity are those between EOS/attached RAM's and EOS/ground stations. No communication link presently exists between the EOS and the tracking and data relay satellite (TDRS).

Figure 4-4 illustrates the external communications links from EOS to ground, while Table 4-3 quantitizes the data requirements. The primary communications link from EOS to ground is via S-band, utilizing an omni directional antenna system. Although there exists the capability to transmit 25 kbps data to ground, this can be augmented by use of the TV mode to effectively increase this capability to 1 Mbps.

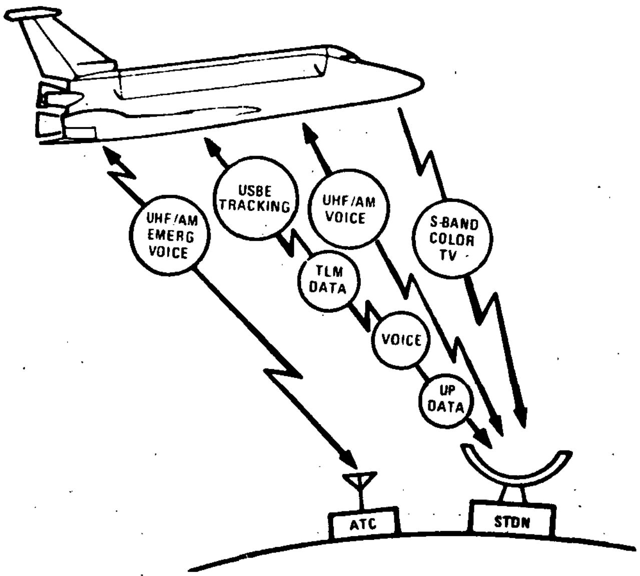


Figure 4-4. EOS External Communication Links

Figure 4-5 illustrates the EOS internal communications links together with the interface links.

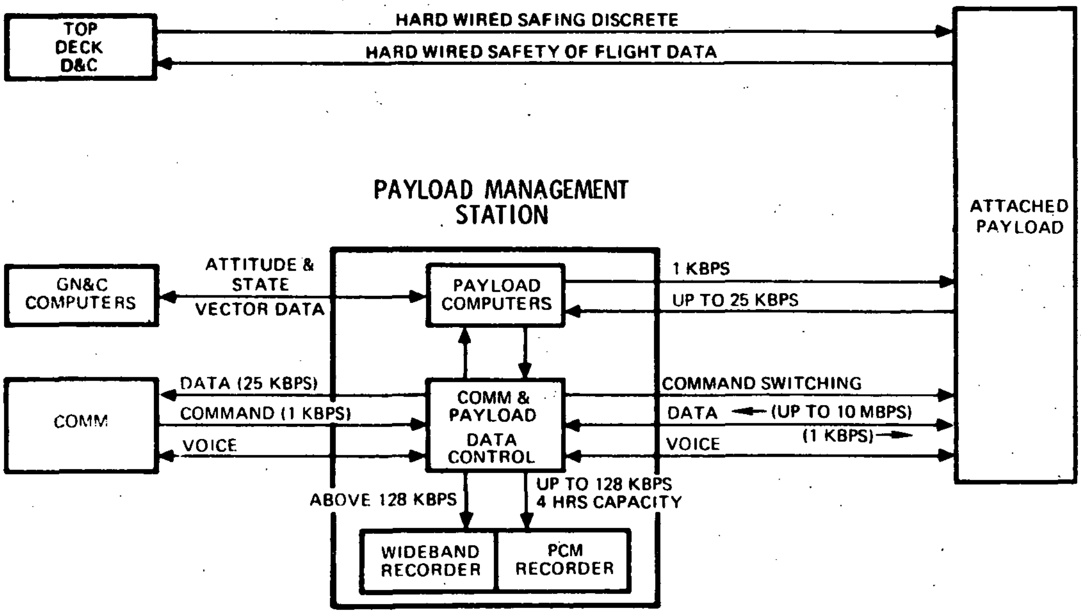


Figure 4-5. EOS Internal Communication Links

It should be noted that although there exists the capability to handle 10 Mbps of data across the interface, the EOS does not have the capability to transmit that rate to ground, nor does the ground network model have the capability to process this data rate.

Orbiter/Payload Model

The EOS is designed to deliver specific payload weight requirements to circular orbits; these requirements are summarized in the table below.

Orbit Characteristics		Payload Capability (lb)
Inclination (deg)	Altitude (n mi)	
28	100	65,000
55	270	25,000
90	100	40,000

Because the EOS is expected to deliver and support payloads at altitudes in addition to those specified in the previous table, there are defined parametric data relating payload weight to orbit altitude for three orbital inclinations. These data are presented in Figures 4-6, 4-7, and 4-8, and are defined for EOS conditions with or without the air-breathing system (ABES IN or OUT), and for both payloads up only and payloads up and down. Corresponding to the various altitudes are the orbit maneuvering system (OMS) propellant requirements. A more detailed definition of these payload/altitude requirements are presented in Appendix A7.

Sharing common propellant tanks with the OMS of the EOS is the propulsion system that performs attitude maneuvering (ACPS). The amount of propellant required for maintaining attitude hold is defined in Figure 4-9.

Changes in velocity of the shuttle orbiter may be required to maintain orbit characteristics (altitude). As a result of aerodynamic drag on the orbiter, the orbiter altitude will decrease as a function of time. Figure 4-10 presents the altitude loss of an orbiter at three initital altitudes (100, 200, and 300 nautical miles). From this illustration, for a period of 25 days the orbiter experiences an altitude loss of only 0.1 nautical mile for an orbiter initially at 300 nautical miles. It may also be observed that after only 5 days for an orbiter initially at 100 nautical miles an altitude loss of 10 nautical miles is experienced. Figure 4-11 presents the magnitude of the delta velocity required to sustain a given orbit altitude for three shuttle orbiter attitude configurations. Thus, an orbiter flying with the +X-axis along the velocity vector requires 50 fps delta V to maintain a 100-nautical mile orbit for 7 days.

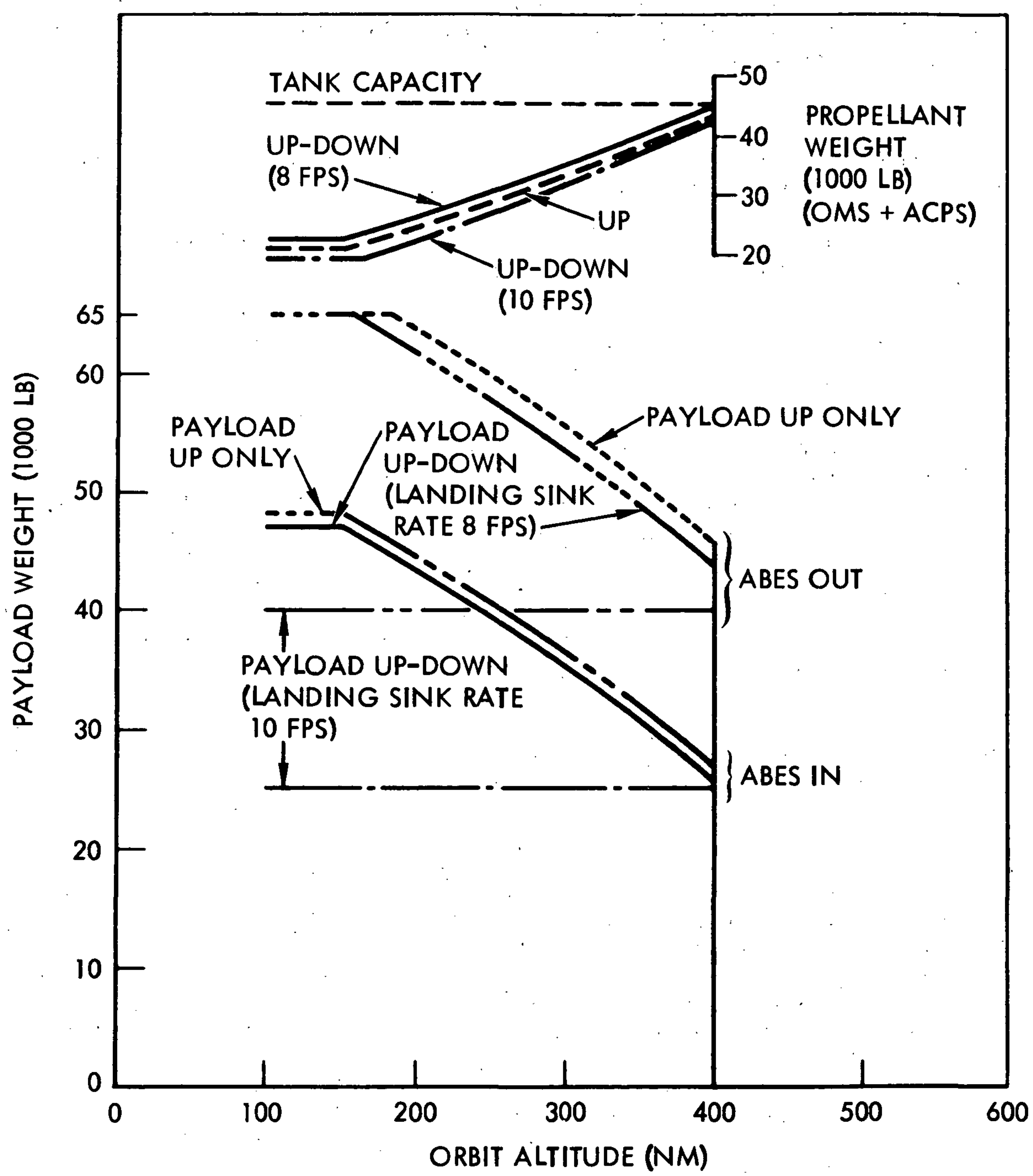


Figure 4-6. Payload Capability - Propellant Requirements
28.5 Deg. Inclination Angle

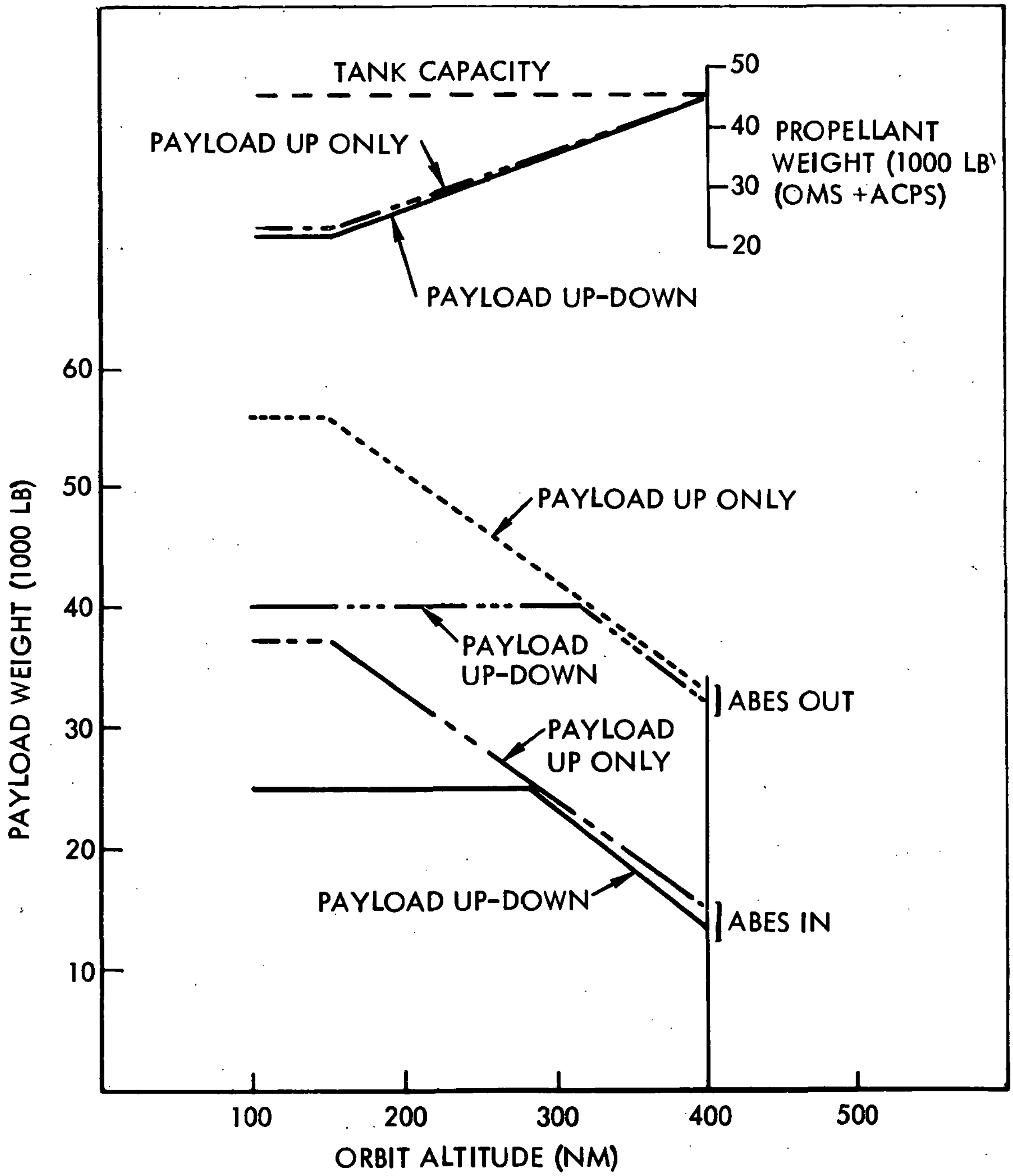


Figure 4-7. Payload Capability - Propellant Requirements
55 Deg. Inclination Angle

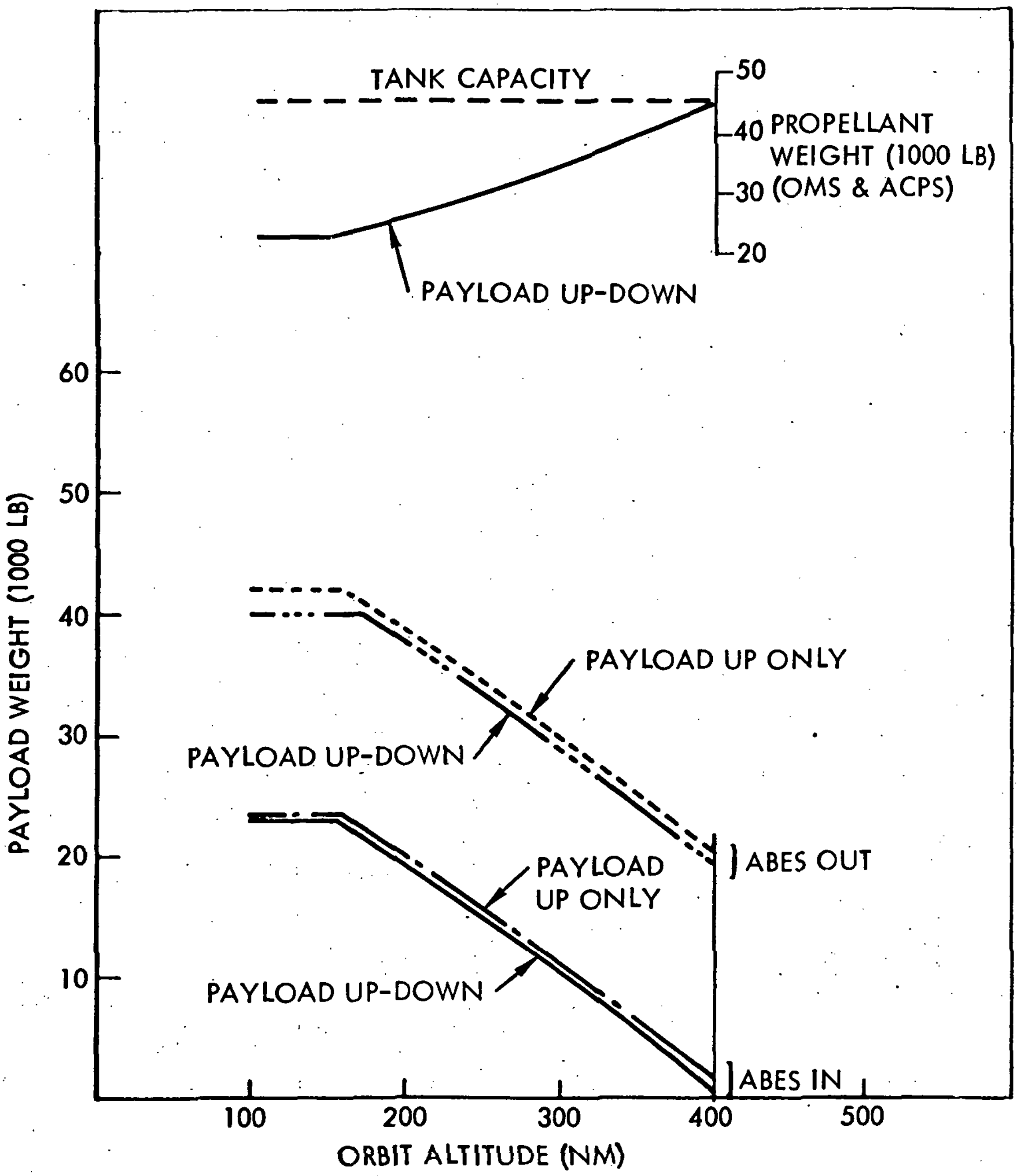


Figure 4-8. Payload Capability - Propellant Requirements
90 Deg. Inclination Angle

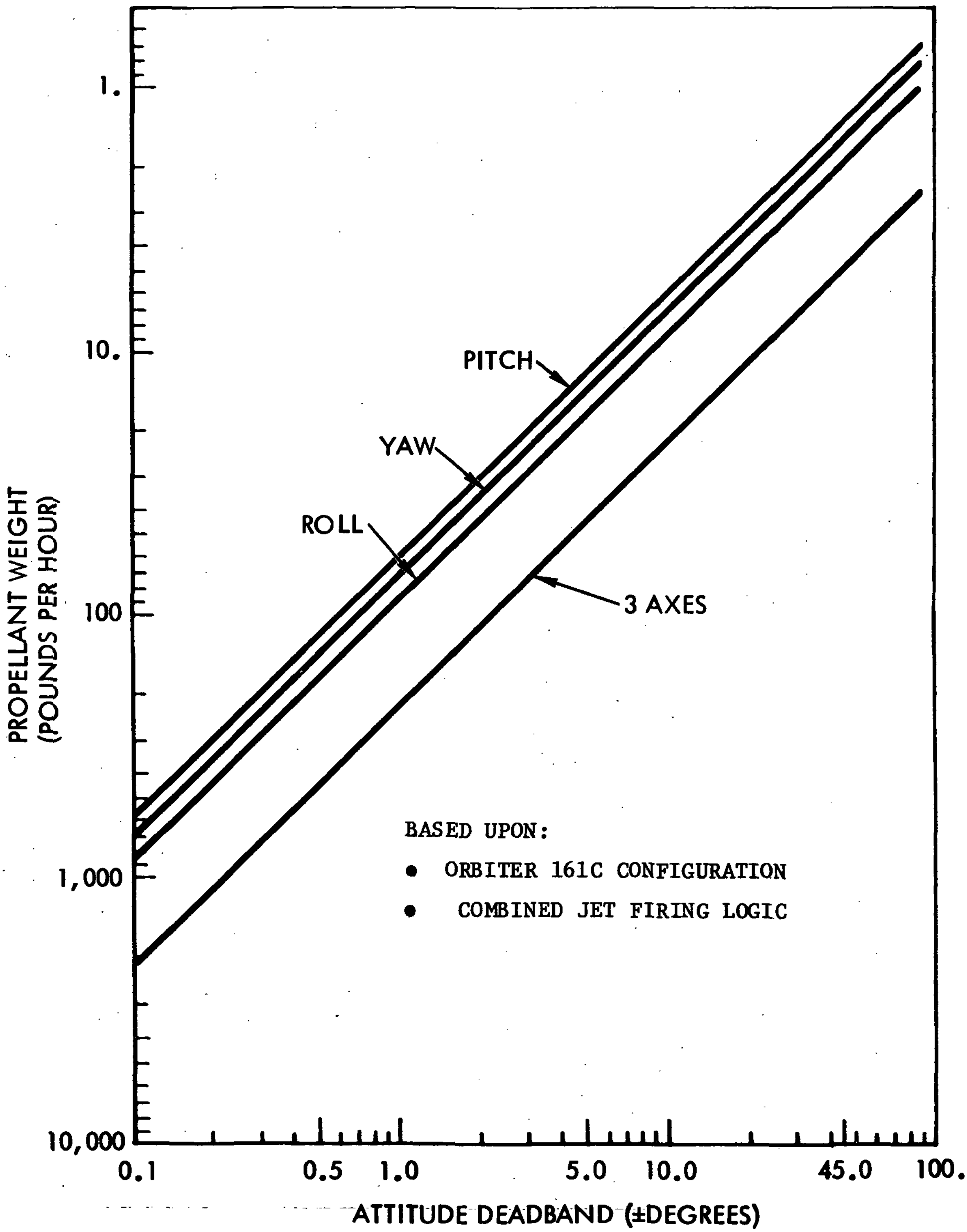


Figure 4-9. Attitude Hold, ACPS Propellant Requirement

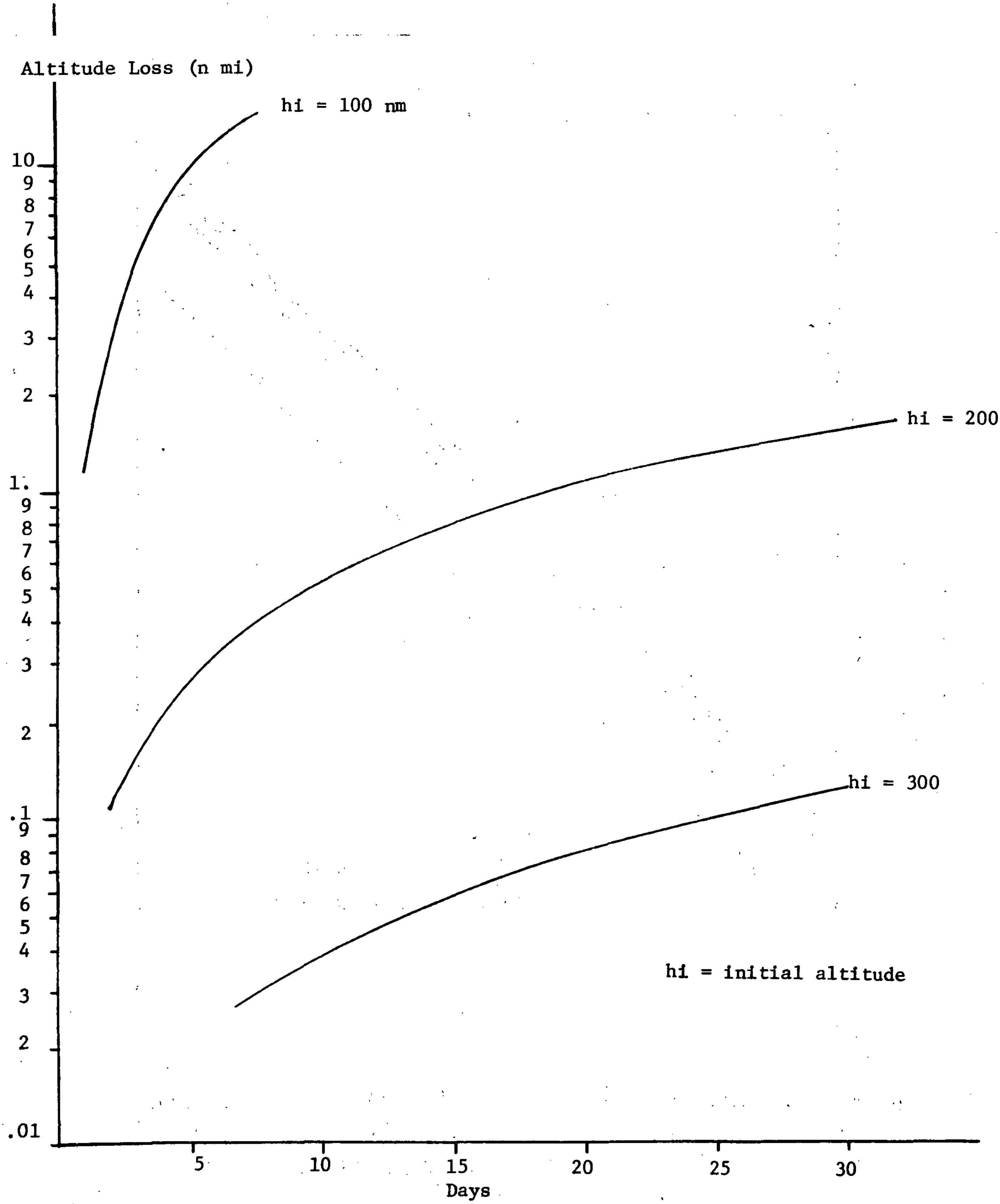


Figure 4-10. Shuttle Altitude LOSS
(+X Along Velocity, $W/_{CDA} = 124$)
1959 ARDC

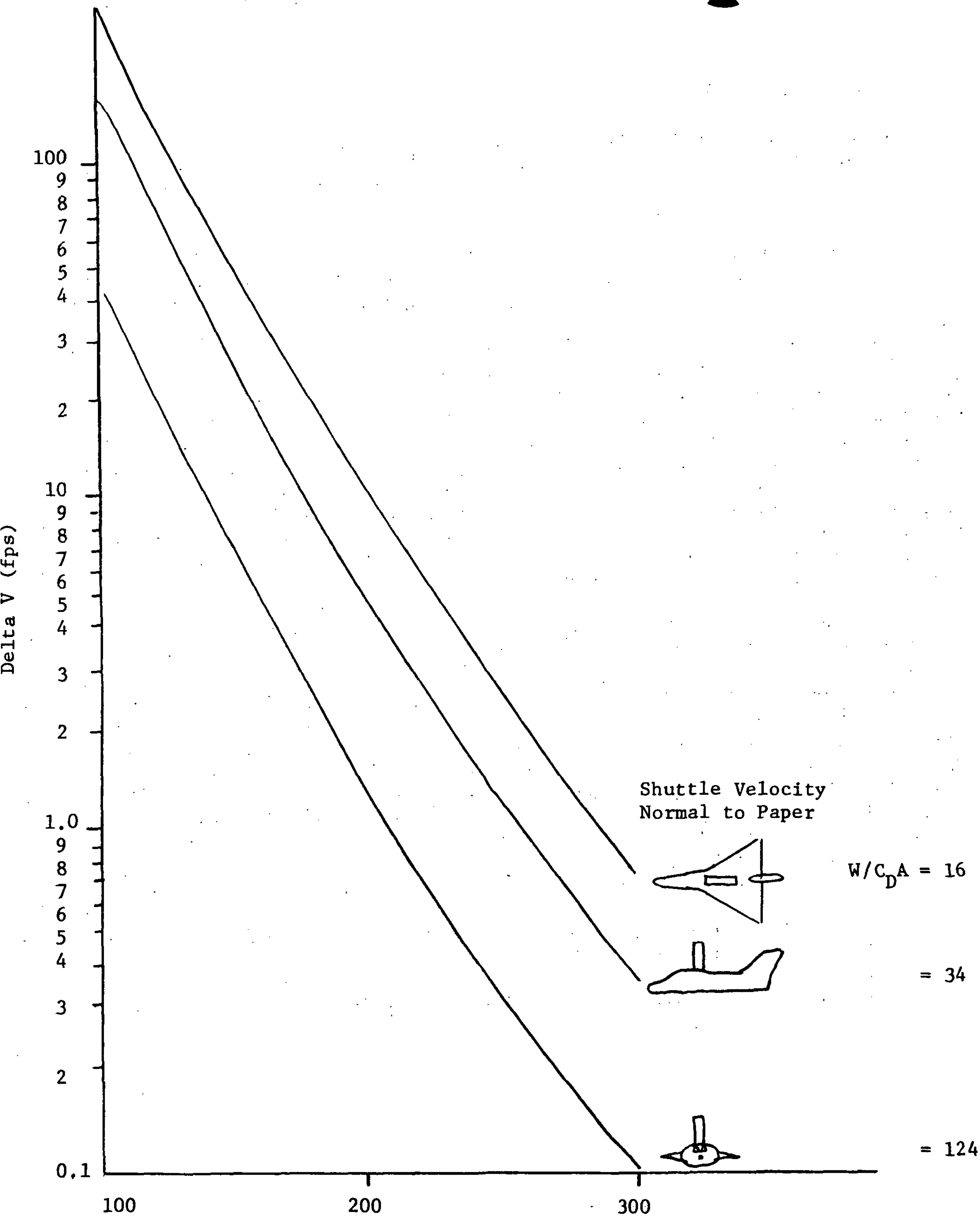


Figure 4-11. Shuttle 7-Day Orbit Makeup (30 day = 4.3 X "7 - Day Required") 1959 ARDC

RAM DESIGN CONCEPT MODEL

As presented earlier in this section, a design concept model is required for each of the three elements involved with RAM operations; these being the MSS, EOS, and RAM. The development of the design concept model for the attached RAM is now offered.

From the lowest common spectrum of configurations, the family of payload carriers from the RAM system can be identified and they are illustrated in Figure 4-12. The pressurized RAM has three identifiable derivatives: sortie RAM, RAM support module (RSM), and payload modules of two (or more) volumes. The unpressurized RAM is illustrated as a truss-type pallet representative of the basic function to be performed. Illustrated in Figure 4-13 is the relationship of each of the RAM payload carriers. The RAM "family" portrays a partitioning of the module types into categories of payload applicability. Of interest to the attached element operations are all five of the RAM module types - free-flyer, pallet, sortie RAM, RSM, and payload module. Configuration alternatives for both the sortie RAM and payload module are illustrated. These configurations are mission dependent and are bolted on to one end of the basic module, either a sortie RAM or payload module. The other end of the module serves as the berthing/docking interface, this being adapted to either the orbiter or MSS, whichever is appropriate.

With the payload carriers defined it is now appropriate to define the payloads themselves. These payloads can be thought of as being representative of the mission objectives or requirements. Serving as the basis for the RAM payloads is the 1971 Blue Book, further defined and supplemented by the MSFC Shuttle Payload Planning Activity. A baseline set of the RAM payloads was selected to fulfill the intent of the Reference Experiments Plan provided by the NASA for the seven Blue Book disciplines. Payloads were defined in the categories with the applicable attached element operations mode defined in parentheses: sortie mission RAM payloads (RAM operations), free-flying RAM payloads (servicing and checkout), and station-attached RAM payloads (RAM operations). Fifty-four baseline RAM payloads are summarized in Table 4-4. The payload data are divided into the following categories:

- Physical - total weight and volume, pressurized weight and volume
- Mission - orbit, orientation, pointing
- Resource - crew and power data
- Environment - acceleration, contamination, etc.

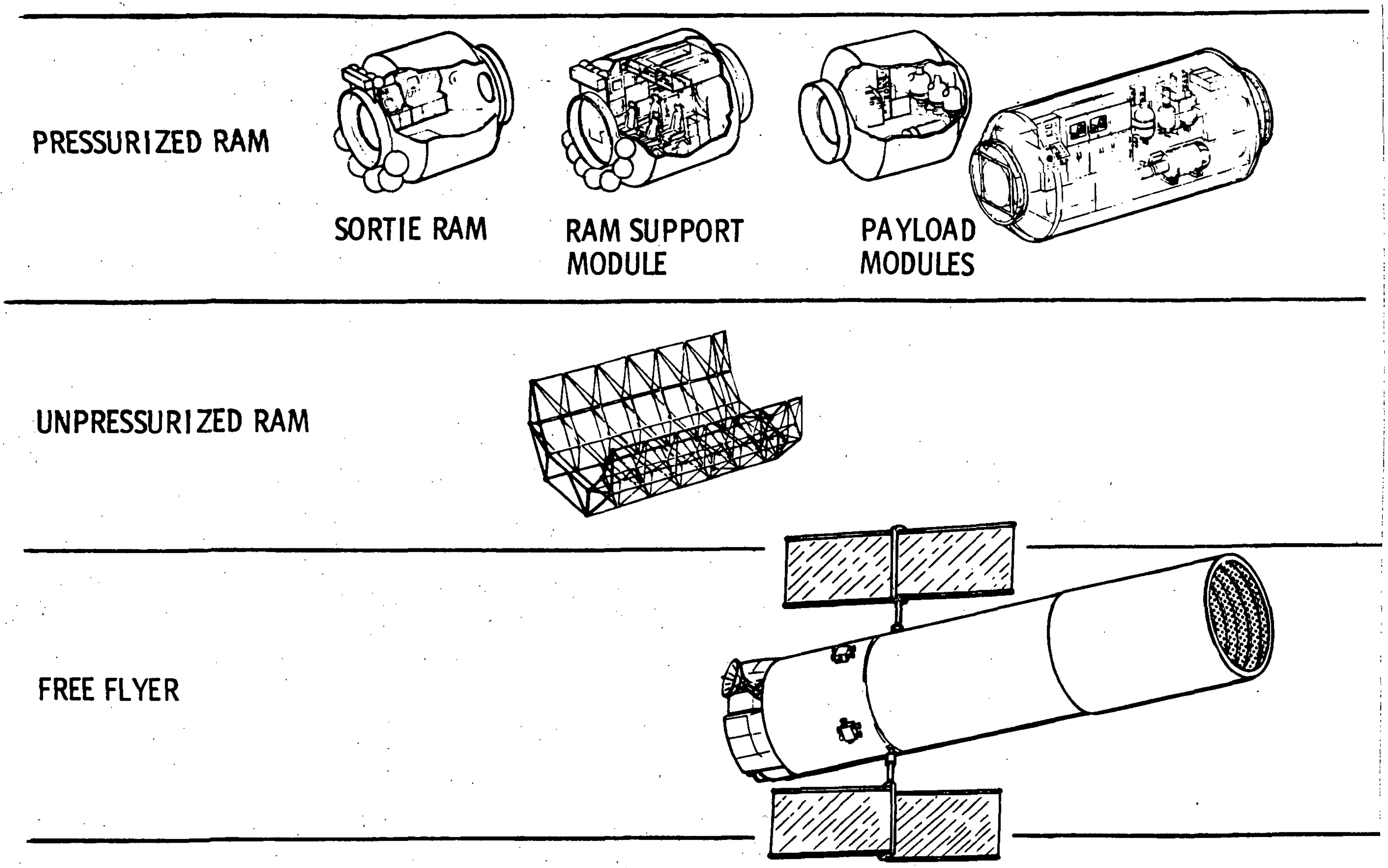
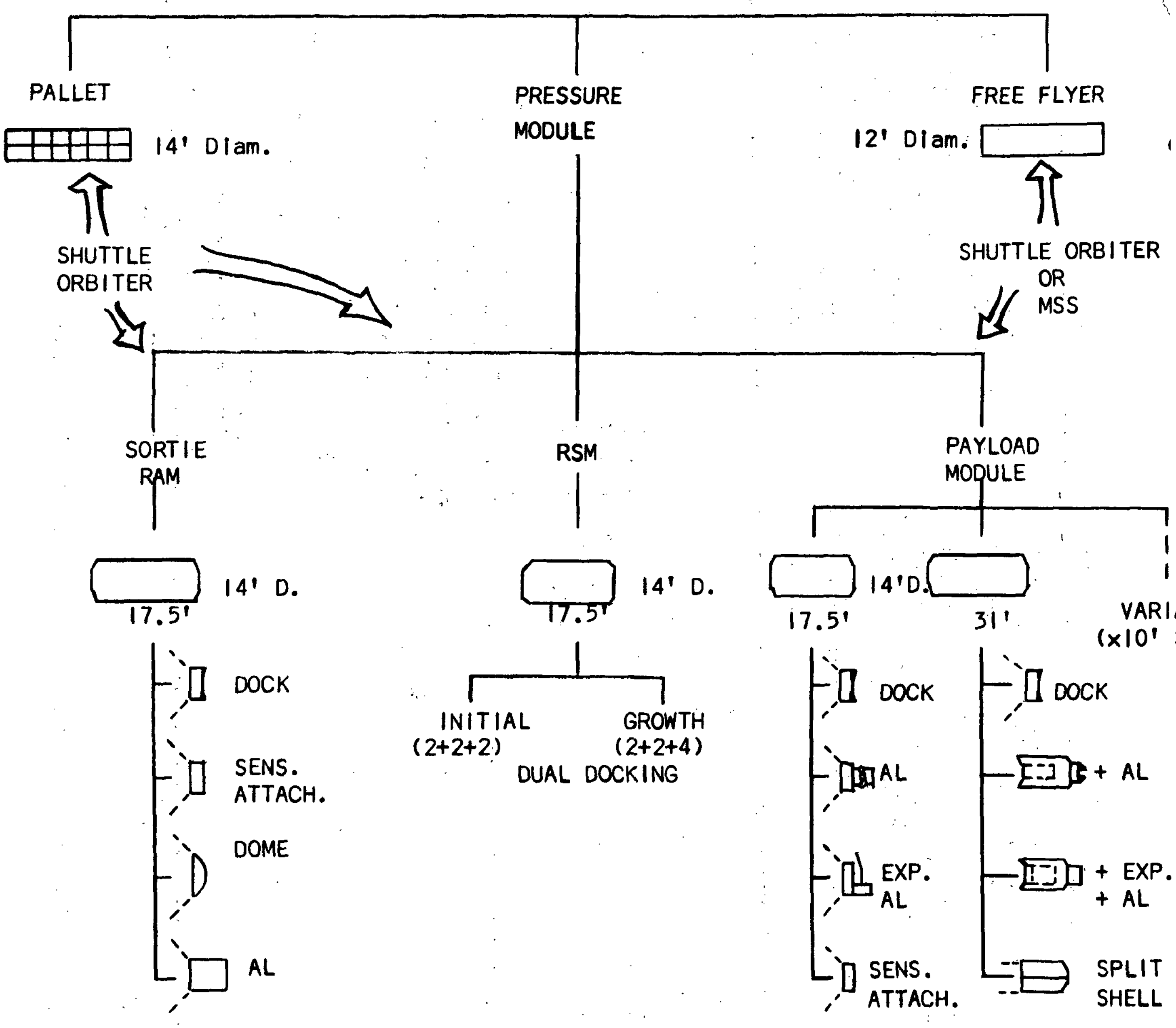


Figure 4-12. RAM Systems - Family of Payload Carriers



AL	Air Lock
EXP.	Experiment
SENS. ATTACH.	Sensors Attachment

Figure 4-13. RAM "Family"

Table 4-4 RAM Payload Summary Data

Payload Class	Discipline	(1) P/L No.	Code	RAM Payload Title	Physical: Exper Equip Weight Total (lb)	Physical: Exper Equip Volume Total (ft³)	Physical: Press Exper Weight Total (lb)	Physical: Press Exper Volume Total (ft³)	Mission: Orbit Preferred	Mission: Orbit Acceptable	Mission: Orientation	Mission: Viewing Constraint	Mission: Pointing Accuracy; Stability	Mission: Point Duration (hr/obs)	Resources: Crew Size Initial/Adv.	Resources: Skills	Resources: Skill hr/day Initial/Adv.	Resources: Power (W) Avg (on) Initial/Adv.	Resources: Power (W) Peak	Resources: Peak Power Duration (hr)	Resources: Elect. Energy (kW-hr/day) Initial/Adv.	Resources: Data Other Than Digital	Resources: Data Digital Rate (Bps)	Environment: Accel. (g)	Environment: Contam.	Environment: Radiation (rad/hr)	Environment: Temp (°K)	Special
Sortie	Astronomy	A3S1B		Austere Solar Astronomy (Telescope)	1,238	121	180	6	Sun sync, 200 n.mi.	Any within rad limits	Solar	Sunline >170 km horizon	10 arc-sec; 0.5-1.0 arc-sec/obs	0.01-0.8	2/4†	Astronomer/Astrophysicist	24/48	225	200Δ	0.7	11.0	Film H-α film	800	$< 10^{-3}$	Particles gases	$<10^{-3}$	286 ±1	
		A6S1B		Austere IR Astronomy (ARC Telescope)	10,000	284	2,190	121	28-55 deg, 270 n.mi.	0-55 deg, 200-400 n.mi.	Stellar	>45 deg from Sun ≥30 deg from Earth	1.0 arc-sec; 0.5 arc-sec/obs	0.1-5	2/4	Astronomer/Astrophysicist	24/48	1100	1100Δ	0.75	37.5	—	3.2 k	$< 10^{-3}$	Particles gases	$<10^{-3}$	Telescope ≤3	
		A8S1V		Combined Austere Astronomy (Solar Telescope & High Energy Array)	2,278	216	440	48	Sun sync, 200 n.mi.	Any within rad limits	Solar, stellar	Sunline >170 km from horizon	10 arc-sec; 0.5-1.0 arc-sec/obs	0.01-0.8	2/4†	Astronomer/Astrophysicist	24/48	623	200Δ	0.7	17.2	Film	3.3 k	$< 10^{-4}$	Particles gases	$<10^{-3}$	301 ±2	
		A8S1W		Combined Austere Astronomy (UV Wide Field Telescope & High Energy Array)	1,890	239	530	108	<55 deg, >300 n.mi.	<55 deg, >200 n.mi.	Stellar	≥60 deg from Sun ≥15 deg to horizon	5-60 arc-sec; 1 arc-sec/obs	1 sec-1 hr	2/4†	Astronomer/Astrophysicist	24/48	500	150Δ	up to 60 min	13	Film	4 k	$< 10^{-4}$	Particles gases	$<10^{-3}$	289-291	
		A8S1X		Combined Austere Astronomy (UV Narrow Telescope & High Energy Array)	2,550	471	624	108	<5 deg, 400-500 n.mi.	<55 deg, 200-400 n.mi.	Stellar	≥60 deg to Sun ≥25 deg to horizon	1 arc-sec; 1.0 arc-sec/obs	0.2-0.8	2/4†	Astronomer/Astrophysicist	24/48	500	150Δ	0.1	13	Film	4 k	$< 10^{-4}$	Particles gases	$<10^{-3}$	289-291	
		A8S1U		Combined Austere Astronomy (ARC Telescope & High Energy Array)	10,968	380	2,458	169	28-55 deg, 270 n.mi.	0-55 deg, 200-400 n.mi.	Stellar	>45 deg from Sun ≥30 deg from Earth	1 arc-sec; 0.5 arc-sec/obs	0.1-5	2/4	Astronomer/Astrophysicist	24/48	1264	1100Δ	0.75	37.5	—	7.5 k	$< 10^{-3}$	Particles gases	$<10^{-3}$	Telescope ≤3	
		A8S1Z		Combined Austere Astronomy (IR Telescope & High Energy Array)	3,497	619	1,210	341	0 deg, 200-400 n.mi.	0-55 deg, 200-400 n.mi.	Stellar	>90 deg from Sun >60 deg from Earth	1 arc-sec; 1 arc-sec/obs	≤ 0.75	2/4	Astronomer/Astrophysicist	24/48	451	TBD	TBD	TBD	—	2.6 k	$< 10^{-3}$	Particles gases	$<10^{-3}$	65-85° F	
		A9S1J		Combined Austere Astronomy (Solar Telescope & High Energy Array)	2,681	343	668	108	<10 deg, 400 n.mi.	45-55 deg, 270 n.mi.	Solar	On solar disc >22 deg from horizon	10 arc-sec; 2.5 arc-sec/obs	≤0.75	2/4	Astronomer/Astrophysicist	24/48	491	185Δ	0.1	11.8	—	541 k	$< 10^{-3}$	Particles gases	$< 10^{-3}$	286 ±1 272-274	
	Physics	P5S1B		Combined Space/Plasma Physics (Austere)	3,950	192	1,148	44	Polar, ≥100 n.mi.	> 50 deg, 250 n.mi.	Earth	None	120 arc-sec; 12 arc-sec/sec	96 continuous	2/4	Optical/Electromechanical, Physicist/Nuclear Physicist	24/48	3000/3600	900Δ	3	53/58	—	7 M	—	Sensitive	—	—	Airlock
		P7S1A		Combined Cosmic Ray Physics & Chemistry (Austere)	2,636	229	1,070	166	<200 n.mi. 28 1/2 deg	Any	Parallel to air stream	None	1.0 deg; 0.1 deg/sec	10	2/4	Physicist, Phys. Chemist, Optical/Electromechanical	24/48	1750/1750	0	—	42.9/54	Film	40 k	—	—	—	—	Airlock
		P5S2A		Combined Space/Plasma Physics (Intermediate)	4,075	203	1,083	40	Polar, ≥100 n.mi.	>50 deg, 250 n.mi.	Stellar	Dark	1.6 arc-sec; 0.5 arc-sec/sec	1	2/4	Optical/Electromechanical, Physicist/Nuclear Physicist	24/48	3000/3600	1400Δ	2	55/62	—	7 M	—	Sensitive	—	—	Airlock
		P8S2B		Combined Space/Plasma/Cosmic Ray Physics (Intermediate)	6,567	291	1,464	57	Polar, ≥100 n.mi.	>50 deg, 250 n.mi.	Earth	None	±120 arc-sec 12 arc-sec/sec	96 continuous	2/4	Optical/Electromechanical, Physicist/Nuclear Physicist	24/48	3900/3900	0	—	45/66	—	7 M	—	Sensitive	—	—	Airlock
		P7S3A		Combined Cosmic Ray Physics & Chemistry (Complete)	11,920	757	10,829	697	<300 n.mi.	Any	Parallel to air stream	None	1.0 deg; 0.1 deg/sec	10	2/4	Optical/Electromechanical, Physicist/Nuclear Physicist	24/48	2400/2400	1500Δ	2	46/60	TV, Film	40 k	$<10^{-4}$	gases	—	—	Airlock
	Earth Observations	E1S1N		Earth Observation (Weather) - Austere	4,066	724	3,071	137	Polar. 100 n.mi.	50 deg*	Earth	±60 deg from nadir	±0.5 deg; 0.01 deg/sec	15 min/obs	2	Meteorologist, Tech's, Oceanographer	13.8	3400	900Δ	0.5/day	7.9	Film	125 k	$<10^{-5}$	Sensitive	—	—	
		E1S1O		Earth Observation (World Land Use Mapping) - Austere	4,818	396	3,820	124	Polar, 100 n.mi.	50 deg*	Earth	±60 deg from nadir	±0.5 deg; 0.05 deg/sec	25 min/obs	2	Photo Tech/Cartographer, Geographer, Geologist, Tech	16	4800	900Δ	0.9/day	14.7	Film	50.1 M	NA	Sensitive	—	—	
		E1S1P		Earth Observation (Air & Water Polution) - Austere	3,785	341	3,180	112	50 deg, 100 n.mi.	— *	Earth	±60 deg from nadir	±0.5 deg; 0.05 deg/sec	12 min/obs	2	Meteorologist, Oceanographer, Hydrologist, Tech's	17.6	3000	800Δ	~milli-secs	9.8	Film	51.3 M	—	Sensitive	—	—	
		E1S1Q		Earth Observation (Resource Location) - Austere	4,805	401	3,730	122	Polar, 100 n.mi.	50 deg*	Earth	±60 deg from nadir	±0.5 deg; 0.05 deg/sec	15 min/obs	2	Geographer, Agronomer, Optical, Photo Tech	16.8	4800	900Δ	0.75/day	11.2	Film	50 M	—	Sensitive	—	—	
		E1S1R		Earth Observation (Disaster Assessment) - Austere	4,407	394	3,380	115	70 deg, 100 n.mi.	50 deg*	Earth	±60 deg from nadir	±0.5 deg; 0.05 deg/sec	3 min/obs	2	Meteorologist, Geologist, Agronomist, Tech	13.8	2600	2800Δ	3-6 min/day	5.1	Film	51.4 M (800 M growth)	—	Sensitive	—	—	1.8×10^9 bits/day near R. T.
		E1S1S		Earth Observation (Ocean Resources) - Austere	3,098	527	2,280	97	Polar, 100 n.mi.	50 deg*	Earth	±60 deg from nadir	±0.5 deg; 0.05 deg/sec	15 min/obs	2	Meteorologist, Oceanographer, Optical/Electromechanical	14.6	2600	500Δ	~milli-secs	7.7	Film	51.3 M	—	Sensitive	—	—	
	COM/NAV	C1S1E		Communication/Navigation (Lab I) - Austere	1,334	67	870	45	Polar	28 deg-polar	Earth	180 deg	0.01 deg; 1 deg/sec	15 min/obs	2/4	Electronics/Microwave, Optical/Electromechanical	24/48	1100	800Δ	1.5	14.5	Real time digital stor	0.8 M	—	Sensitive	—	—	300 kbps R. T. Trans
		C1S1F		Communication/Navigation (Lab I) - Austere	1,330	79	838	42	Polar	28 deg-polar	Earth	180 deg	0.01 deg; 0.1 deg/sec	15 min/obs	2/4	Electronic/Eng/Microwave	24/48	1250	550Δ	1.5	16.0	Real time digital stor	0.3 M	—	—	—	—	30 kbps R. T. Trans
		C1S2C		Communication/Navigation (Lab II) - Intermediate	3,110	170	1,477	75	Polar	28 deg-polar	Earth, stellar, entry	180 deg	0.01 deg; 0.1 deg/sec	60 min/obs	2/4	Electronics, Optics, Microwave, Electromech	24/48	1500	1000Δ	1.5	16.0	Real time digital stor	1.3 M	—	Sensitive	—	—	300 kbps R. T. Trans
	Material Science	M1S1E		MS Configuration 1 - Operations Level 1	2,676	274	2,676	274	Any	Any	NA	NA	NA	NA	2/4	Electromechanical Technician, Metallurgist, Chemical Technician	24/48	0.1-1 k	4-12 k	1.5	28.6	TV	10 k	$<10^{-4}$	NA	NA	—	
		M1S1F		MS Configuration 1 - Operations Level 2	2,676	274	2,676	274	Any	Any	NA	NA	NA	NA	2/4		24/48	0.1-1 k	4-12 k	1.5	34.3	TV	10 k	$<10^{-4}$	NA	NA	—	
		M1S1G		MS Configuration 1 - Operations Level 3	2,676	274	2,676	274	Any	Any	NA	NA	NA	NA	2/4		24/48	0.5-1.5 k	4-30 k	1.5	49	TV	10 k	$<10^{-4}$	NA	NA	—	
		M1S2B		MS Configuration 2 - Operations Level 3	4,348	468	4,348	468	Any	Any	NA	NA	NA	NA	2/4		24/48	0.5-1.5 k	4-30 k	1.5	49	TV	10 k	$<10^{-4}$	NA	NA	—	

* 30- to 60-degree Sun elevation angle for UV & visible region sensing. NA = not applicable.
† Can be operated by one man/shift.
(1) For source of P/L numbers refer to [redacted]-DDA71-003A, RAM Derived System Requirements, dated 12-17-71

Table 4-4 RAM Payload Summary Data, Contd

Payload Class	Discipline	(1) P/L No.	Code	RAM Payload Title	Physical: Exper Equip Weight Total (lb)	Physical: Exper Equip Volume Total (ft^3)	Physical: Press Exper Weight Total (lb)	Physical: Press Exper Volume Total (ft^3)	Mission: Orbit Preferred	Mission: Orbit Acceptable	Mission: Orientation	Mission: Viewing Constraint	Mission: Pointing Accuracy; Stability	Mission: Point Duration (hr/obs)	Resources: Crew Size Initial/Adv.	Resources: Skills	Resources: Skill hr/day Initial/Adv.	Resources: Power (W) Avg (on) Initial/Adv.	Resources: Power (W) Peak	Resources: Peak Power Duration (hr)	Resources: Elect. Energy (kW-hr/day) Initial/Adv.	Resources: Data Other Than Digital	Resources: Data Digital Rate (Bps)	Environment: Accel. (g)	Environment: Contam.	Environment: Radiation (rad/hr)	Environment: Temp (°K)	Special
Sortie (Contd)	Technology	T1S3A		Complete Contamination Measurements	540	29.9	379	19.7	Any	—	Sun Vector	NA	0.5 deg; 0.05 deg/sec	14	2	Optical/Electromechanical, Physicist/Nuclear Physicist	2-8	825	360Δ	0.5	1.9	TV	107 k	—	—	—	—	Piggyback
		T2S1A		Propellant Transfer Experiment	6,460	825	300	19	Any	—	NA	NA	NA	NA	2/4†	Electromechanical Tech	6.0	200	1000Δ	2	4.4	—	6.6 k	Shuttle ambient	—	—	—	
		T2S2E		Combined Cryogenic Storage & Fluid Systems Experiment	21,160	3052	5,840	142	Any	—	NA	NA	NA	NA	2/4†	Electromechanical Tech	12.0	750	1800Δ	3 min	4.5	Film	1 k	Shuttle ambient	—	—	—	
		T2(D)2B		Detached Long-Term Cryogenic Storage Equipment	6,970	1325	—	—	Sun sync	Any	Inertial & Earth	NA	NA	NA	NA	NA	NA	500	—	—	12.0	—	4.6 k	Low-g coast	—	—	—	
		T3S1A		Astronaut Maneuvering Unit Experiment	880	27.7	595	6.3	Any	—	Stable during EVA	Clear view of exp	NA	NA	2/4#	Optical/Electromech Tech	21.5/43	330	40Δ	0.05	1.2/2.4	Film, TV	5 k	—	—	—	—	EVA
		T3S2B		Maneuverable Work Platform Experiment	2,125	210	655	8.2	Any	—	Stable during launch, retrieval	Clear view of exp	NA	NA	2/4#	Optical/Electromech Tech, Electronics/Microwave, M.E.	36/72	300	400Δ	0.25	4.6/9.2	TV	8 k	—	—	—	—	EVA
		T4S1A		Short Duration Advanced Spacecraft Systems Test	1,000	50	1,000	50	Any	—	NA	NA	NA	NA	2	General skill	5.0	500	—	—	2.5	—	0.14 M/day	—	—	—	—	Piggyback
		T5S2B		Teleoperator Experiment	1,485	138	355	25	Any	—	Stable during exp	NA	NA	NA	2/4†	Optical/Electromech Tech	NS	160	140Δ	12	12.2	TV	40 k	—	—	—	—	
	Life Science	L8S1B		Life Sciences Lab (Mini-7)	4,423	320	4,423	320	0 deg, 250 n.mi.**	Any	NA	NA	NA	NA	2/4	Biol Tech, M.D., Electromech Tech, Behavioral Sci.	24/48	3300	NS	NS	45.6	TD Std + High Res. TV	300	$\le 10^{-5}$, 95% of time	NA	Minimum	—	EVA; dump 10%/day rec. data
		L8S2B		Life Sciences Lab (Mini-30)	9,037	867	9,037	867	0 deg, 250 n.mi.**	Any	NA	NA	NA	NA	2/4	Biol Tech, M.D., Electromech Tech. Behavioral Sci.	24/48	3300	NS	NS	50.2	TD Std + High Res. TV	500	$\le 10^{-5}$, 95% of time	NA	Minimum	—	
		L8(D)1A		Bioresearch Module	400	19.6			> 200 n.mi.	>200 n.mi.	NA	NA	NA	NA	1	Electromech Tech	TBD	90-150	—	—	TBD	—	2000	$<10^{-4}$	NA	Minimum	—	Piggyback
Free Flyer	Astronomy	A5O2D		High Energy Stellar Astronomy Observatory	2,086	176	—	—	0 deg, 400-500 n.mi.	0-55 deg, 200-400 n.mi.	Stellar	≥60 deg to Sun ≥22 deg to Earth	2 arc-sec; 1 arc-sec/obs	0.01-6	2‡	Astronomer/Technician	16	450	—	—	10.8	TV	124M max	$<10^{-4}$	Particles gases	$<10^{-3}$	273-277	
		A1O3B		X-Ray Astronomy Observatory	9,658	1192	666	48	0 deg, 400-500 n.mi.	0-55 deg, 200-400 n.mi.	Stellar	>45 deg from Sun >22 deg from Earth	1 arc-sec; 1 arc-sec/obs	≤9.5	2‡	Astronomer/Astrophysicist	18	740	200Δ	0.92	17.8	TV	126 M max	$<10^{-4}$	Particles gases	$<10^{-3}$	272-274	
		A2O2B		Advanced Stellar Astronomy Observatory (LST)	12,696	2579	1,838	378	28.5 deg 400 n.mi.	28-55 deg, 250-350 n.mi.	Stellar	≥45 deg to Sun ≥22 deg to Earth	1 arc-sec; 0.005 arc-sec/obs	0.3-6	2‡	Optical Scientist/Technician	24	1000	180Δ	0.8	14.2	Digital camera, TV	288 M/frame	$<10^{-4}$	Particles gases	$<10^{-3}$	293-295	
		A3O3B		Advanced Solar Astronomy Observatory	9,003	2748	1,320	96	<10 deg, 400 n.mi.	45-55 deg, 270 n.mi.	Solar	0.3 deg of Sun center	1 arc-sec; 0.017 arc-sec/obs	≤0.75	2‡	Astronomer/Astrophysicist	24	1480	450Δ	0.01	36	TV	700 M max	$<10^{-4}$	Particles gases	$<10^{-3}$	293-295	
	Technology	T1O3B		Complete Contamination Measurement	79.5	4.2	30	1.6	Any	—	NA	NA	NA	NA	NA	NA	NA	125	—	—	3.4	—	40.8 k	—	—	—	—	Piggyback
		T4O1A		Long Duration Advanced Spacecraft Systems Test	1,000	50			Any	—	NA	NA	NA	NA	NA	NA	NA	500	—	—	0.15	—	6 M/day	—	—	—	—	Piggyback
Station Attached	Physics	P6A3A		Combined Space/Plasma Physics Laboratory	14,351	816	6,828	499	Polar, 100 n.mi.	>50 deg, 250 n.mi.	Earth/stellar	Dark	1.6 arc-sec; 0.5 arc-sec/sec	Continuous	3/6	Physicist, Nuclear Physicist, Tech	30/60	3900/3900	2000Δ	2	55/75	—	12 M	$<10^{-4}$	Sensitive	—	—	Airlock
		P3A3A		Cosmic Ray Laboratory	34,494	694	34,494	694	28 deg, 200 n.mi.	55 deg, 270 n.mi.	Away from Earth	No data if viewing Earth	1.0 deg; NA	NS	2	Physicist, Electromechanical Tech	5.1	690	160Δ	24 hr once/week	16.6 nominal 20.4 worst case	—	30 k	NA	Not critical	—	—	Thin windows
	Earth Observations*	E1A2B		Intermediate Earth Observations Lab	6,072	444	4,995	162	55 deg, 270 n.mi.	Any*	Earth	±60 deg from nadir	0.5 deg; 0.05 deg/sec	15 min/obs	2/4	Meteorol., Oceancg., Geol., Hydrol., Agron., Optical	20	4800	900Δ	10 min/day intermit.	26.2	Film	51.4 M (800 M growth)	—	Sensitive	—	—	1.8×10^9 bits/day near R.T.
		E1A3B		Complete Earth Observations Lab	7,271	1055	5,281	193	55 deg, 270 n.mi.	Any*	Earth	±60 deg from nadir	0.5 deg; 0.01 deg/sec	25 min/obs	4	Meteorol., Oceancg., Geol., Hydrol., Agron., Optical & Others	28	4800	900Δ	1/day intermit.	48.8	Film		$<10^{-5}$	Sensitive	—	—	
	COM/NAV	C1A2B		Communication/Navigation (Lab II) - Intermediate	3,110	170	1,477	75	Polar	28 deg, polar	Earth	360 deg	0.01 deg; 0.1 deg/sec	90 min/obs	2/4	Optical/Electromech Tech Electronics/Microwave	20/40	1500	1000Δ	1.5	31.6	Real time digital stor	1.6 M	-	Sensitive	-	—	30 kbps R.T. trans
		C1A3B		Communication/Navigation (Lab III) - Complete	3,541	235	1,576	81.3	Polar	28 deg, polar	Earth	360 deg	0.01 deg; 0.1 deg/sec	90 min/obs	2/4	Electronic, Electro-Optical, Microwave, Electro-Mech	20/40	1500	1000Δ	1.5	65.4	Real time digital stor	1.6 M	-	Sensitive	—	—	1×10^6 kbps R.T. trans
	Material Science	M1A3B		MS Configuration 2 - Operations Level 4	4,650	610	4,650	610	Any	Any	NA	NA	NA	NA	2/4	Electromech. Tech. Metallurgist Chemical Technician	20/40	0.5-2 k	4-50 k	1.5	21.3 nominal	TV	10 k	$<10^{-4}$	NA	NA	—	
	Technology	T1A3A		Complete Contamination Measurement	460	26.2	309	16.2	Any	—	Solar	NA	0.5 deg; 0.05 deg/sec	14	2	Physicist, Electromechanical Technician	2-16	825	360Δ	30 min	1.9	TV	107 k	—	—	—	—	Piggyback
		T4A1A		Medium Duration Advanced Spacecraft Systems Test	1,000	50	1,000	50	Any	—	NA	NA	NA	NA	NS	NS	NS	500	—	—	2.5	—	33.4	—	NS	—	—	Piggyback
	Life Science	L8A1B		Life Sciences Lab (Midi-30)	15,445	1921	15,445	1921	0 deg, 250 n.mi.**	Any	NA	NA	NA	NA	2/4#	Biol Tech, M.D., Elect Tech, Behavior Sci., M.E.	20/40	3600	NS	NS	60	TV Std + Hi Res. TV + Voice	16 k	$\le 10^{-5}$, 95% of time	NA	Minimum	—	EVA
		L8A2B		Life Sciences Lab (Maxi-Nom)	17,084	2130	17,084	2130	0 deg, 250 n.mi.**	Any	NA	NA	NA	NA	2/4#	Biol Tech, M.D. Elect Tech, Behavior Sci., M.E.	20/40	3600	NS	NS	60		16 k	$\le 10^{-5}$, 95% of time	NA	Minimum	—	EVA

* 30- to 60-degree Sun elevation angle for UV & visible region sensing.
† Can be operated by one man/shift.
\# Shuttle crewman supplies EVA monitoring assist.
(1) For source of P/L numbers refer to GDCA-DDA71-003A, RAM Derived System Requirements, dated 12-17-71

‡ Free-flying module revisited for servicing. NA = not applicable. NS = not specified.
** Radiation consideration only

4.5 OPERATIONAL PROCEDURES

Detailed operational procedures are presented in Appendix B for each of the three attached element operations modes, i.e., RAM operations, service and checkout, and quiescent storage. A summary of each of these detailed procedures is presented in this section. The procedure developed for RAM operations involves a RAM attached to a shuttle orbiter with a pivotal extension mechanism. Service and checkout procedures involve the return of a detached RAM to a MSS for servicing and checkout of its experiments and subsystems. The procedures developed for quiescent storage apply to an earth orbit resupply module (cargo module) in support of an MSS. Although each of these modes is developed for a particular element-to-element interface, the procedures are, to a certain extent, developed generically so as to relate to other applicable element-to-element pairs. It may be noted that the functional requirements are related numerically to the operational procedures and are presented in Section 4.6.

The aforementioned element-to-element pairs were selected for the procedural development because they not only highlight most of the required operations but they also present the more complex situation required of the particular operational mode.

It may be noted that a separate set of procedures for checkout was not developed, since checkout is a subset and included in service and checkout.

Presented in Figure 4-14 is a simplified illustration of the three operational procedures together with their interrelationships. This illustration provides in overview of each of the three operational procedures, together with their commonality relationship.

Presented in Appendix B is a matrix that identifies the applicability of each of the three operational procedures to the element pairs which have an attached element operations interface. Those pairs that have no interface involving this activity are so indicated with a "NA". Of the 49 potential element pairs, 28 have been selected as having an attached element operations interface. Referring to this matrix it may be seen that of the 28 attached element operations pairs, 2 are for RAM operations, 18 are defined for service and checkout, 4 for quiescent storage, and 8 for checkout only. Four of the element pairs are represented by two procedures (service and checkout, quiescent storage) and are therefore double counted.

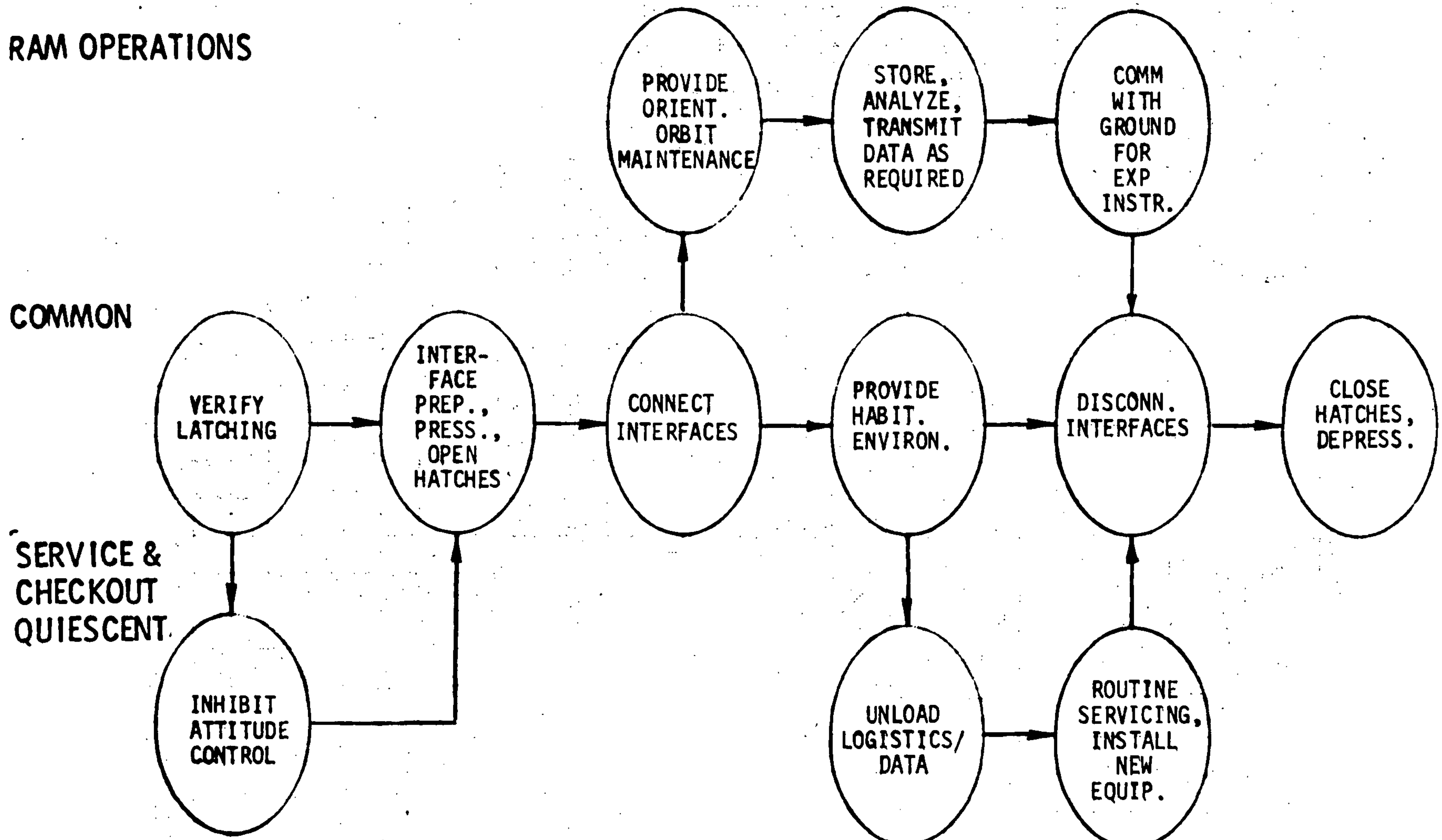


Figure 4-14. Attached Element Operations Procedural Comparison

4.6 FUNCTIONAL REQUIREMENTS

This section presents the functional requirements defined for attached element operations activity. Requirements for support of RAM operations are related to vehicle orientation, electrical power, and orbital maintenance while those for servicing and checkout are concerned with monitoring, calibrating and routine servicing. Each of the functional requirements presented herein is formatted in three parts; a statement of the requirement, a quantification of the requirements (if applicable), and the rationale supporting the requirement. Adjacent to each of the functional requirement statements are notations indicating the applicable procedure.

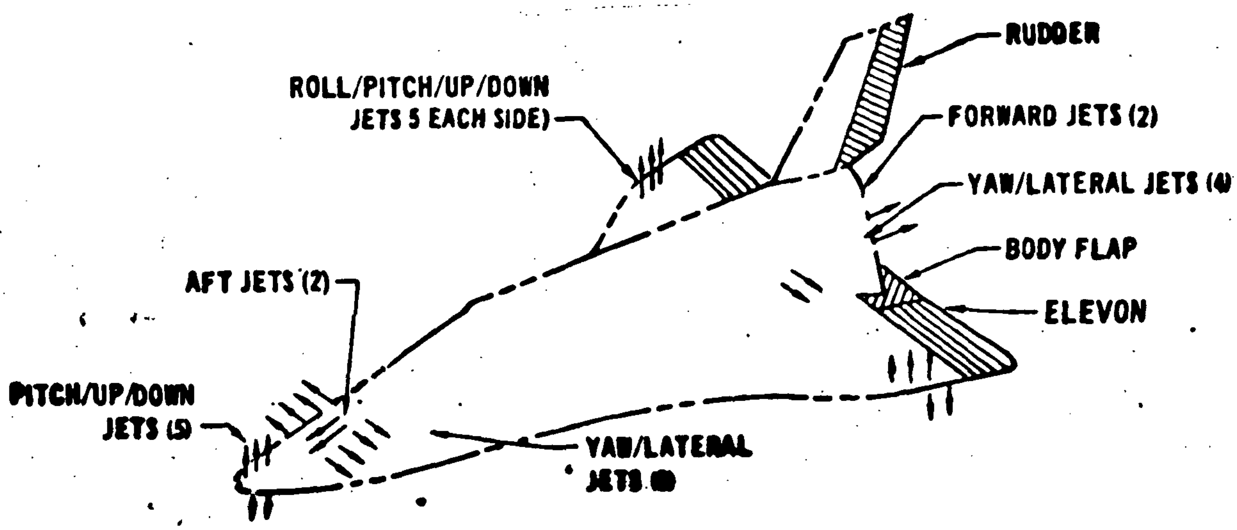
Functional Requirements

Functional Requirements	Related Procedure: RAM Operations	Related Procedure: Service and Checkout	Related Procedure: Quiescent Storage
	12-1	12-2	12-3
1. There shall be a means of supplying electrical power in support of the attached RAM's, pallet experiments, detached RAM's being serviced by an active vehicle, and other elements attached to and being supported by an MSS or a Shuttle orbiter. In meeting the power requirements there exist several alternatives: the experiment may contain a self supporting power source such as a battery. The RAM may be supported by a RAM Support Module (RSM) that contains an electrical power source and distribution; the active element (MSS or orbiter) may supply electrical power from its own power source across the interface to the attached element; there may be some combinations of the above, applied alternatively depending upon the power load that would vary in time according to the experiment program time line. The following defines the limits of electrical power anticipated for the array of anticipated RAM's and pallets: Peak power (watts): Min 100, Max 50,000 Average power (watts): Min 100, Max 4,800 Energy (Kw-hr): Min 1, Max 110 (7 day sortie) Energy (Kw-hr): Min 1, Max 476 (30 day sortie)	X	X	
2. The EOS shall be capable of imparting translational impulses during the on-orbit RAM sequence in order to sustain experiment program altitude requirements. Reference Table 4-4 for orbit altitude requirements. Orbit maintenance or upkeep may be required not only to sustain altitude but also to achieve some degree of ground trace (viewing) periodicity. In addition, a delta-V translation may be applied to "escape" or depart from a region of atmospheric pollution due to effluents.	X		

	Related Procedure: RAM Operations 12-1	Related Procedure: Service and Checkout 12-2	Related Procedure: Quiescent Storage 12-3
3. The following data parameters shall be provided to the RAM by the Orbiter or the MSS: orbit position (3 parameters), velocity (3 parameters), vehicle orientation in inertial space (3 parameters), vehicle stability (3 parameters), and time. Accuracy of these parameters will be sufficient to meet experiment data processing requirements. A means shall be provided for synchronizing the payload systems with the orbiter computer clock.	X	X	X
4. A means shall be provided for transmitting and displaying subsystem safety parameters of the RAM at the control and display station of the host vehicle.	X	X	X
5. A means shall be provided for verifying the integrity of the attachment interface.	X	X	X
6. There shall be a place and means of stowing or securing the interface hatches such that they do not interfere with normal and contingency operations.	X	X	X
7. The supporting element (Orbiter, MSS) shall provide attitude pointing, orientation maneuvering, attitude hold deadband (limit cycle), and attitude rate capability. For some experiments the RAM must be aligned to a specific target with a given accuracy for a given period. Other experiments require attitude stability only. Table 4-4 defines the attitude requirements for the RAM payloads in terms of direction, viewing, stability, and duration. In meeting these requirements, the RAM may utilize that control provided by the active element or there may be a separate stable platform provided in the RAM.	X		

	Related Procedure: RAM Operations 12-1	Related Procedure: Service and Checkout 12-2	Related Procedure: Quiescent Storage 12-3
8. A means of securing the RAM and associated equipment will be required during times of orbiter delta-V thrusting.	X		
9. There shall be no engine firing, venting from any associated vehicles, nor any waste dumping external to the orbit configuration during selected experiment programs. Reference Figure 4-15 for the orbiter attitude control engine location and Table 4-5 for the NR Orbiter effluent model.	X		
10. There may need to be special shielding of experiments during passage through the South Atlantic anomaly. Some experiments will need to be shut down during passage through the South Atlantic anomaly.	X		
11. Payloads operations shall exclude mandatory use of the Orbiter pilot and co-pilot. The shuttle crew may support the payload upon request and upon a non-interference basis with shuttle operations.	X	X	X
12. The orbiter shall, as a minimum, provide habitability accommodations for the payload support personnel located in the orbiter cabin during phases of the mission other than on-orbit operations. Time required for accommodation could be up to 48 hours depending upon the launch conditions.	X		X
13. The attached payloads, either in an active or dormant state, shall not degrade the safety of the active supporting element (MSS, orbiter) nor violate their established safety level and requirements.	X	X	X

CONFIGURATION 1



CONFIGURATION 2

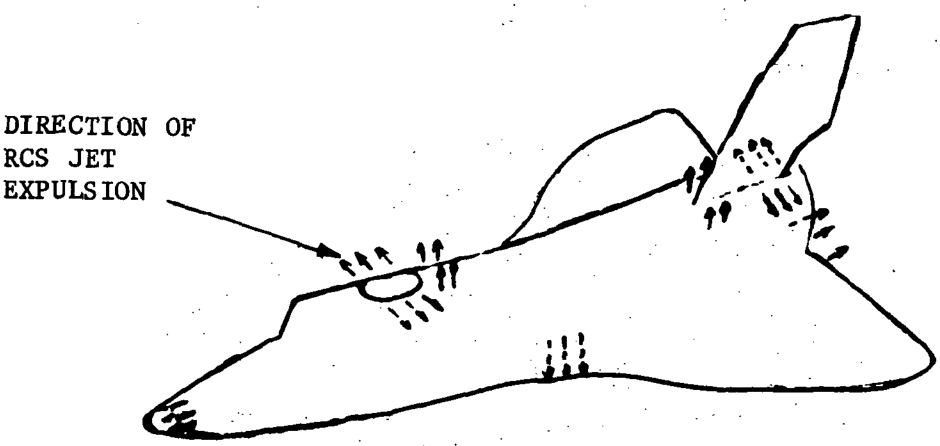


Figure 4-15. Orbiter Attitude Control

Table 4-5. NR Orbiter Effluents

Effluent	Rate	Comment
H_2O	410 lb/hr	Reduces after launch. Some water may be stored and used for experiments with proper design.
H_2 H_2O	50 lb/hr 280 lb/hr }	When in 0.5-degree attitude hold
H_2	.4 lb/hr 10.0 lb/hr	When auxiliary propulsion used Main propulsion venting
O_2	6.0 lb/hr 2.0 lb/hr	Main propulsion venting Cabin leakage
CO_2	.07 lb/hr	Controlled venting (24-hour storage)
Urine	3 lb/man/day	Controlled venting (24-hour storage)
Fecal vapor	.25 lb/man/day	Controlled venting (24-hour storage)
N_2	7.0 lb/hr	Cabin leakage

	Related Procedure		
	RAM Operations	Service and Checkout	Quiescent Storage
	12-1	12-2	12-3
14. The active supporting element (Orbiter, MSS) shall be capable of receiving experiment data across the interface, with subsequent recording and storage. The active element must also be capable of relaying commands between the supported module (RAM, pallet) and the ground station. Table 4-4 defines the digital data rate (BPS) for the RAM Experiments.	X		
15. A means shall be provided for examining the interior of all modules that are about to be manned. This examination may consist of direct visual inspection through hatch windows, viewing with a CCTV, or it may involve an assortment of sensing devices to verify the safe environment in the module.	X	X	X
16. The atmosphere will be monitored for harmful contaminants in each habitable area. This monitoring capability shall exist both prior to opening hatches in docked modules and during attached operations.	X	X	X
17. Attached payloads shall be designed such that they can be isolated at the attachment plane from any attached pressurized compartment in case the RAM is damaged or rendered untenable.	X	X	X
18. The EOS orbiter design shall allow shirtsleeve access to the interior of the pressurized payloads.	X		

Item	Requirement	RAM Operations 12-1	Service and Checkout 12-2	Quiescent Storage 12-3
19.	There shall be a volume provided for enabling an EVA operation. In addition, there will be necessary lighting capability, guidance aids, safety features for carrying out the EVA operation.	X	X	
20.	There shall be a means of equalizing pressure between the interface volume and active/supporting vehicles and passive/attached modules.	X	X	X
21.	A means of depressurizing the docking interface volume will be required. This may consist of a valve opening to space vacuum or a portable pump down motor.	X	X	X
22.	A means of purging and cleaning the atmosphere of an attached module must be provided. The active/support vehicle must be capable of remotely controlling this function.	X	X	X
23.	There shall be a means of deploying and retracting various extended probes, antennas, sensors, solar arrays, etc. of an attached element, remotely from an active supportative vehicle. This capability will allow retraction/closure/sealing of hatches prior to pressurization of the attached element. It will also allow for deployment and checkout of these extended probes, etc., prior to deployment of an unmanned payload. The means of control will be initiated from the active vehicle with the interface through hardline and/or RF link.		X	
24.	There shall be a means of purging the fluid interconnect lines. This will be accomplished subsequent to fluid transfer and prior to disconnect. The lines will be purged to prohibit spillage and escape of harmful liquids and vapors.	X	X	X

	Related Procedure		
	RAM Operations	Service and Checkout	Quiescent Storage
	12-1	12-2	12-3
25. There shall be a means of pressurizing the docking interlock volume from the active vehicle. Air composition and pressures shall be that of the active/supportive vehicle.	X	X	X
26. There shall be a means of monitoring the passive/attached vehicle subsystem parameters from the active/supportive vehicle.	X	X	X
27. The MSS shall provide a compatible shirtsleeve environment to the attached element. Fans and ducts will be required to minimize air stagnation, adequate design of the active system will reflect leak rates across the element interface and the attached element itself.	X	X	X
28. A RAM attached to an EOS shall provide its own environmental control system capability. Reference trade study A6 in Appendix A.	X		
29. Attached elements may require crew and cargo transfer activities and shall be sized and furnish provisions per those requirements.	X	X	X

ELEMENT PAIRS REQUIREMENTS MATRIX

To a large extent the design influences and drivers related to attached element operations are precipitated by other orbital operations activities, i.e., crew and cargo transfer, mating, etc. However, there are several areas of design that relate uniquely to attached element operations that are defined herein. Figure 4-16 related these design requirements to each of the 28 element-to-element pairs associated with attached element operations. The element pairs are grouped according to the type of procedures developed in Appendix B. Associated with the design requirements shown in Figure 4-16 are the related functional requirements developed and numbered in the previous tabulation (12-1) RAM Operations, (12-2) Service and Checkout, and (12-3) Quiescent Storage.

Referring to the matrix of Figure 4-16, some observations are appropriate. RAM operations, because of their inherent demand on active element support, involve nearly all of the design requirements. Quiescent storage, because of its low activity, involves the fewest number of design requirements. It becomes obvious from Figure 4-16 that there are certain design requirements that pertain to all the attached element operations element-to-element pairs. These requirements relate generally to health and safety considerations and are relatable to other orbital operations activities.

In addition to the tabular listing of functional requirements previously presented, Table 4-6 presents the vehicle functional requirements by element pairs.

RNATIVES	RELATED FUNCTIONAL REQUIREMENT	7	7	7	2,8,9	1	28	19	27	4,13,18	27	24	25
	ELEMENT PAIRS / DESIGN REQUIREMENTS IMPOSED BY ATTACHED OPERATIONS	Orientation-Attitude Maneuvering	Attitude Stability Local Hold	Attitude Stability Inertial Hold	Translational Delta V (Orbit Upkeep)	Elect. Power Interconn.	Air Ducting	Comm. Interconn. (RF)	Comm. Interconn. Hardline	Monitor Health and Safety	Monitor Subsystems	Operate External Sensors, Antennas, Probes of Passive Veh. from Active Veh.	Transfer Fluids
AM perations	EOS/Att. RAM	X	X	X	X	X	X	X	X	X	X		X
	MSS/Att. RAM	X	X	X	X	X	X	X	X	X	X		X
ervice and heckout	EOS/EOS					X	X		X	X	X		
	EOS/Space Base Tug					X			X	X	X		
	EOS/Det. RAM					X	X	X	X	X	X	X	X
	EOS/Ret. & Resup. Sat.					X		X	X	X	X	X	
	EOS/MSS					X			X	X	X		
	EOS/OPD					X			X	X	X		X
	Space Base Tug/SB Tug					X			X	X	X		
	Space Base Tug/Det. RAM					X			X	X	X	X	
	SB Tug/Ret.&Resup. Sat.					X		X	X	X	X	X	
	Space Base Tug/MSS					X			X	X	X		
	SB Tug/CPS (CLS)					X			X	X	X		
	Space Base Tug/RNS					X			X	X	X		
	Space Base Tug/OPD					X			X	X	X		X
	MSS/DRAM					X	X		X	X	X		X
	MSS/EO Resup. Mod.					X			X	X	X		X
	EO Resup. Mod/OPD					X			X	X	X		X
	CPS(CLS)/OPD					X			X	X	X		X
	RNS/OPD					X			X	X	X		X
escent torage	Space Base Tug/MSS					X			X	X	X		
	Space Base Tug/OPD					X			X	X	X		
	MSS/EO Resup. Mods.					X			X	X	X		X
	EO Resup. Mod/OPD					X			X	X	X		X
heckout nly	EOS/Deliv. Sat.			X		X			X	X	X	X	
	EOS/Deliv. Sat. + 3rd Stage	X		X		X		X	X	X	X	X	
	EOS/EO Resup. Mod.					X			X	X	X		
	EOS/CPS (CLS)					X			X	X	X		
	EOS/RNS					X			X	X	X		
	EOS/OLS					X			X	X	X		
	Space Base Tug/Deliv. Sat. + 3rd Stage	X		X		X		X	X	X	X	X	
	Space Base Tug/EO Resup. Mod.					X			X	X	X		

Figure 4-16. Design Drivers - Alternative Relationship

Table 4-6. Functional Requirements

RAM OPERATIONS		
Functional Requirement	EOS/RAM	MSS/RAM
Power		
1. Peak: Minimum	100	100
Maximum	35,000	35,000
2. Average: Minimum	100	100
Maximum	4,800	4,800
3. Energy: Minimum	1	1
Maximum, 7-day	110	110
30-day	476	476
Isolate module	Yes	Yes
Visual inspection of module interior	Yes	Yes
Monitor atmosphere for habitable environments	Yes	Yes
Payload capability**		
Attitude control*		
1. Pointing	Direction	Direction
2. Limit cycle	±0.5 degree	±0.25 degree
3. Stability: Drift	0.05 deg/sec	0.05 deg/sec
Orbiter crew	Noninterference	Noninterference
Depressurization of docking interface	Yes	Yes
Subsystem interface lines	180° sep.	180° sep.
1. Hydrogen/oxygen	180° sep.	180° sep.
2. Redundant connectors	180° sep.	180° sep.
3. Redundant fluid lines	180° sep.	180° sep.
4. Cryo/wiring	Separated	Separated

*See Tables 4-1 and 4-3

**Reference Appendix A7

Table 4-6. Functional Requirements (Cont.)

SERVICE AND CHECKOUT		
Functional Requirement	EOS/DRAM	EOS/Satellite
Isolate module	Yes	--
Visual inspection of interior	Yes	--
Monitor atmosphere for habitable environment	Yes	--
Data		
Monitor and control	Hardline	Hardline
Communications	Intercom voice Hardline data	Hardline data
Rigidization		
1. Primary	Yes	--
2. Secondary	Yes	--
Use of orbiter crew	Noninterference	Noninterference
Depressurization of docking interface	Yes	--
Deploy and retract extended probes	RF & mech.	RF

QUIESCENT STORAGE	
Functional Requirement	EOS Resupply Module/MSS
Power (watts)	
1. Peak	600
2. Average	400
Isolate modules	Yes
Orbiter crew	Noninterference
Depressurization of docking interface	Yes

FUNCTIONAL REQUIREMENTS ANALYSIS

Throughout this section, the emphasis has been directed toward functional requirements and their applicability to procedures and element pairs. This subsection substantiates a portion of those requirements by documenting the analysis utilized in the functional requirement definition.

Docking/Berthing Port Diameter

The major activity affecting interface hatch diameter is cargo transfer. The unique characteristic of the RAM is that it operates with either EOS or MSS support. Attached RAMs in the EOS supported mode, contain their own internal stores (with the exception of some smaller items) and are not driven to a larger hatch for on-orbit operations. RAMs attached to MSS are generally supplied from the cargo resupply module via MSS. While specific cargo would be slightly smaller than the largest MSS cargo, hatch size would be driven to the same diameter both in the interest of commonality and in consideration of a potential synergistic benefit of direct resupply module docking to the RAM. DRAMs have periodic attached operations for resupply and servicing both in EOS and MSS attached modes. In the EOS case the expected mode is a RAM support module for resupply, while for MSS the mode is the same as for attached RAMs In summary, RAMs should have an MSS compatible interface, primarily because of close approximation to MSS cargo sizes, and for commonality. Hatch size requirements are presented in Section 2, "Cargo Transfer."

Attached Element Operations Supplemental Analyses

In Appendix A there are presented two additional analyses that relate to the attached element operations. One analysis relates to the monitor and control requirements associated with the service and checkout mode of operations. An extensive review of SOAR payloads revealed their respective monitor and control requirements. The second analysis initially presents the EOS payload capability as a function of altitude, orbit inclination, up-down payload, and ABES IN or OUT. Subsequent to this presentation, there is a procedure suggested for performing tradeoffs among EOS payload weights, attitude hold requirements, orbit variations, and propellant considerations.

4.7 DESIGN INFLUENCES AND PREFERRED APPROACH SELECTION

As discussed earlier in the alternate approaches section (4.3), there are three modes of operation for which operational procedures were developed: (1) RAM operations, (2) service and checkout, and (3) quiescent storage. The alternate approaches defined for this activity are dependent, independent, and modular dependent. The objective of this section is to examine the modes of operation and develop a preferred approach selection for each mode.

The preferred approach for two of the operational modes, service/checkout and quiescent storage, is the dependent alternative. By the very nature of their operation, orbital elements involved in service and checkout and quiescent storage are, for all practical purposes, dependent upon the supporting element. In the case of a detached RAM (free flyer) that has returned to the shuttle or the MSS for servicing, it is certainly more appropriate to draw upon the shuttle or the MSS for environmental control support than to provide an independent environmental control system in the RAM. Since detached RAMs are not manned in the free-flying mode, it would not be justifiable to provide environmental control support for such a short period of time during servicing. Like the free flyer being serviced by the MSS, an earth orbit resupply module would depend upon the MSS for environmental control support. Since this module is transported to and from orbit nearly every two months, it would be less than effective to add the additional weight to the resupply module for environmental control, particularly in light of the fact that the MSS already has that capability.

The third mode of attached element operations, RAM operations, is significantly more complex than the other two modes. The preferred approach selection was conducted at the functional level (e.g., communications, environmental control, etc.). In general RAMs supported by the MSS are dependent upon the MSS except for unique sensor requirements. The preferred approach for the EOS-RAM combination is primarily modular dependent with access to basic EOS capabilities.

RAM OPERATIONS

Although RAM operations involve the fewest number of element-to-element pairs they represent the most involved functional requirements and operational procedures. In order to proceed with alternate approach selection for RAM operations, an understanding of the objectives and functions of a RAM are requisite. Section 4.4 discussed design concept models for the RAM payloads. These payloads are the manifestation of the basic mission objectives (experiment program objectives) and are defined in the 1971 Blue Book. The allocation of experiments to RAMs and RAMs to a mission sequence plan represents a major influence on total program cost. Since program cost is a factor that is continually being reviewed and subject to change, it is reasonable to expect that the makeup of RAM payloads are also subject to change. As a result, the alternate approach selections will also be affected. Therefore, in order to pursue the alternate approach selection and preserve a level of flexibility for programmatic changes, much of the analysis is presented parametrically.

In addition, wherever possible, the rationale for decision making is documented thus providing a baseline for evaluation of future programmatic changes.

The alternate approach selection for RAM operations is presented by element pair and further discussed by functional requirement. At the conclusion of the RAM operations alternate approach selection, a table will be presented that summarizes the results.

EOS/Attached RAM

Communications

The alternate approach selection for communications involves the analysis of three program elements: RAM, EOS, and ground stations. Two modes of communication are required for EOS/attached RAM missions; they are data transmission (analog-TV and digital) and voice. Tracking or orbit determination can be provided directly by the EOS and will not require additional communication/data transfer link for RAM support. Similarly the EOS includes a voice link with ground. This same link can be made available to RAM experimenters on an as needed basis.

Data requirements for the RAM operations range up to 50 Mbps and volumes of data up to 3.5 x 10^{11} bits/day; some data are required in real time and some are stored on magnetic tape. Because the requirements vary significantly among the EOS attached RAM s the Data Management System (DMS) required to accept, process, and display experiment data demands a great deal of versatility and flexibility. In addition, subsystem checkout and monitoring requirements must be accommodated by the DMS. As a result of the wide range of requirements, these functions should be provided by and within the RAM payloads with proper judicious distribution to the EOS for subsystem monitoring of critical parameters.

The EOS design concept model indicates that up to 1 Mbps data transmission capability is available over the S-band links. This assumes the proper conditioning of signals for transmission over the TV link. The RAM design concept models indicate data rates being generated up to 50 Mbps, obviously well out of reach of the EOS design concept. Three concepts are offered as a means of making the requirements and capabilities compatible for the high-data-rate RAMs.

1. Data recording--Since EOS/attached RAM missions are relatively short in duration (less than 30 days), much (if not all) of the data is not required for real-time use on the ground. As a result, the data can be recorded on board the RAM for subsequent delivery to ground. An estimate of the volumetric requirements of RAM data has been conducted. This estimate represents the largest data generator (an earth observation RAM, 7-day sortie mission). The maximum amount of data accumulated for an attached

RAM over a 7-day period is 3.5×10^{11} bits. Regarding the amount of storage capability and tape capacity, the present state of the art indicates the capability of 6×10^9 bits per reel. However, a potential capability exists of 6×10^{10} bits per reel, an order of magnitude increase in the state of the art (reference DS-158B).

Combining the data requirements with the capabilities, the following number of tape reels results.

Present state of the art

$$\text{No. reels} = \frac{3.5 \times 10^{11} \text{ bits/7 days}}{6 \times 10^{9} \text{ bits/reel}}$$

$$\simeq 60 \text{ reels/7 days}$$

Projected state of the art

$$\frac{3.5 \times 10^{11} \text{ bits/7 days}}{6 \times 10^{10} \text{ bits/reel}}$$

$$\simeq 6 \text{ reels/7 days}$$

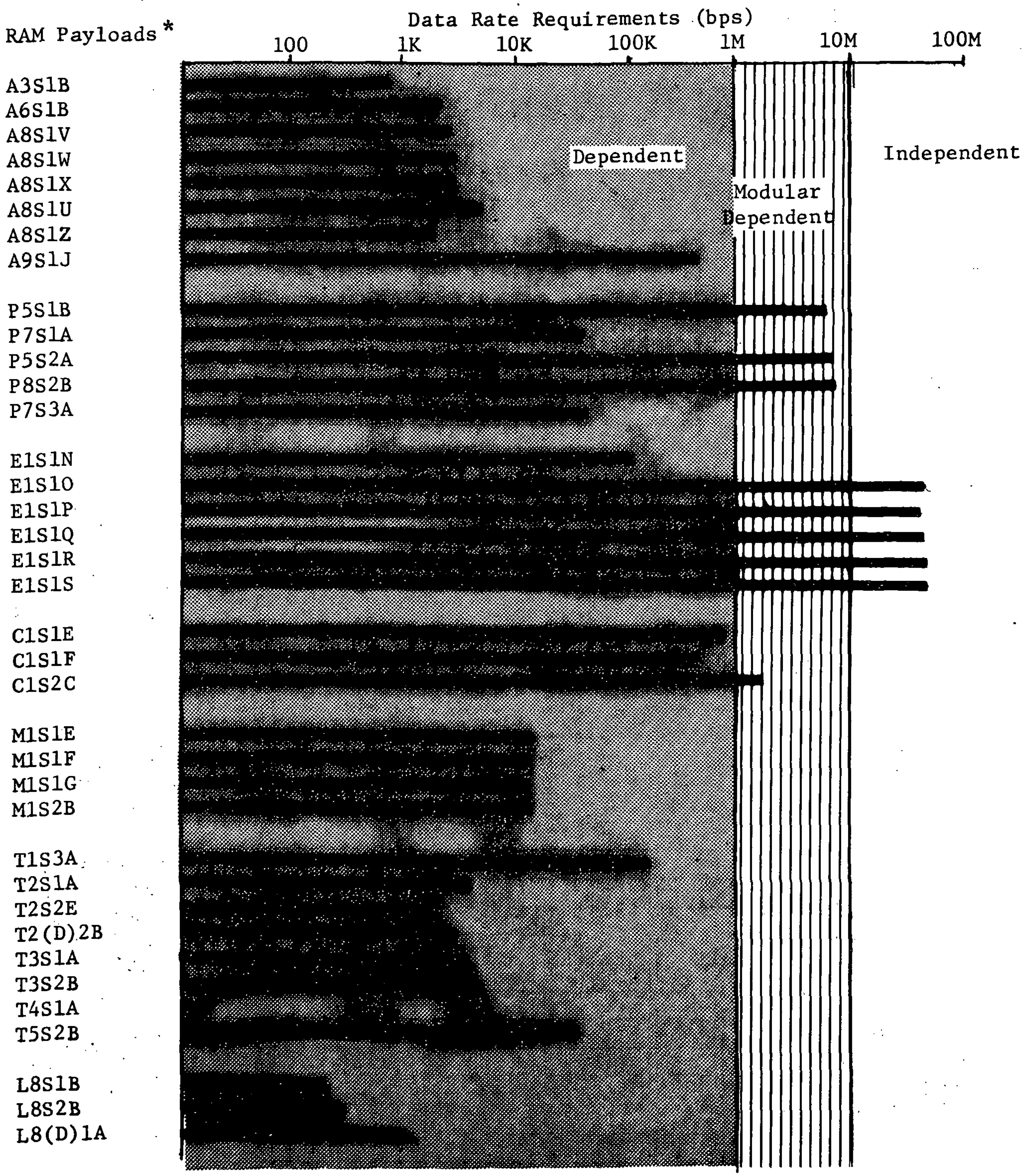
Assuming each reel (1200 feet of tape $\approx$ 10-inch diameter by 1-inch wide) to occupy about 1/10 of a cubic foot, then the present state-of-the-art tapes would occupy 5 cubic feet. The advanced state-of-the-art reels would occupy less than 0.5 cubic foot of space. These volumetric requirements are, as previously mentioned, based on a 7-day sortie mission.

2. For data rates that are greater than 1 Mbps but less than 10 Mbps a candidate solution is offered. Data processing and an adequate transmitter could be included in the RAM modular dependent approach. A hardline RF link could be established across the EOS/RAM interface to the EOS S-band omni antenna. Ground network recorders would also have to be updated to handle 10 Mbps data rates.

3. The third concept, which is for meeting data rate requirements in excess of 10 Mbps, requires that the RAM provide the transmission capability entirely independent of the EOS. To meet the bandwidth requirements, transmission via Ku-band would be required. This would then allow transmission to the TDRS, provided the RAM were equipped with a directional antenna

Table 4-8 illustrates the data rate requirements for the RAM payloads in histogram format. Imposed on these requirements are the EOS communications capabilities as discussed above, together with a definition of the alternate approach selected.

Table 4-8. Attached RAM Data Requirements



* Refer to Table 4-4 for payload titles.

Environmental Control

Functions of the environmental control system are primarily those which provide comfort and safety for the experiment crew. The environmental control system has a close relationship with the habitability and thermal control systems and is, therefore, considered in conjunction with environmental control alternate approach selection.

A study was conducted in the RAM program to evaluate the best arrangement or allocation of the environmental control functions between the shuttle orbiter and an attached RAM. A total of six alternative configurations were analyzed and then compared. They are:

Completely Dependent

A1 External ducts, hatch closed
A2 Internal ducts, hatch closed
A3 Internal ducts, hatch open

Partially Dependent and Independent

B Dependent humidity, CO_2 + odor, pres. cont., hatch open
C Dependent CO_2 + odor, press. cont., hatch open
D Independent, hatch closed (option - open)

An illustration of the above six alternatives is shown in Figure 4-17.

Based upon the trade analyses presented in Appendix A6, Concept D, independent, is the recommended approach for all attached RAM/EOS missions with a closed airlock hatch. This selection minimizes EOS scar weight and provides low sensitivity to EOS or RAM crew size. Concept D includes not only life support but also thermal control and heat rejection. This recommendation does not preclude pallets nor simple RAM s compatible with EOS excess capability, assurring also heat rejection compatibility where most RAM s exceed EOS capability.

Thermal Control

Thermal control of the RAM is required to ensure adequate heating and cooling to ensure a cabin temperature of 65 F to 75 F, and provide experiment and equipment thermal control. The selection of thermal control techniques is influenced by mission phases other than orbital phases. Environmental conditions during boost and entry must be considered; however, this study is concerned only with on-orbit operations. Three heat rejection concepts were evaluated: radiator, evaporators, and phase change materials. As a result of evaluation, water was chosen as the heat transfer fluid within habitable compartments; freon would be used outside habitable compartments with heat transfer to a radiator for rejection to space. This thermal control system is independent of the EOS.

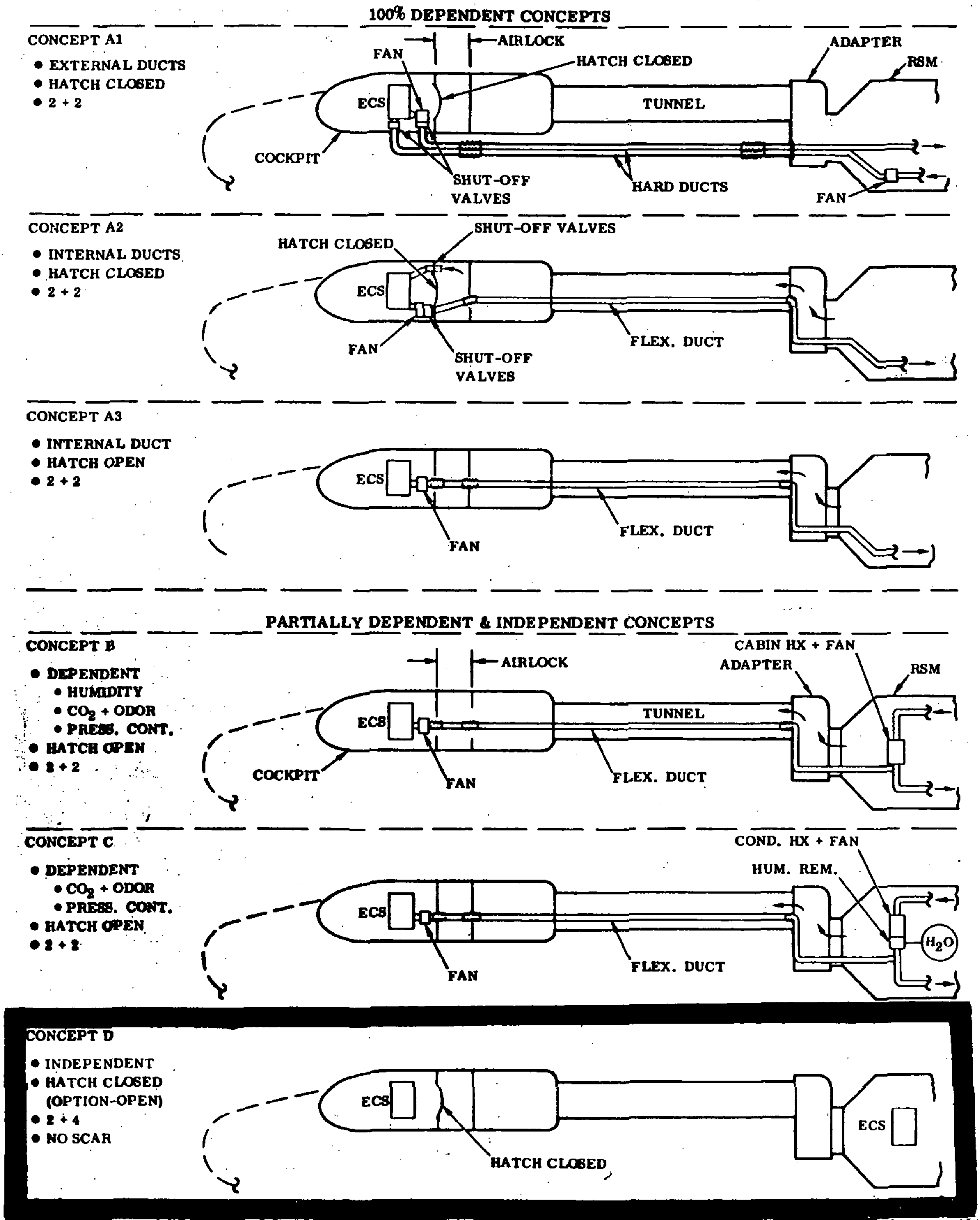


Figure 4-17. Candidate Concepts for Shuttle/RAM ECS Functions Allocations

Attitude Control

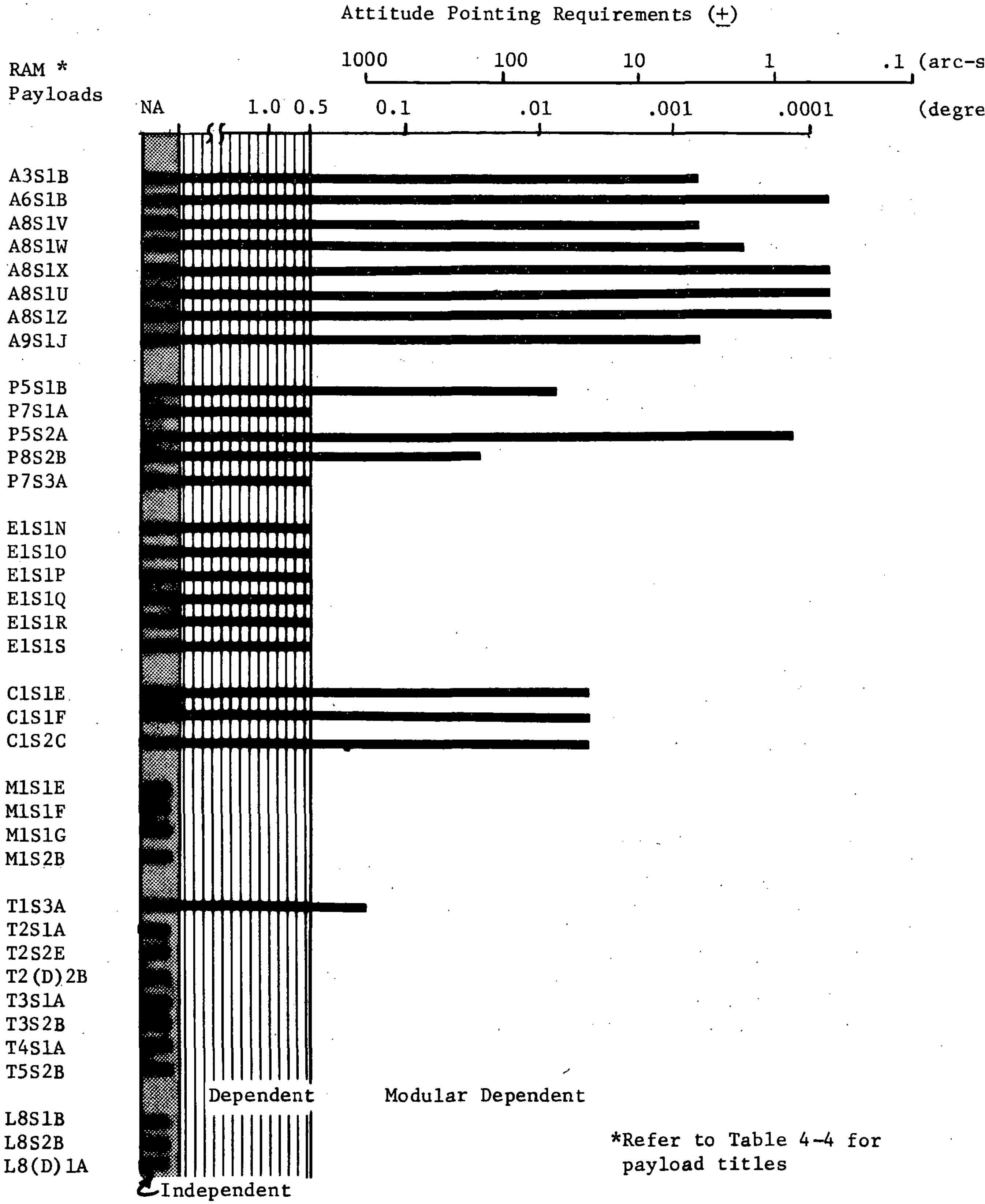
One of the primary functional requirements for RAM operations involves attitude requirements, this being divided into two subfunctions--pointing and stabilization. Pointing is defined as the gross direction pointing of the operating vehicle (ARAM) and the on-going maintenance of this pointing through attitude mode control (i.e., local attitude hold, inertial). Stabilization is defined as the fine pointing and stabilization for achieving requirements that cannot be maintained by the supporting vehicle. Referring to Table 4-4, one may observe that a large number of payloads require pointing accuracy and stability, whereas some (i.e., life sciences, technology, material sciences) require no special pointing or stability requirements at all. Basically, the selection of dependent, independent, or modular alternatives is derived as follows. The EOS design concept model indicated vehicle pointing to within ± 0.5 degree. The largest error source contributing to this 0.5 degree accuracy is the thermal distortion between the EOS attitude measurement base and the payload location. The potential exists for improving the EOS-controlled pointing accuracy by placing the attitude sensors at the payload, thus circumventing the effects of thermal distortion on pointing. Individual experiment pointing accuracy requirements that are more stringent than EOS capability must be provided through RAM contained sensors and stable platforms. Table 4-9 illustrates the pointing requirements for each of 23 payloads, together with the EOS design capability of ± 0.5 degree.

By similar analysis, stability alternate approaches are selected among dependent, independent, and modular dependent. Obviously, those payloads requiring no stabilization are independent of the EOS. The remaining 23 payloads need to be partitioned between dependent and modular dependent. The EOS design concept indicates that a stability capability of .05 degree/second is obtained with a combined RCS jet firing; however, utilization of a single jet firing can reduce this to 0.025 degree/second. Table 4-10 illustrates the stability requirements for the RAM payloads, together with the EOS design capability. Those payloads requiring stability to a finer degree than offered by the EOS will need to have their instruments mounted on their own stable platform designed to meet the vernier required.

Electrical Power

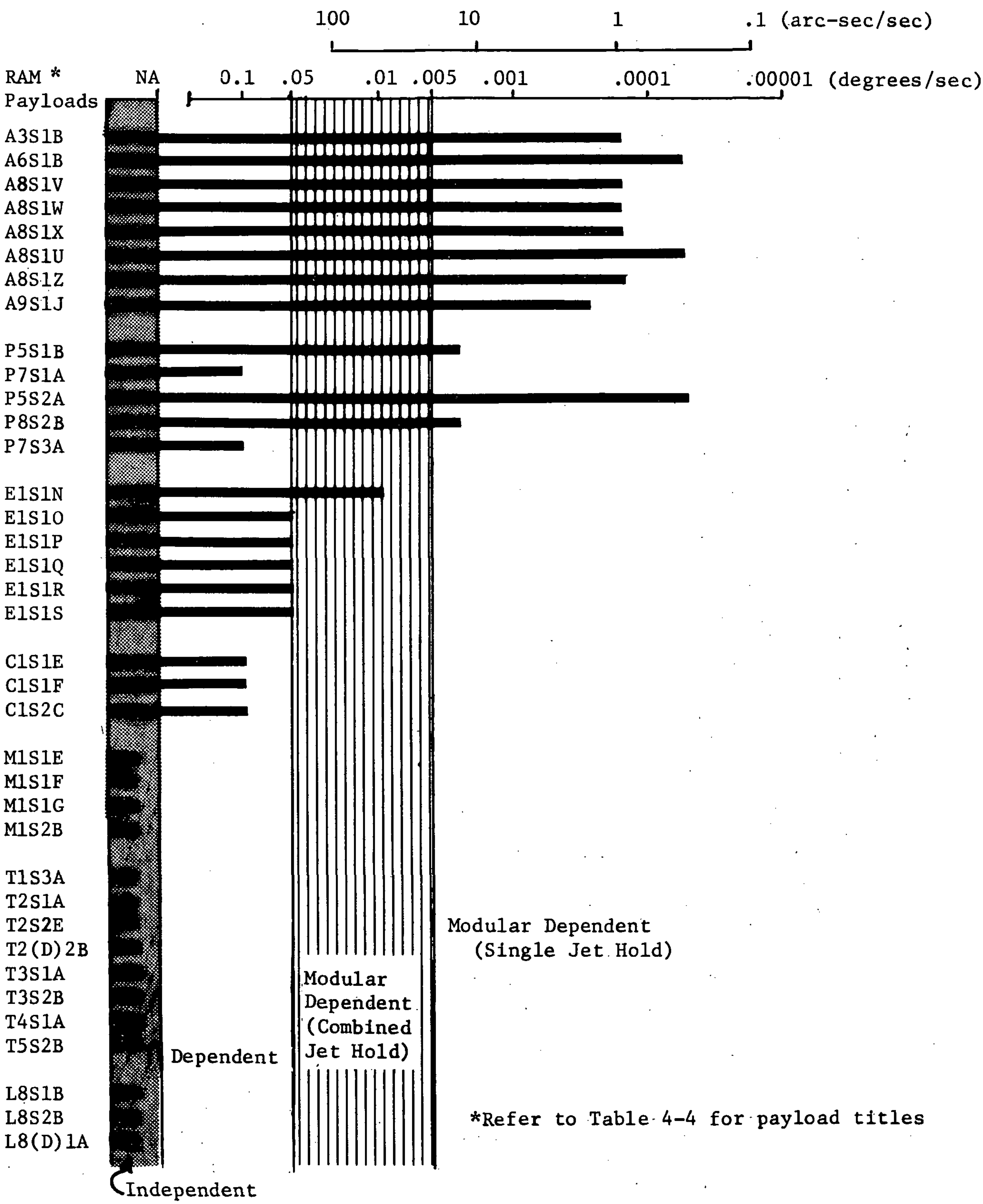
Electrical power requirements are presented in Table 4-4. The present shuttle design concept model provides 500 watts (average), 800 watts (peak), and a total energy of 20 kilowatt hours for payload use. As a result, the EOS will need to provide this power capability at the payload interface. If the payload requirements are less than the capability of the EOS, then the RAM may be dependent on the EOS. If, however, the payload requirements are in excess of this capability, then the alternative approach could be either independent by providing its own power source, or be modular dependent by providing additional cryogenic capability but utilizing the EOS fuel cells.

Table 4-9. Attached RAM Attitude Pointing Requirements



*Refer to Table 4-4 for payload titles

Table 4-10. Attached RAM Attitude Stability Requirements



Orbital Payload

In this section we have addressed the analysis to RAM payloads that are configured in specific packages and for which specific mission requirements are defined. The previously described analysis indicated that for a number of functions there existed the need to augment the RAM or the EOS in order to provide compatibility among experiment/mission objectives and system capabilities. The next phase of analysis would be to select hardware, consumables, and the like, to meet this compatibility. However, this cannot be done unilaterally without measuring the effect on the mission requirements. For example, the addition of a transmitter on the RAM will reduce the payload weight capability by a corresponding weight. If the reduction in weight capability cannot be tolerated, then a reduction in orbital altitude will need to be implemented. This process of examining changes in payload and mission requirements results from operation on the payload/orbit altitude curves presented as part of the EOS design requirements in Section 4.4. An analysis is presented in Appendix A7 that illustrates this tradeoff among mission requirements and payload requirements.

RAM Payload Allocation

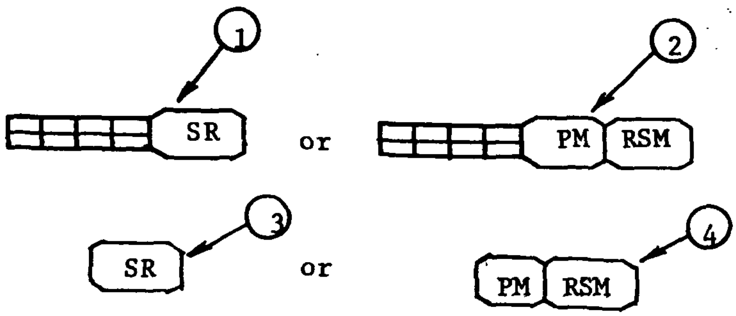
Section 4.4 defines the family of RAM carriers as part of the RAM design concept model. In this section we have examined the individual functional requirements of the RAMs and have arrived at an alternate approach selection wherever appropriate.

Given the RAM configurations and the individual payload requirements, a compatible RAM/payload may now be configured. Figure 4-18 illustrates the pairing of sortie RAM payloads with a compatible RAM support module configuration. The selection of pressure modules, free-flyers or pallets for a given payload is a function of crew support requirements, payload size, and attached/detached criteria. Those payloads that are assigned to pallets can function independent of direct crew support. These experiments usually encompass those with sensors or direction-sensitive instrumentation. The crew support that is required can be performed in either a sortie RAM or RSM/payload module that is adjacent to the pallet. For those payloads that require direct crew support, such as changing of film, observing materials phenomenon, and the like, the experiments are contained either within a sortie RAM or a payload module/RSM. The choice of the size of the payload module, of course, is a function of the size of the experiment program equipment. Finally, those payloads (experiments) that have special stability requirements beyond those attainable with an EOS-attached configuration, are dedicated to a free-flyer module. The payloads shown in Figure 4-18, as dedicated to a free-flyer, were chosen for this mode because of the stability requirements (0.005 arc-sec) precluding compatibility with the EOS. A definition of the payloads in Figure 4-18 is provided in DS 158B.

Alternate Approach Selection Summary

In this section the analysis was directed toward the selection of alternate approaches for RAM operations. The three alternate approaches were dependent, independent and modular dependent, and were defined at the functional level. The alternate approach selections for the EOS/attached RAM element pair are summarized in Table 4-11.

Payloads * — Payload Configurations



Payloads *	Payload Configurations		
A3S1B, A6S1B, A8S1U, A8S1V, A8S1W, A8S1X, A8S1Z, A9S1J	(1)	or	(2)
C1S1E, C1S1F	(3)	or	(4)
E151N	(1)	or	(2)
E1S1O, A1S1P, E1S1Q, E1S1R, E1S1S, M1S1E, M1S1F, M1S1G	(3)	or	(4)
P5S1B	(3)	or	(4)
B7S1A	(3)	or	(4)
T2S1A	(1)	or	(2)
T3S1A	(3)	or	(4)
L8S1B	(3)	or	(4)
M1S2B, P5S2A, P8S2B, P7S3A	(4)		
T2S2E	(4)		
T3S2B	(2)		
T5S2B	(4)		
L8S2B	(4)		
L1S2C	(2)		
A103B, A202B, A303B, A502C	Free Flyer		

NOTE: The circled numbers designate the configuration as defined in the above four sketches.

Key

SR	Sortie RAM
PM	Payload Module
RSM	RAM Service Module
	Pallet

*Refer to Table 4-4 for payload titles.

Figure 4-18. Sortie RAM Payloads

Table 4-11. Alternate Approach Selections
EOS-Attached RAM Operations

Element Pair	Function	Approach			Rationale
		Dependent	Independent	Modular Dependent	
EOS/RAM	Communications				
	Tracking	X			Available on EOS
	Voice	X			Available at the interface
	Data				
	< 1 Mbps	X			Avail. on EOS and interface
	1 to 10 Mbps *			X	RAM provides transmitter, uses EOS antenna
	Up to 50 Mbps		X		Magnetic tape storage, up to 6 cubic feet plus equip.
	Data Management		X		
	Environmental Control				Minimize EOS scar and sensitivity to EOS/RAM crew size. Analysis contained in Appendix A6. (applies to all Environmental Control items)
	Atmosphere stores		X		
	Atmos. pressure controls		X		
	Emergency O_2		X		
	Air circulation		X		
	Humidity control		X		
	Contaminant monitoring		X		
	Contaminant removal		X		
	CO_2 removal		X		
	Atmos. temperature control		X		
	Waste management		X		
	Water management		X		
	Thermal Control		X		Shuttle capable of sustaining only its own thermal control

*Ground network model is limited to 1 Mbps--requires update of recorder

Table 4-11. Alternate Approach Selections (Cont.)
EOS-Attached RAM Operations

Element Pair	Function	Approach			Rationale
		Dependent	Independent	Modular Dependent	
EOS/RAM (Cont.)	Attitude Control				(Reference Tables 4-9 and 4-10)
	Pointing				
	≥ ±0.5 deg.	X			EOS capability
	< ±0.5 deg.			X	Augment EOS
	Stabilization (Comb. jet firing)				
	≥ ±.05 deg/sec	X			EOS capability
	< ±.05 deg/sec			X	Augment EOS
	Stabilization (Single jet firing)				
	≥ ±.005 deg/sec	X			EOS capability
	< ±.005 deg/sec			X	Augment EOS
	Electrical Power				
	< 500 watts avg. and 20 kw hr	X			EOS capability
	> 500 watts avg. or 20 kw hr		X	X	Augment EOS or independent system
	Orbital Payload	X			Reference Appendix A7

MSS/Attached RAM

It was pointed out earlier in Section 4.4 that the MSS was designed specifically for the purpose of supporting a manned experiment program, whereas the EOS has been designed primarily as a transportation vehicle. It would therefore be expected that the dependency of the attached RAM s on the MSS is established to a much greater degree than the dependency on the EOS. As was presented for the EOS/RAM pair, the alternate approach selection is presented by functional requirement.

Communications and Data Management

All scientific data from the experiment payloads are "dumped" into the space station for storage, processing or transmission. The data rate and volumes are defined in Table 4-4 and range up to 51.4 Mbps and a maximum volume of 4.5×10^{10} bits/orbit (6.8×10^{11} bits/day). Analog data are required for a limited number of payloads; the maximum bandwidth is 10 MHz. Voice transmission to and from ground is required for the attached RAM payloads and is provided by the MSS. No RAM tracking function is required for space station-attached missions. Guidance and navigation parameters will be provided by the MSS as required.

Environmental Control and Thermal Control

Essentially, environmental control and life support to the MSS attached RAM s are available from the MSS and therefore are dependent upon by the MSS. Figure 4-19 presents a schematic diagram of the ECS concept. Those functions that need to be provided by the RAM are emergency oxygen supply, atmosphere distribution and circulation, atmosphere temperature control and pressure suit support.

As was discussed in the EOS/attached RAM element pair, the thermal control of MSS attached RAM s employs the same concept - water/freon coolant loop to the radiators to space. As a result, the approach selection is independent of the MSS.

Attitude Control

Like the EOS, MSS attitude control functions are delegated to two modes--pointing and stabilization. If the attached RAM requires no attitude control, then it obviously is independent of MSS operation. However, the attached RAM must assume a modular dependent approach if the pointing requirements are more stringent than ± 0.25 degree and the stability requirements are les than 0.05 degree per second.

A tabulation of the station attached RAM s attitude pointing and stability requirements, together with the MSS capabilities, are presented in Table 4-12. Imposed on this table are the three alternate approach selections.

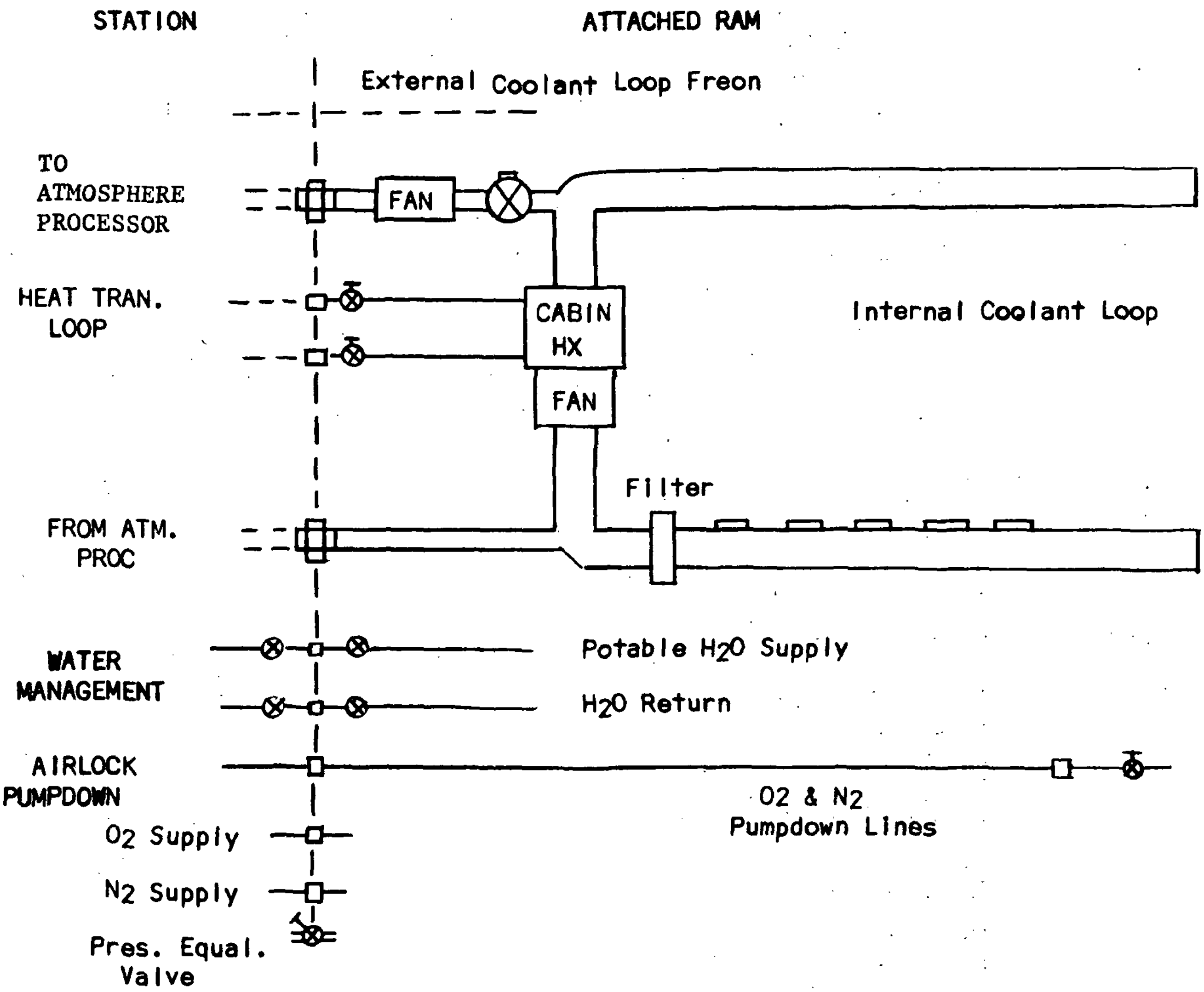
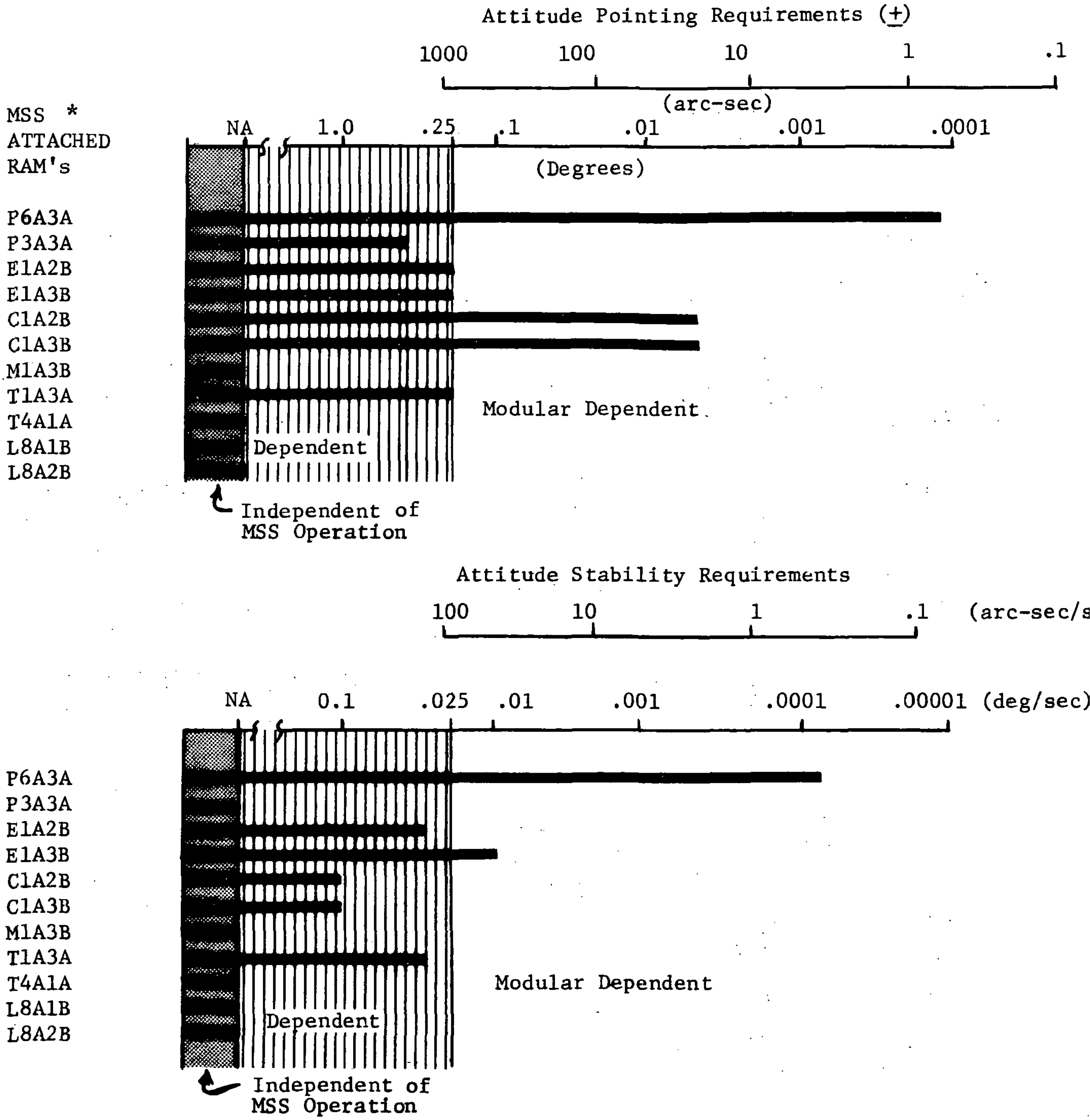


Figure 4-19. Station Attached RAM ECS Concept

Table 4-12. MSS/Attached RAM Attitude Requirements



* Refer to Table 4-4 for payload titles.

Electrical Power

Electrical power requirements for the MSS attached RAMs are capable of being met by the MSS with the proper interface provided.

Alternate Approach Selection Summary

In this section, the analysis was directed toward the selection of alternate approaches for RAM operations. The three alternate approaches were dependent, independent, and modular dependent and were defined at the functional level. The alternate approach selections for the MSS/attached RAM element pair are summarized in Table 4-13.

Table 4-13. Alternate Approach Selection MSS-Attached RAM Operations

Element Pair	Function	Approach: Dependent	Approach: Independent	Approach: Mod. Depend.	Rationale
MSS/RAM	Communications				Available in MSS
	Tracking	X			
	Voice	X			
	Data	X			
	Data Management	X			
	Environmental Control				Available in MSS, other independent functions required for RAM
	Atmosphere stores		X		
	Atmos. Pres. controls		X		
	Emergency oxygen		X		
	Atmos. circulation		X (1)		
	Humidity control	X			
	Contaminant monitoring			X	
	Contaminant removal	X			
	CO_2 removal	X			
	Atmos. temp. control	X			
	Waste management		X (2)		
	Water management	X			
	Thermal Control	X			Available in MSS

(1) Required to be independent for only the RAM functions

(2) Trash and waste water storage

Table 4-13. Alternate Approach Selection (Cont.)
MSS-Attached RAM Operations

Element Pair	Function	Approach: Dependent	Approach: Independent	Approach: Mod. Depend.	Rationale
MSS/RAM (Continued)	Attitude Control				
	Pointing				
	$\geq \pm 0.25$ degree	X			MSS capability
	$< \pm 0.25$ degree			X	Augment MSS
	Stabilization				
	$\geq \pm .05$ deg/sec	X			MSS capability
	$< \pm .05$ deg/sec			X	Augment MSS
	Electrical Power	X			Available from MSS

SERVICE AND CHECKOUT

At the beginning of this section (4.7), it was mentioned that the thrust of the alternate approach selection would be concentrated almost totally upon the RAM operations mode. However, there are a few observations relevant to the other two modes of operation; service and checkout, and quiescent storage.

Service and checkout involve an interface between two elements where the supporting element provides many of the support functions, including the replenishment of consumables. A typical service and checkout mission involves a detached (free flyer) RAM being returned to an MSS. For this case, all functions of the RAM are dependent upon the MSS except for thermal control, where the thermal control is provided by the RAM. Unlike the MSS, the EOS is capable of supporting only its own environmental control functions and therefore cannot be relied (dependent alternative) upon for support. Consequently, a support module will be required at the EOS/RAM interface; this being perhaps a sortie RAM that has environmental control functions. During the initial delivery to orbit of the free-flyer RAM, an extensive servicing and checkout will not normally be required. However, if for some reason it should, and since the EOS will not have a sortie RAM attached to it for support, some other means of providing a habitable environment will be required. Since this is a low frequency of occurrence event, it appears that use of IVA would be the most effective approach.

During service and checkout there will be a requirement to either verify the payload attitude calibration or, in some cases, to provide signals to the payload to aid in the calibration. In addition, some satellites will require special pointing and stabilization during the revisit portion of the mission. Both of these functions are dependent on the supporting vehicle.

A summary of the alternate approach selection is presented in Table 4-14 for each of the element pairs associated with service and checkout.

Table 4-14. Preferred Approach Selection - Service and Checkout

Element Pair(s)	Function	Approach: Dependent	Approach: Independent	Approach: Mod. Depend.	Rationale
EOS/DRAM (for initial delivery to orbit and if entry into the DRAM is reqd.)	ECS-Habitable atmosph.			X	Since only a few missions of this type occur then use of an IVA and portable module is most cost effective.
	circulation			X	
	contam. control			X	
	thermal			X	
	Attitude-Pointing	X			Already available in current EOS design.
	Stabilization	X			
Tug/Tug, EOS/OPD, Tug/CLS, Tug/RNS	ECS-Habitable atmosph.	X			Compatible design solution, cost effective, commonality and multiple usage.
	Circulation	X			
	Contamination	X			
	Thermal	X			
	Attitude-Pointing	X			
	Stabilization	X			
MSS/DRAM	ECS-Hab. Atmosphere	X			Least cost, MSS already has capability
	Circulation	X			
	Contamination	X			
	Thermal	X			
	Thermal		X		
	Attitude-Calibration	X			Already available on MSS

Table 4-14. Preferred Approach Selection - Service and Checkout (Cont.)

Element Pair(s)	Function	Approach: Dependent	Approach: Independent	Approach: Mod. Depend.	Rationale
EOS/MSS EOS/Tug CLS/OPD RNS/OPD	ECS-Habitable Atmos.		X		Supporting element has capability.
	Circulation		X		
	Contamination Cont.		X		
	Thermal		X		
	Attitude-Calibration	X			During checkout, EOS, CLS, or RNS control is adequate.
	Stabilization	X			
Tug/Satellite EOS/Satellite	Attitude-Pointing	X			Required for calibration and performance of some experiments while attached
	Stability	X			
	Calibration	X			
EOS/DRAM + Sortie RAM (Revisit missions)	ECS-Habitable Atmos.			X	Cost effective, commonality and multiple usage
	Circulation			X	
	Contamination			X	
	Thermal			X	
TUG/DRAM	Attitude-Calibration	X			

QUIESCENT STORAGE

The primary element pair involved in quiescent storage is an earth orbit resupply module (sometimes known as a cargo module) attached to the MSS. Although the title, quiescent storage, suggests little or no activity, there is continual activity in and out of the attached resupply module since it is utilized as a pantry. Consequently, a habitable environment is required in the resupply module. The ECS functions are most effectively provided for by the MSS. The selection is based on the desirability of maintaining the weight of the cargo module at a minimum. The additional scar weight imposed on the resupply module for ECS support systems cannot be tolerated due to the repeated up-down delivery of this vehicle. While attached to the MSS, the space-based tug is also subject to entry and, again, the MSS provides the most effective ECS support. In addition, the tug attitude reference system will need to be aligned prior to its subsequent independent operation. Short periods of quiescent storage, which can occur for the MSS/ARAM and MSS/DRAM element pairs, are associated with RAM operations and service and checkout, respectively, and are covered under those modes of operation.

Table 4-15 summarizes the preferred approach selection for quiescent storage operations.

Table 4-15. Preferred Approach Selection - Quiescent Storage

Element Pair(s)	Function	Approach			Rationale
		Dependent	Independent	Mod. Depend.	
MSS/EO Resupply Module	ECS-Habitable atmos.	X			To maximize deliverable payload capability of EO Resupply Module, ECS provided by on orbit MSS.
	Circulation	X			
	Contamination Cont	X			
	Thermal	X			
MSS/Space Based Tug	ECS-Habitable atmos.	X			MSS has capability.
	Circulation	X			
	Contamination Cont	X			
	Thermal	X			
	Attitude-Alignment	X			Required to reesetablish platform alignment.

5.0 ATTACHED ELEMENT TRANSPORT

There are several mission phases involved in the transport of a payload by a propulsive vehicle from one earth orbit to another. Rendezvous, stationkeeping, orbit phasing, and orbit transfer all may be carried out while one element is attached to another. The attached element transport activity includes the support provided by a major propulsive element to an attached payload during and between main engine thrusting maneuvers in earth orbit. Accommodation of the thrust loads at the element pair interface, the control of the propulsive vehicle, and the status monitoring of the payload are part of this activity. Support by a propulsive vehicle to an attached payload subsequent to arrival at the orbital destination is covered in the Attached Element Operations activity, section 4.0. Transport of payloads by the EOS orbiter during the boost and entry phases is not included in this study.

Attachment to the thrusting vehicle may be either internally as a payload in the orbiter cargo bay or externally as a module being transported by a tug. Consequently, attached element transport is closely related to the interfacing activities designated as mating and EOS payload retraction and stowage. In addition, operations associated with the attached element transport activity may occur in connection with other interfacing activities such as orbital assembly or rendezvous. Reporting of operations or remote control of the operations while the two elements are attached would require data transfer and thus would also involve the communications activity. Procedures, techniques, and requirements established for any of these interfacing activities are applicable to attached element transport.

5.1 SUMMARY

Element interfaces and mission models involved in the element-to-element interactions identified with attached element transport are discussed in paragraph 5.2 and described in Figure 5-1 in matrix format. Most of the interactions occur as interfaces with the EOS orbiter and the space-based tug. Alternate approaches to attached element transport are discussed in paragraph 5.3 and depend mainly on the attachment, control, and monitor concepts.

Various docking port design concepts are discussed in paragraph 5.4 for the purpose of selecting viable baseline models. A more detailed comparison of fifteen concepts is presented in Appendix A8. The following four concepts were selected for more detailed consideration: (1) multiple probe and drogue, (2) ring cone, (3) square frame, and (4) international.

Operational procedures are summarized in paragraph 5.5 and presented in detail in Appendix B. Because the differences in operations for transport of payloads internally as compared to externally are relatively small, one procedure is applicable to both modes of attachment.

Paragraph 5.6 presents and discusses functional requirements and related analyses. Retention system, control and status monitoring, and thrust vector alignment requirements are included. A docking loads analysis was conducted for the various propulsive vehicle/payload combinations for transport with the external mode of attachment. The estimated axial loads can be accommodated by any of the four docking port concepts selected for evaluation. Payload delivery with the high thrust CPS requires that the payload modules be delivered in a disassembled configuration on a specially designed adapter to provide distribution of the loads in an axial direction. The RNS can deliver payloads in an assembled configuration (such as an OLS) without causing excessive bending moments at the docking port interfaces.

Paragraph 5.7 presents preferred approach selections for control of the logistics vehicle and status monitoring of the payload during transport. Alternate means for both internal and external attachment, and the associated design influences, are discussed. No requirement has been identified for transport of an externally attached payload by the EOS orbiter. The worst-case loads that will design the EOS orbiter cargo bay payload attach points and mechanisms are those that occur during the boost and entry phases. The logistics vehicle control modes selected are the same as those selected for the rendezvous activity, i.e., the autonomous mode when the logistics vehicle is manned, and ground control for unmanned cases. The only required interface identified between the logistics vehicle and the attached payload is for purposes of hazard monitoring of payload systems when the vehicle is manned. All other monitoring can be performed by ground control.

5.2 ELEMENT INTERFACE AND MISSION MODEL MATRICES

Because this interfacing activity by definition involves thrusting maneuvers, one side of the interface is represented by the propulsive elements in the inventory. Any of the elements except the EOS orbiter may be the transported element. The orbiter is an exception because it is not modular nor does it have attachment points to accommodate thrusting by another vehicle. Figure 5-1 presents a matrix identifying the possible combinations of interacting elements involved in the attached element transport activity.

The EOS orbiter may serve as the transporting element for any of the other elements except the orbit insertion stage (OIS), and nonmodular concepts of the CPS, RNS, OLS, and OPD. The EOS may carry an element or a module of an element during rendezvous, orbit transfer, or orbital assembly.

Any of the tugs may serve as a transporter of a satellite requiring a kickstage for emplacement. One stage of a ground-based tug may transport another during phasing, orbit transfer, and rendezvous maneuvers, especially when performing high-energy missions. A ground-based tug also might be required to recover another tug, either ground-based or space-based, and transport it to an orbiter for return to the earth's surface. Likewise, a space-based tug might transport another space tug or stage to an available space base. Neither tug transports RAM's that are attended by an EOS orbiter but might deliver RAM's to a space station or recover free-flying modules and return them to an MSS for servicing. Either tug type might transport returnable satellites, resupply modules, and modules of the geosynchronous space station, but only the space tug would be employed in orbital assembly of a low earth orbit space station or an OPD. Likewise, only the space tug would be used in the transport of large vehicles such as the CPS, RNS, or the large lunar payload assemblages while in earth orbit. The space tug also might transport an OIS either for insertion into a disposal trajectory or for refueling and conversion for use as an inter-orbital or cislunar shuttle. An OIS would be a transporting element when carrying CPS, RNS, OLS, or OPD nonmodular configurations during orbital delivery rendezvous maneuvers. The CPS and RNS also may be considered transporters of RAM's, resupply modules, and/or space stations to geosynchronous altitude.

The matrix presented in Figure 5-2 shows for each of the 64 element-to-element interactions the particular mission models that identify this interfacing activity. There are a total of 126 occasions where an attached element transport interaction between two of the elements might be expected to occur. Table 5-1 indicates how many occasions are associated with each element in the inventory. There is at least one occurrence of this activity identified in each mission model.

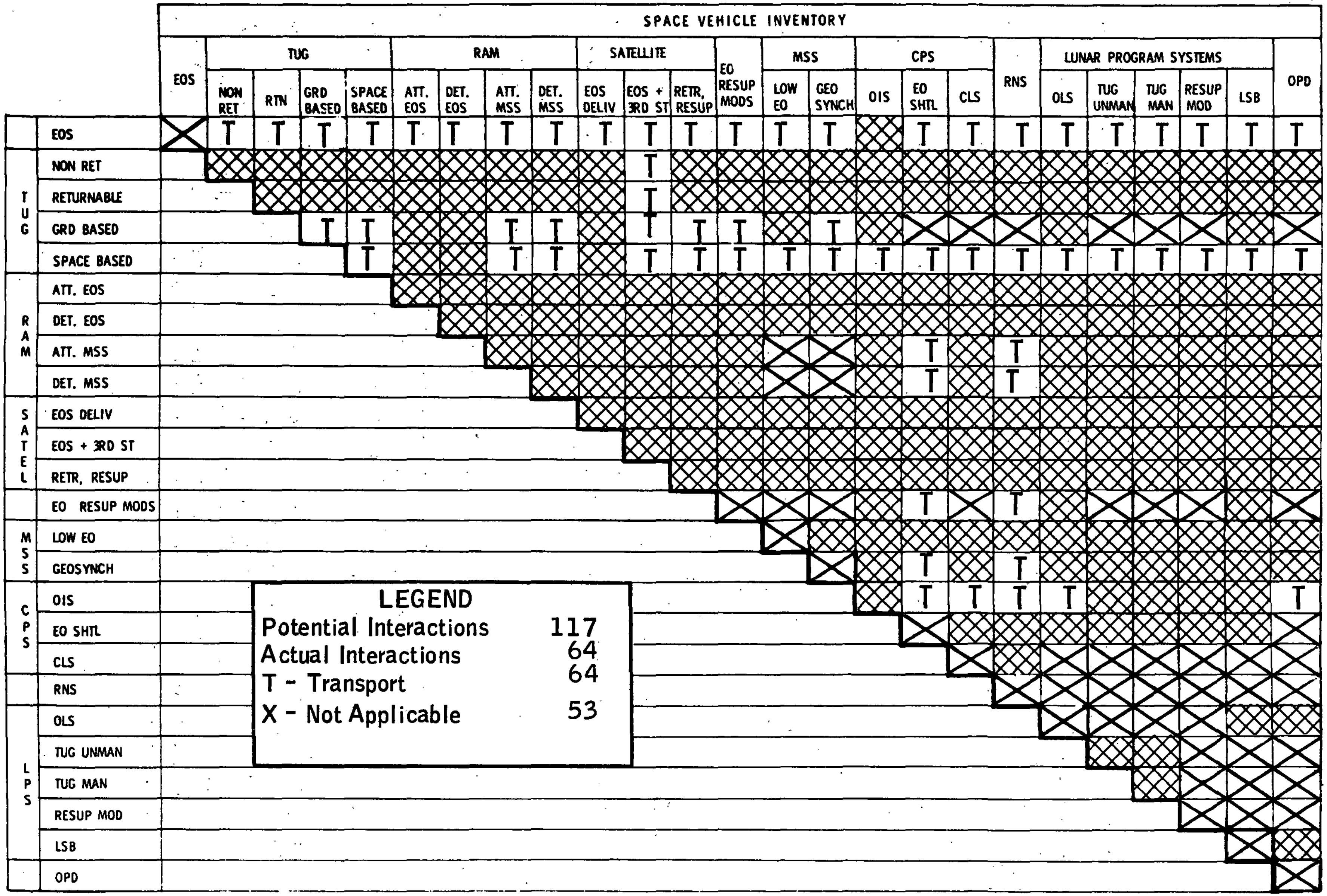


Figure 5-1. Attached Element Transport Interactions

Table 5-1. Attached Element Transport Interactions Associated with Inventory Elements

EOS	23
Nonreturnable Tug	2
Returnable Tug	2
Ground-Based Tug	9
Space-Based Tug	20
EOS Attached RAM	1
EOS Detached RAM	1
MSS Attached RAM	5
MSS Detached RAM	5
EOS Delivered Satellite	1
EOS plus 3rd Stage Delivered Satellite	5
Return, Resupply Satellite	3
EO Resupply Module	5
Low EO MSS	2
Geosynchronous MSS	5
CPS - OIS	6
CPS - EO Shuttle	7
CPS - CLS	3
RNS	7
OLS	3
Lunar Tug - Unmanned	2
Lunar Tug - Manned	2
Lunar Resupply Module	2
LSB	2
OPD	3

		SPACE VEHICLE INVENTORY																								
		EOS	TUG				RAM				SATELLITE			EO RESUP MODS	MSS		CPS			RNS	LUNAR PROGRAM SYSTEMS					OPD
			NON RET	RTN	GRD BASED	SPACE BASED	ATT. EOS	DET. EOS	ATT. MSS	DET. MSS	EOS DELIV	EOS + 3RD ST	RETR, RESUP		LOW EO	GEO SYNCH	OIS	EO SHTL	CLS		OLS	TUG UNMAN	TUG MAN	RESUP MOD	LSB	
	EOS		1	2	1,2 7,8	1,2	3	1,2	2,5	1,2,4,5, 10,11	1	1,4	2,4,5	2,5, 10,11	1,2,4,5	1,2,4, 5,10,11		1,2, 4,5	1,2, 4,5	1,2, 4,5	1,2,4, 5,10,11	2,5, 10,11	2,4,5, 10,11	2,5, 10,11	2,5, 10,11	1,2, 4,5
TUG	NON RET											1														
	RETURNABLE											7														
	GRD BASED				8	8			8	7,8		7	8	8		7,8										
	SPACE BASED					4			5	4,5, 10,11		4	4,5	5,10, 11	4,5	4,5	6	4,5,6	4,5,6	4,5,6	4,5	5	4,5	5	5	4,5,6
RAM	ATT. EOS																									
	DET. EOS																									
	ATT. MSS																	10,11		11						
	DET. MSS																	10,11		11						
SATEL	EOS DELIV																									
	EOS + 3RD ST																									
	RETR, RESUP																									
	EO. RESUP MODS																	10,11		11						
MSS	LOW EO																									
	GEOSYNCH																	10,11		11						
CPS	OIS																	9	9	9	9					9
	EO SHTL																									
	CLS																									
	RNS																									
LPS	OLS																									
	TUG UNMAN																									
	TUG MAN																									
	RESUP MOD																									
	LSB																									
	OPD																									

Figure 5-2. Applicable Mission Models for Attached Element Transport

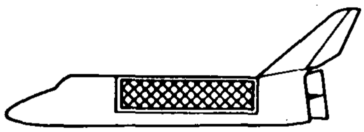
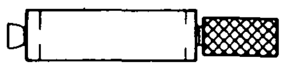
5.3 ALTERNATE APPROACHES

There are two general classes of approaches for the achievement of transport of one element by another in space. One is dependent upon how the two elements are attached and the other is the means used to control the operations of the combined vehicles.

ATTACHMENT APPROACHES

Depending upon the operational characteristics of the elements, attachment may be internal or external. Because the EOS orbiter must be able to carry payloads through the earth's atmosphere, its attachment points are located inside the cargo bay. The tug, on the other hand, often will be moving elements larger than itself and, thus, will employ external attachment. It is assumed that the other propulsive vehicles also will employ external attachment while transporting.

The two approaches for attachment are illustrated below.

	INTERNAL ATTACHMENT	EXTERNAL ATTACHMENT
ATTACHED ELEMENT TRANSPORT		

CONTROL AND MONITOR APPROACHES

Control of the transport operations could be accomplished by either ground control, one of the attached elements, or a third orbital element. Either automatic or manual techniques are applied to all three approaches. Transport of a statelite by a third stage normally would be automated and controlled by ground. All transport operations involving the EOS orbiter could be manual and controlled by the orbiter. Thrusting maneuvers of a space-based tug deploying a RAM tended by the MSS involves three elements and could be manual (manned tug) or automatic (unmanned tug). Control approaches are discussed in detail in communications, rendezvous, and detached element operations and are only briefly summarized in the analysis of this activity.

Two approaches for monitoring of the attached payload and its subsystems during transport are (1) by the logistics vehicle and (2) by ground control. If the logistics vehicle is unmanned, ground control is ultimately involved in the first approach by virtue of its control of the transport.

5.4 DESIGN CONCEPT MODELS

A discussion and analysis of docking port concepts for the purpose of selecting viable baseline models for use in dynamic loads analyses is presented in Appendix A8. A total of 15 concepts were considered, four of which were selected for docking and thrusting loads analyses. The four selected are (1) multiple probe and drogue, (2) ring cone, (3) square frame, and (4) international. The following four paragraphs present a brief description of each of these concepts.

The multiple probe and drogue concept as shown in Appendix A, Figure A8-15 employs three probes and three drogues on each vehicle. During the docking operation these probes on one vehicle would be activated while the probes on the mating vehicle would remain passive or act as a redundant system. Only the drogue cones are required where the mating payloads are passive. Capture latches are contained in the probe fingers and are engaged when the probe finger is seated in the drogue. The actuator contained within the shock mounted struts pulls the two mating vehicles together. Structural interface loads are transferred by latches located either on the transfer tunnel or the vehicle outer shell structure.

The ring cone concept shown in Appendix A, Figure A8-16 was proposed for hard docking a Space Station. The mating operation is performed by fitting together two identical machined rings, one on each of the mating vehicles. Alignment is achieved by matching notches and tapers on the rings. Shock struts and actuators located on the inside perimeter of the docking enclosure provide attenuation and actuation for the capture and locking latches.

The square frame concept is shown in Figure A8-17. This concept employs a square frame mating fixture containing guide arms and capture latches and eight shock absorber actuators. The square frame serves to align the modules in the roll axis because the engaging guide arms are camed into the corners of the frame. Load transfer latches are located on the outer shell structure. Package transfer is accomplished through hatches in the hemispherical airlocks.

Figure A8-18 in Appendix A illustrates a modification to the concept being considered for the international docking study. This concept employs a mating fixture consisting of a tubular ring with three tubular nodes that extend approximately four feet beyond the ring. These nodes fit between the nodes on an identical fixture during the docking operation. Six shock mounted screwjacks extend the ring and capture latches to mate within the ring on the mating vehicle. The screwjacks are activated to draw the two vehicles together. Locking latches are located around the inside diameter of the ring or on the outer shell structure.

Three logistics vehicles were included in the attached element transport activity studies of dynamic loads due to thrusting, and methods of accommodating these thrust loads at the element pair interfaces. These three vehicles and their baselined thrust levels are as follows:

Space Tug	70,200 pound thrust
RNS	75,000 pound thrust
CPS	960,000 pound thrust

5.5 OPERATIONAL PROCEDURES

In mission phases where an element is attached to a propulsive vehicle for movement from one orbital position to another while in earth orbit, the interface activity between these two elements while in such movement is Attached Element Transport Activity. The transporting vehicle must be performing a thrusting maneuver while carrying the attached element. A number of elements may be transporting elements, such as orbiter, tug, RNS, OIS and CPS; or transported elements such as tug, RAM, satellite, resupply module, or station module. Attachment to the thrusting vehicle may be either internally as a payload in the orbiter cargo bay or externally as a module being transported by a tug. Except for those cases where the two elements are attached on the ground and brought up together to initial orbit, mating is a prerequisite to transport. In addition, this activity may occur in connection with other interfacing activities, including mating, orbital assembly, rendezvous and separation. Communications will be inherent in the reporting of operations or remote control of their operations while the two elements are attached, and require data transfer.

The procedure for attached element transport operations involving either internal attachment (e.g., orbiter) or external attachment (tug) with an attached RAM payload is described in Appendix B. The operations are essentially identical for both internal and external attachment, and involve monitoring and checkout of the attached element, alignment of the thrust vector of the transporting element with the center of gravity of the combined elements, main engine thrusting, orbit verification and communications for command and data transfer. Mating of the elements is of course prerequisite to such operations.

DESCRIPTION

Figure 5-3 shows a block flow diagram of the operations involved. Essential operations during transport will include monitoring and checkout of the attached element, alignment of the thrust vector of the transporting element with the center of gravity of the combined elements, main engine thrusting, verification of the orbit, and communications for command and data transfer. These functions may be performed during all associated operations carried out while the elements are in orbital transport.

The procedure is essentially identical for both internal and external attachment. Some differences will exist in some details of the retention assembly design, dynamic loads and deflections, and alignment action, without significantly altering the nature of the specified operations.

The operational procedure presented in Appendix B shows the detailed sequence of operations for attached element transport, including the element performing the operation, the rationale for the operation, and the reference to the functional requirements supported by this operation.

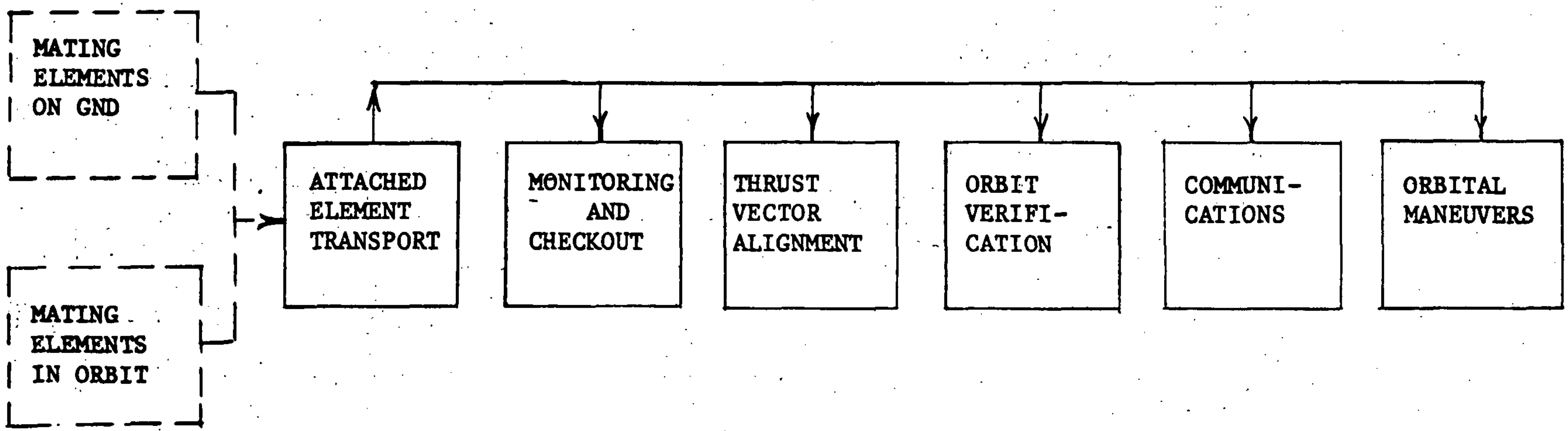


Figure 5-3. Block Diagram of Attached Element Transport Procedure
Internal or External Attachment

The differences in operations for transport of payloads internally as compared to externally are relatively small and one procedure is applicable to both modes of attachment. The differences that do exist for initial attachment and for rigidization are the same as those occurring is associated interfacing activities as shown below:

Initial attachment	Same as Mating and EOS Payload Retraction and Stowage
Rigidization	Same as Orbital Assembly

The Procedures Applicability matrix, presented in Appendix B relates the procedures to the interfacing elements in the space vehicle inventory. Of the 17 elements listed, only four (EOS orbiter, RTN tug, space-based tug and OIS) are transporter vehicles of other elements; the CPS is considered only in a non-modular mode, RNS and OLS in a modular mode, and OPD in either modular or non-modular mode. Thus, EOS may transport 14 elements, RTN tug 1 element, space-based tug 12 elements, and OIS 2 elements.

Within each box in the matrix, an entry is shown, indicating the applicability of the attached element transport procedure for the pair of interfacing elements involved.

5.6 FUNCTIONAL REQUIREMENTS

The functional requirements for attached element transport are defined and discussed below. In general, they are applicable to both internal and external attachments, and varying control approaches.

1. The retention assembly holding the two elements together during the transport must be capable of withstanding any dynamic loads imposed by maneuvers performed by the transporting element.

   For internal attachment in the orbiter cargo bay, the design of the trunnion and latch arrangement assembly for holding the elements together and the payloads during boost into orbit will determine how well the requirement is met. The maximum dynamic loads expected will occur during boost and entry, and are: $N_x = \pm 3.0$ g, $N_y = \pm 0.5$ g, and $N_z = \pm 2.5$ g. The maximum load expected during on-orbit thrusting with payload attached internally is 0.2 g. No requirement exists for EOS orbital transfer thrusting while attached payloads are external to the cargo bay.

2. The retention assembly shall be capable of accommodating payloads of various configurations and dimensions.

   For internal attachment, the means for tie-down in the orbiter cargo bay must be adaptable to the handling points of the transported element. Maximum dimensions of current orbiter cargo bay is 15 feet in diameter and 60 feet in length. Pallets and cradles may be used to accommodate smaller than bay size payloads. For external attachment the size of the attached element is not significant. However, any element to be transported must be equipped with a docking/attachment mechanism compatible with that installed on the transporting element. In cases where more than one module is to be transported by the same vehicle, in a stacked configuration, the modules internal to the stack must be equipped with attachment mechanisms at both ends.

3. The transporting element shall be capable of aligning its thrust vector with the center of gravity of the combined elements.

   Failure to achieve alignment of the thrust vector with the combined elements center of gravity results in increased complexity of guidance control. For internal attachment, the requirement can be met by provisions for carrying payloads of different masses in various positions in the cargo bay. For external attachment, the positioning of the docking mechanisms and the adjustments for transport of widely varying masses need to be considered. This is particularly significant for a space tug transporting a CPS or RNS to and from an OPD where the tug is moving a mass many times its own and its mass and perhaps its center of gravity may be changing as the refueling operation proceeds. Alignment aids and illumination may be utilized to advantage.

4. Retention assembly must be capable of accommodating expected thermal and structural deflections of the transported element.

   Thermal and structural deflections of the transported element may be experienced during transport. These may occur along either or both the Y-axis and Z-axis. Additional equipment may not be required to handle such deflections. However, the manner of keeping the thrust vector alignment within tolerance may be affected and some adjustments may be required.

5. The control center shall have the means to verify the attachment of the two elements prior to initiation of any thrust maneuver.

   Attachment must be verified as rigid before a thrust maneuver is taken in order to assure that no damage would be caused to the attachment mechanism by loads imposed on open latches or non-load bearing components. For internal attachment, illumination and viewing the retention assembly in the orbiter cargo bay will be required. Such means could be similar to that used for EOS payload retraction and stowage which utilizes a set of floodlights and cameras. For external attachment, verification may be accomplished in the same manner as for mating, such as possible use of laser radar and optical (visual or TV) systems.

6. The control center shall have the means of monitoring thrust vector alignment throughout the transport activity.

   Monitoring the thrust vector alignment during transport will provide information useful in determining burn parameters and other guidance control data. For internal attachment, this can be accomplished in the same manner and with the same sensors as monitoring of a payload during boost into orbit. For external attachment, verification may be accomplished as in mating, using a communication link (hardwire or RF) for data transfer from sensors in the transported element. Data rates may approach 50 kbps.

7. A transporting element, such as a space-based tug, shall have the capability to transport externally attached elements many times its own weight.

   The space-based tug may be used in the transport of large vehicles, such as CPS, RNS, or the large lunar payload assemblages while in earth orbit. The space tug may also transport an OIS either for insertion into a disposal trajectory or for refueling and conversion for use as an interorbital or cislunar shuttle. The CPS fully loaded will have 1,080,000 pounds of propellant and 120,000 pounds of inert weight for a total weight of 1,200,000 pounds. The fully loaded RNS will have 300,000 pounds of propellant and 90,000 pounds of inert weight for a total weight of 390,000 pounds.

8. The control center shall determine the required thrusting maneuvers, and shall control and command operations of the propulsive vehicle for the transport activity.

   These same functions, or similar functions, are required as a part of three other interfacing activities; namely, rendezvous, stationkeeping, and attached element operations. Comprehensive presentations, at a lower level, of functional requirements related to the above requirement are included in the sections covering these three activities in Part 2 of Volume II.

EXTERNAL ATTACHMENT THRUST LOADS

As stated in the first functional requirement, the retention system holding the two elements together must be capable of withstanding the anticipated dynamic loads encountered during transport. An analysis was conducted to determine the axial loads at the vehicle interface. To estimate the interface load resulting from the propulsive force, it was assumed that the maximum thrust of a given transport is applied through the center of gravity of the combined vehicle and that the vehicles are essentially rigid bodies. The results of this analysis are summarized in Table 5-2. The structural interface loads are low for all vehicle combinations considered except the Chemical Propulsion Stage coupled with the Orbital Lunar Station. The CPS/OLS vehicle combination will require latch mechanisms located on the outer shell structure. Additionally, a structural conical shaped transition is required for primary load transfer between the diametrically different vehicles.

Since all other vehicle combinations have relatively low interface loads, it would not be prudent to design each of these interfaces simply to meet the CPS/OLS requirements. The docking configuration for noted vehicles with low interface loadings would utilize load latches located on the transfer tunnel ring. All four docking concepts evaluated can incorporate the load latches and are adequate for thrusting maneuvers.

The geometrical basis for the dynamic loads analysis is based upon the data presented in Appendix A8.

Table 5-2. Interface Loads

Configuration	Thrust ($lb \times 10^{-3}$)	Axial Load at Interface ($lb \times 10^{-3}$)
Tug/Tug	70.2	35.1
Tug/RNS		55.9
Tug/MSS		11.8
Tug/RAM		11.8
CPS/OLS (fully fueled)	960.0	133.6
CPS/OLS (nearly empty)		590.0
RNS/OLS (fully fueled)	75.0	22.6
RNS/OLS (nearly empty)		47.2

5.7 DESIGN INFLUENCES AND PREFERRED APPROACH SELECTION

The alternate approach paragraph (5.3) identified two categories of approaches; namely, attachment approaches and control approaches. This paragraph examines the element pairs defined in Figure 5-1 to arrive at a preferred approach selection. Regarding the attachment approaches, either internal or external, a selection among those two alternatives is not an appropriate consideration. For the elements that are transported by the EOS, attachment points are clearly internal; whereas for all other logistics vehicles (i.e., CPS, RNS, and tug), attachment points are external.

CONTROL AND MONITOR APPROACHES

The operational approaches for controlling one element during transport of another element are related to rendezvous, stationkeeping, and detached element operations. Three alternate approaches--independent, ground control, and space control--are evaluated in detail in Volume II, Part 2 of this report. Various ground control concepts and potential communications links are also analyzed. The results are briefly summarized in this section.

The major factors governing the preferred approach are:

1. Manning status of the elements involved.
2. Relative range between orbital elements.
3. Data transfer requirements.
4. Communication requirements/constraints.
5. Mission characteristics.

The elements considered as viable transport vehicles are the EOS, tug, CPS, and RNS. In the case of the EOS it is always manned and its on orbit stay time is relatively short. Pre-launch planning can be performed in extensive detail by ground equipment. It is recommended that all transport operations involving the EOS be pre-planned by ground control, entered into the EOS computer, and executed by the EOS in an essentially independent mode. Data rates associated with transport operations can readily be accommodated with an S-band omni communications concept. Proper mission planning will alleviate the constraints imposed by the communication gaps with the ground network.

The broad spectrum of potential unmanned tug operations for transport of other elements is more adaptable to a ground control concept. Kickstage and ground-based tug operations will normally result in beyond line-of-sight operation of the EOS. Similarly, space-based tug operations will seldom be conducted in line of sight of another orbital element. The major exception is the case of a tug deploying/retrieving a RAM operating in conjunction with the MSS. In these cases the space controlled approach (MSS controlling the unmanned tug) is preferred.

The independent approach for control of the manned space-based tug is selected (in Part 2 of Volume 2) to provide continuous control and greater accuracy, particularly at closer ranges. Safety is a major consideration in this selection.

In addition to control of the logistics vehicles during transport, status monitoring and subsystems operations control of the payload during transit must be exercised. Most payloads will be relatively self sufficient with regards to the operations control of their subsystems. Many of the payloads which have relatively sophisticated subsystems requiring some operations control during the transport phase, will become free-flyers upon separation from the logistics vehicle. To satisfy requirements imposed during long periods of operation while separate from a host vehicle, the free-flyers will have a high capability to maintain subsystems operations. This capability can be exercised while being transported in earth orbit, thus imposing no requirement on the logistics vehicle or the ground for subsystems operations control.

Status monitoring of payload subsystems during transport is another matter, and imposes requirements on either the logistics vehicle or the ground. To minimize impact on the logistics vehicle (which may be required to transport a wide variety of payloads), status monitoring by the ground is normally preferred. The exception to this occurs when the logistics vehicle is manned. Under these circumstances safety considerations dictate the independent approach for subsystems hazard monitoring (i.e., logistics vehicle monitoring the payload), with non-hazardous monitoring performed by ground control to minimize impact on the logistics vehicle.

INTERNAL ATTACHMENT

There are a wide variety of possible payload retention concepts. The payload retention concept must accommodate payloads 15 feet in diameter by a length that can vary from payload to payload. Payloads that are smaller in diameter than 15 feet will be retained by standardized pallets. Retention includes payload center-of-gravity (c.g.) control, as required by aerodynamic entry. Of the many potential candidates that exist each is characterized by the number of retention (attach) points, their location (side wall or bottom of the cargo bay) and whether each attach point utilizes latches or simply reacts loads in a slot or channel. An evaluation of several candidates was conducted and documented in Payload Retraction and Stowage, Section 5.0, Part 2 of Volume II. The selection made in the evaluation was the 4-point coplanar retention system illustrated in Figure 5-4. This concept was selected because it provides maximum flexibility to accommodate a wide assortment of single and multiple payloads at a minimum weight penalty.

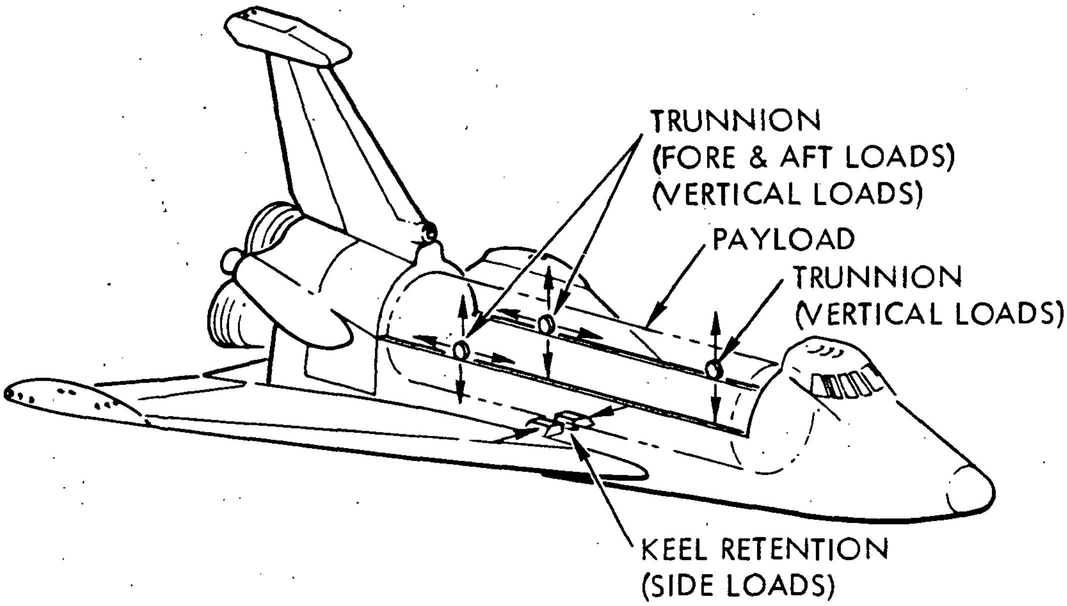


Figure 5-4. Four-Point Coplanar Retention System

Some of the larger payloads cannot easily accept penetrations through their structure due to unique design requirements. As a result, a large clamp or a cylindrical hinge and rotating mechanism have been proposed. Figure 5-5 illustrates one design concept developed for the Tug used in conjunction with the Solar Electric Propulsion stage. While these payloads such as the Tug and Orbit-to-Orbit Shuttle (OOS) will not represent the majority of EOS payloads they will be involved in a significant number of missions.

Several of the OOS tug concepts have experienced a need to utilize a clamp or hinge concept. The launch and landing loads are the prime driver as opposed to the loads experienced during transport. The applicability of these retention devices to the wide spectrum of payloads is limited. The EOS payload deployment activity (Volume II, Part 2, Section 4.0) includes further analyses regarding the commonality evaluation and selection of a preferred payload retention concept.

EXTERNAL ATTACHMENT

Thrust loads experienced during transport of payloads by logistics elements can be grouped into two categories:

1. Loads within the capability of a standard docking concept
2. Loads requiring special adaptations

All transport element pairs except the CPS and its payloads are in the first category. Inasmuch as a standard docking concept, such as the square frame, is adequate there are no unique requirements or preferred approach selections attributable to the attached element transport interfacing activity. Delivery of payloads on either the RNS or the CPS require additional evaluation.

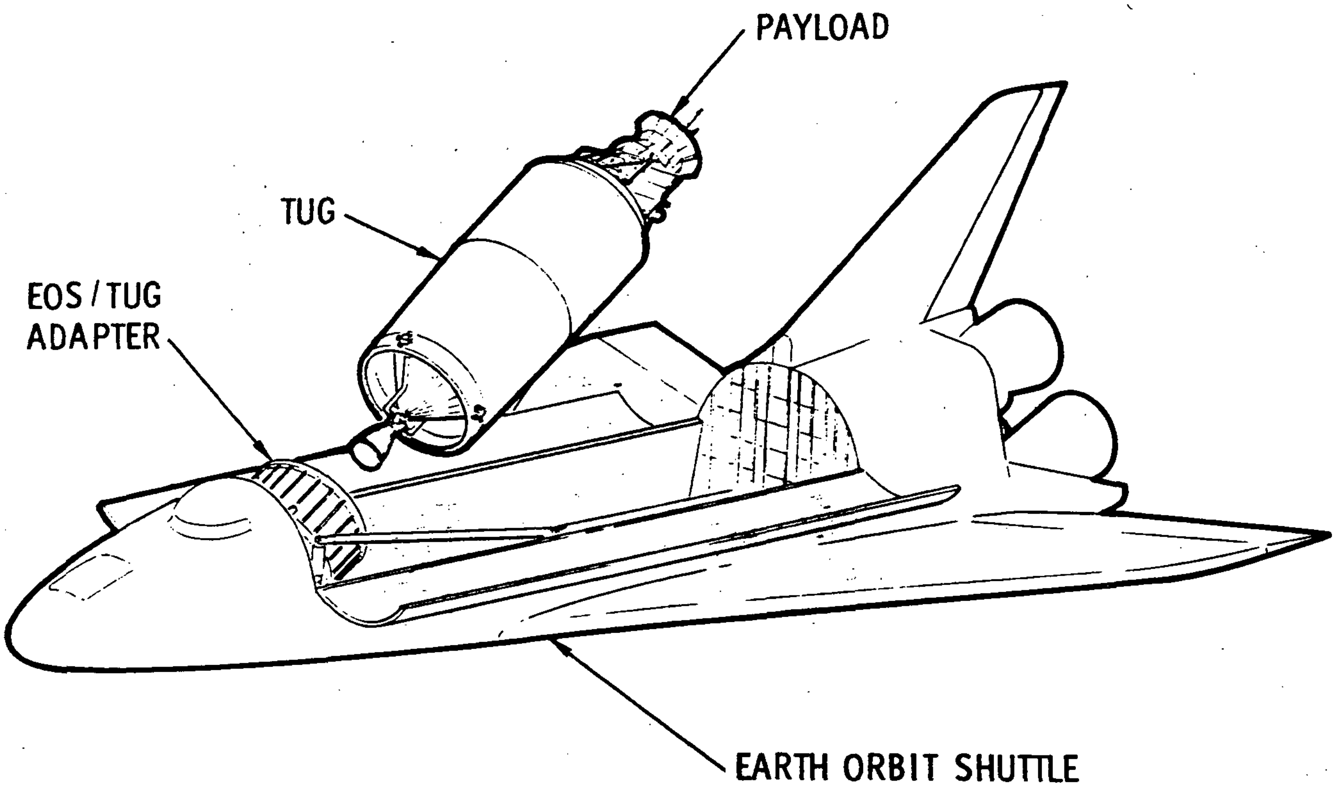
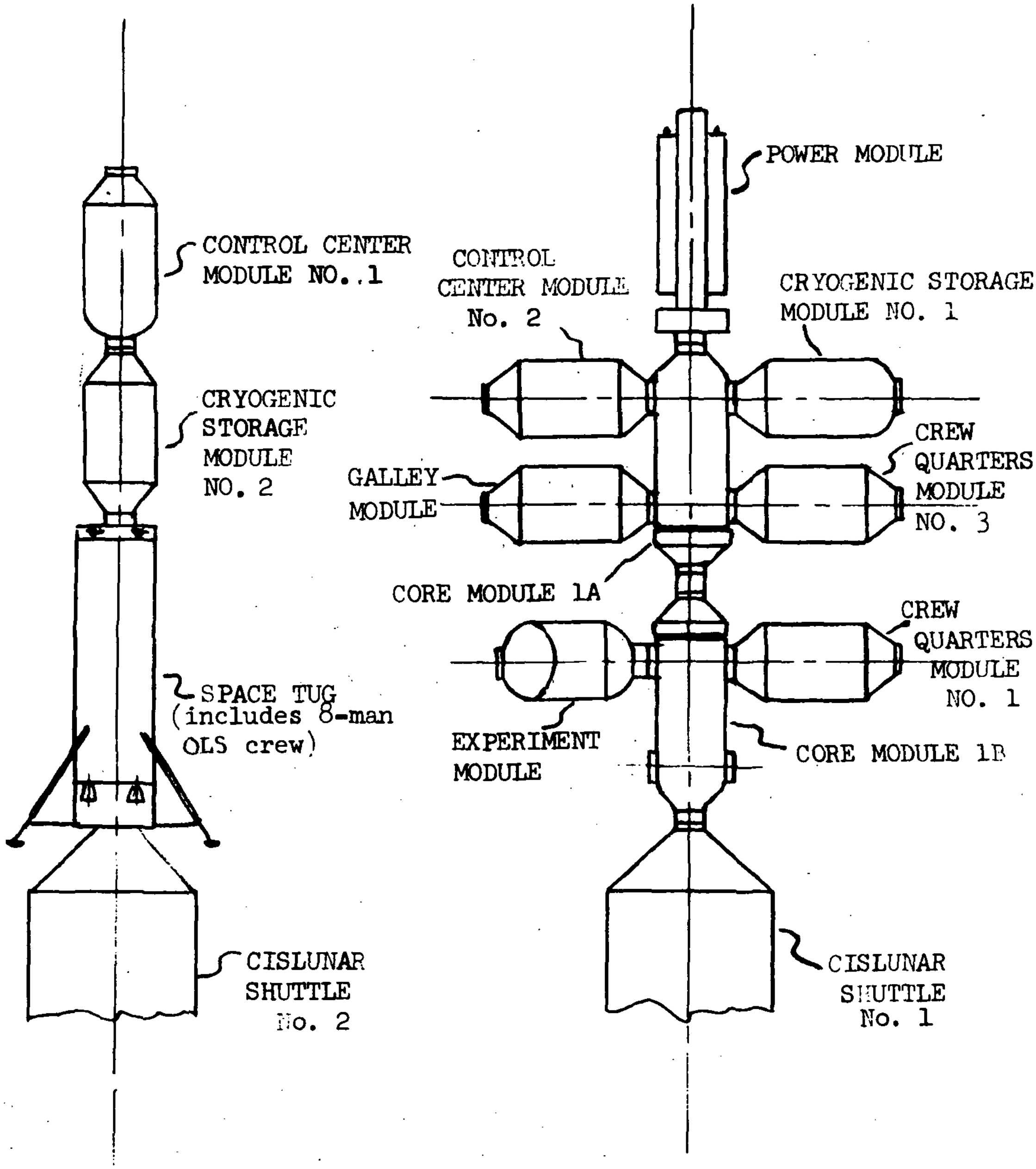


Figure 5-5. Rotating Hinge Retention Concept

The potential payloads for the RNS or CPS are a geosynchronous space station, OLS, LSB, lunar tugs, and resupply modules. Both the geosynchronous station and the OLS may be assembled and checked out in low earth orbit prior to transfer to their higher energy orbits. The LSB is not configured for orbital assembly and checkout. Two obvious approaches for transport of the station are either in the assembled mode or disassembled/stacked module mode. Analyses conducted in the OLS study (DS 350) indicate that delivery is feasible in the assembled mode by a 75,000 lb thrust RNS. However, delivery by a non-throttleable CPS (960,000 lb thrust) in an assembled mode is impractical. Bending loads at the junction of the core module and its radially mounted modules would approach 12 million inch pounds.

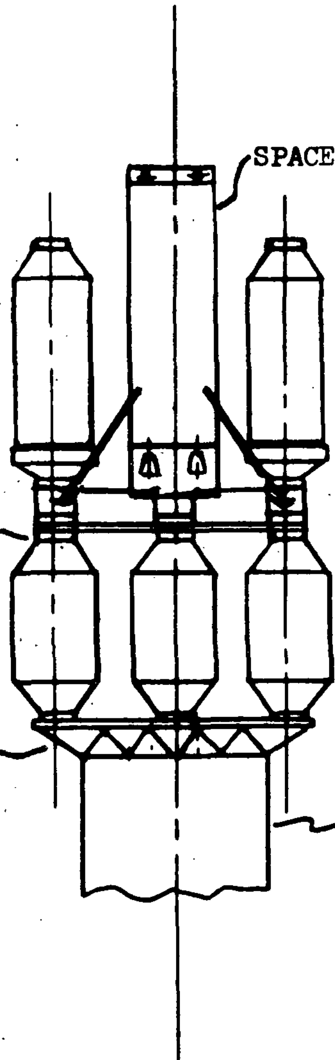
Figure 5-6 illustrates a configuration of assembled modular payloads on an RNS. A standard docking concept can be used for all element and module interfaces.

Figure 5-7 illustrates a stacked configuration of modules for delivery by either the CPS or RNS. Some type of stacked delivery concept is mandatory if the CPS is the delivery vehicle or if the payload is the LSB. The involved assembly process is detailed in the Orbital Assembly activity section. The principal structural problem with this concept is the multiple docking adapters required to stack the modules.



(approximately 149,400 pounds payload) (approximately 158,100 pounds payload)

Figure 5-6. Partially Assembled OLS Delivery Concept



(approximately 310,000 pounds payload)

Figure 5-7. Disassembled OLS Delivery Concept

Several concepts were considered that would facilitate assembly on the CLS and would be structurally adequate. The major problem concerned a design that could be carried to orbit in a 15-foot diameter EOS cargo bay. Various "petal" arrangements were examined but none could be contained within a 15-foot diameter. Figure 5-8 illustrates a concept that will fit in the cargo bay, provide adequate structure, and facilitate the assembly process. It essentially consists of three individual docking adapters "beams" with three docking mechanisms in line on each side of the beam. The outboard docking mechanisms on one side of the beam are hinged to facilitate attachment of modules. It is imperative that the modules be stacked or be as close together as possible during the thrusting maneuver. In line attachment with the desired spacing between modules is not considered feasible even with a manipulator assisting, much less with a direct docking concept.

The assembly sequence for the adapter is as follows:

1. The EOS "elevates" the stack of three beams clear of the EOS mold line.

2. The first beam is docked to the cislunar shuttle (CLS).

3. The CLS rotates 60 degrees and docks to the second beam.

4. The CLS rotates another 60 degrees and docks to the third beam.

Upon subsequent delivery of payload modules the outboard docking mechanisms are sequentially rotated 90 degrees to facilitate mating and then retracted to align the modules with the CLS thrust vector as closely as possible.

The second tier in the build up is accomplished in essentially the same manner. Note the docking mechanisms on both sides of the beams. The lower mechanisms (as shown in Figure 5-10) "cap" the modules in the first tier and provide structural ties between these modules.

Figure 5-9 illustrates a prime alternate concept to the "beam" approach discussed in the previous paragraphs, and is similar to the technique for assembly of the modular RNS and CPS (see Orbital Assembly in Part 2 of Volume II). A central core module, approximately 12 feet in diameter, is used as the main interconnect between modules. Multiple pivotal docking ports are mounted on this core module. As each module is mated to the core, it is pivoted in line (major geometric axes) with the core and latched to the core. The core diameter is smaller than other module diameters to allow space for the retracted docking ports while being transported in the EOS orbiter cargo bay.

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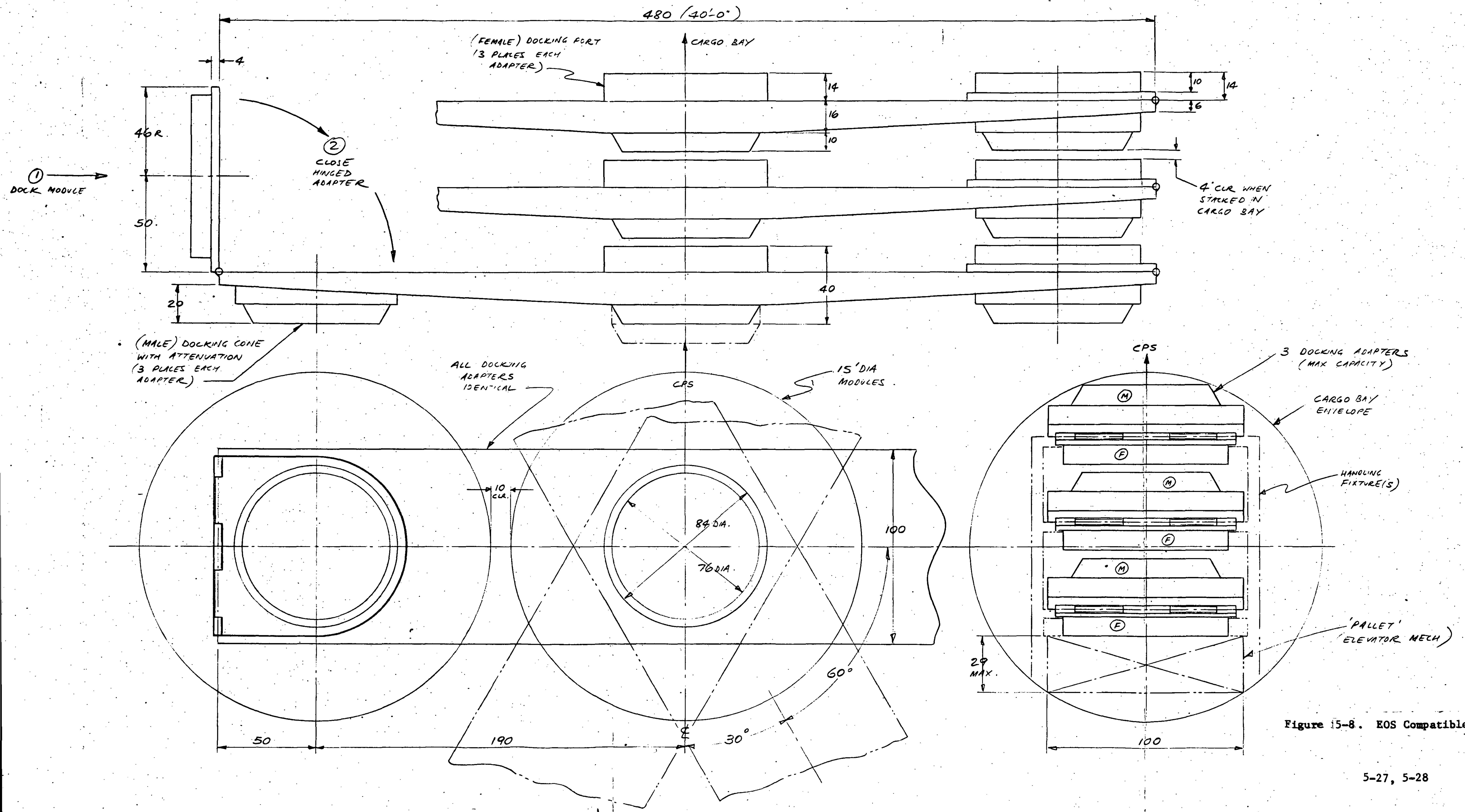

Figure 5-8. EOS Compatible CLS/Payload Adapter

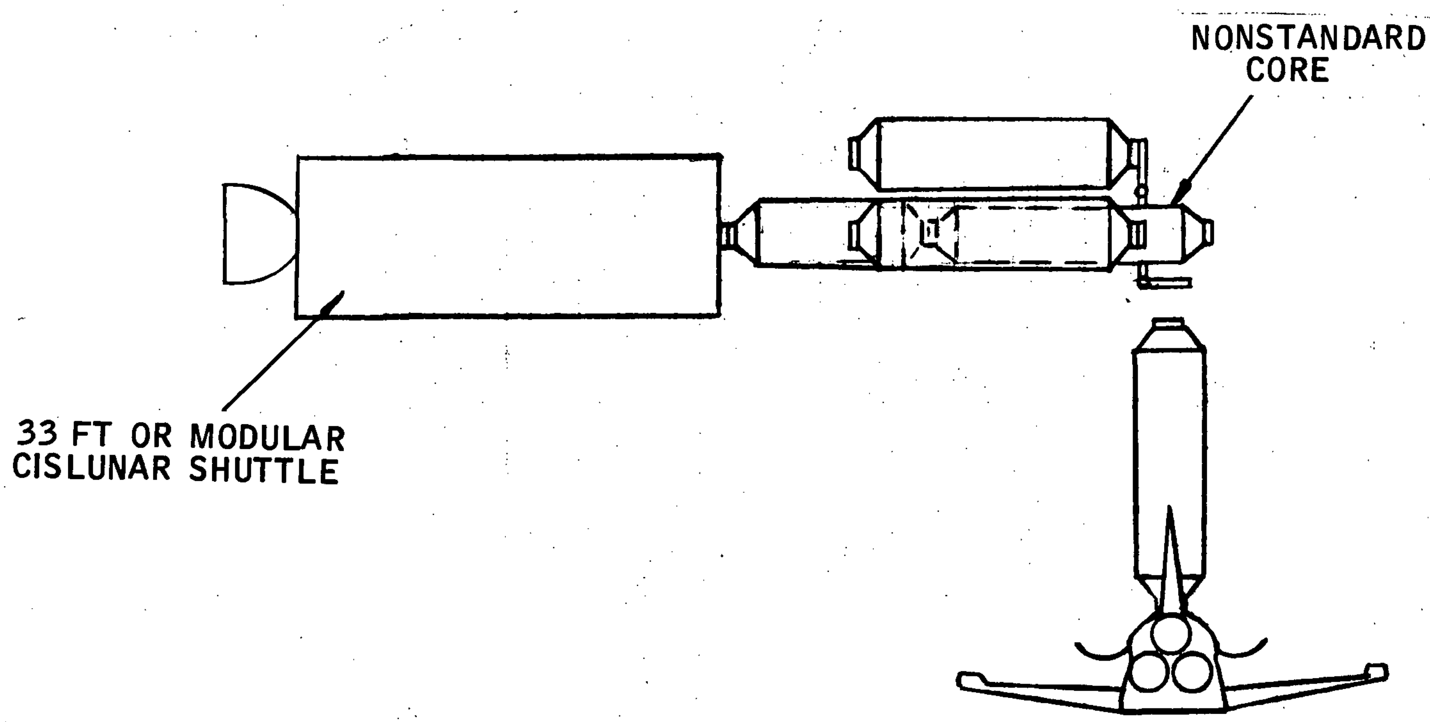

Figure 5-9. Center Core with Multiple Pivotal Docking Ports

DESIGN INFLUENCES

EOS internal attachments are not governed by on-orbit transport operations. Launch and return thrust loads will establish the attachment requirements for all EOS payloads.

Tug and RNS thrust loads can be accommodated by any of the four docking concepts evaluated. Further development and eventual standardization of a docking concept must include consideration of the potential thrust loads of these logistics vehicles.

The OLS and geosynchronous stations may require checkout prior to delivery to their operational orbits. If the transport vehicle is the RNS (75K lb thrust) bending moments up to 2 million inch-pounds could be developed. These potential loads must be considered in designing the structure surrounding core module docking ports of these stations. Evaluation of one contractor's berthing ports on the MSS indicated an additional 250 pounds of structure was required to each port (DS 350). Either of the stations could be delivered in an assembled configuration by the RNS with this additional structure. For RNS delivery of either station in a disassembled configuration, a complex assembly/adapter mechanism is required.

The initial delivery of the OLS or geosynchronous station by the CPS requires that the stations be in a disassembled configuration. This requirement is imposed by the high thrust-loads produced by the two fixed-thrust engines (960K lb total). The LSB, of course, must be delivered in a disassembled configuration because it is not designed to be assembled in orbit. The CPS delivery of disassembled modules requires a complex assembly/adapter, capable of withstanding and distributing considerably higher loads than the adapter required for the RNS.