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N72-32800

CONTRACT NAS9-12068
DRL LINE ITEM 7

MSC-04482
SD 72-SA-0007

ORBITAL OPERATIONS STUDY FINAL REPORT

VOLUME III BASIC VEHICLE SUMMARIES

MAY 1972

APPROVED BY

L. R. Hogan

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Study Manager
ORBITAL OPERATIONS STUDY

FACILITY FORM 602
N72-32800 (ACCESSION NUMBER)
(THRU)
238 (PAGES)
63 (CODE)
(NASA CR OR TMX OR AD NUMBER)
30 (CATEGORY)

Space Division
North American Rockwell

CONTRACT NAS9-12068
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TECHNICAL REPORT INDEX/ABSTRACT

ACCESSION NUMBER						DOCUMENT SECURITY CLASSIFICATION	

TITLE OF DOCUMENT

ORBITAL OPERATIONS STUDY FINAL REPORT
VOLUME III - BASIC VEHICLE SUMMARIES

LIBRARY USE ONLY

AUTHOR(S)

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CODE	ORIGINATING AGENCY AND OTHER SOURCES	DOCUMENT NUMBER
	Space Division of North American Rockwell Corporation, Downey, California	SD 72-SA-0007-3

PUBLICATION DATE	CONTRACT NUMBER
May 1972	NAS9-12068

DESCRIPTIVE TERMS

**Mission Models **Design/Operational Approaches
**Design Influences **Functional Requirements

ABSTRACT

The vehicle related data developed during the Orbital Operations Study are described in this volume. In these analyses the data in Volumes I and II which were developed by interfacing activity have been realigned into the four basic vehicle systems:

- Earth Orbital Shuttle (EOS)
- Research & Applications Module (RAM)
- Space Based, Ground Based, Manned/Unmanned Tugs (Tug)
- Modular Space Station (MSS)

This volume contains data extracted and condensed from the 14 Interfacing Activity Analyses (Vol. II). The principal purpose of this Vehicle Summaries (Volume III) is to collect into four easily accessible sections the pertinent data from three major categories:

- Mission Models and Element Interactions
- Recommended Design/Operational Approaches and Design Influences
- Qualitative & Quantitative Functional Requirements

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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

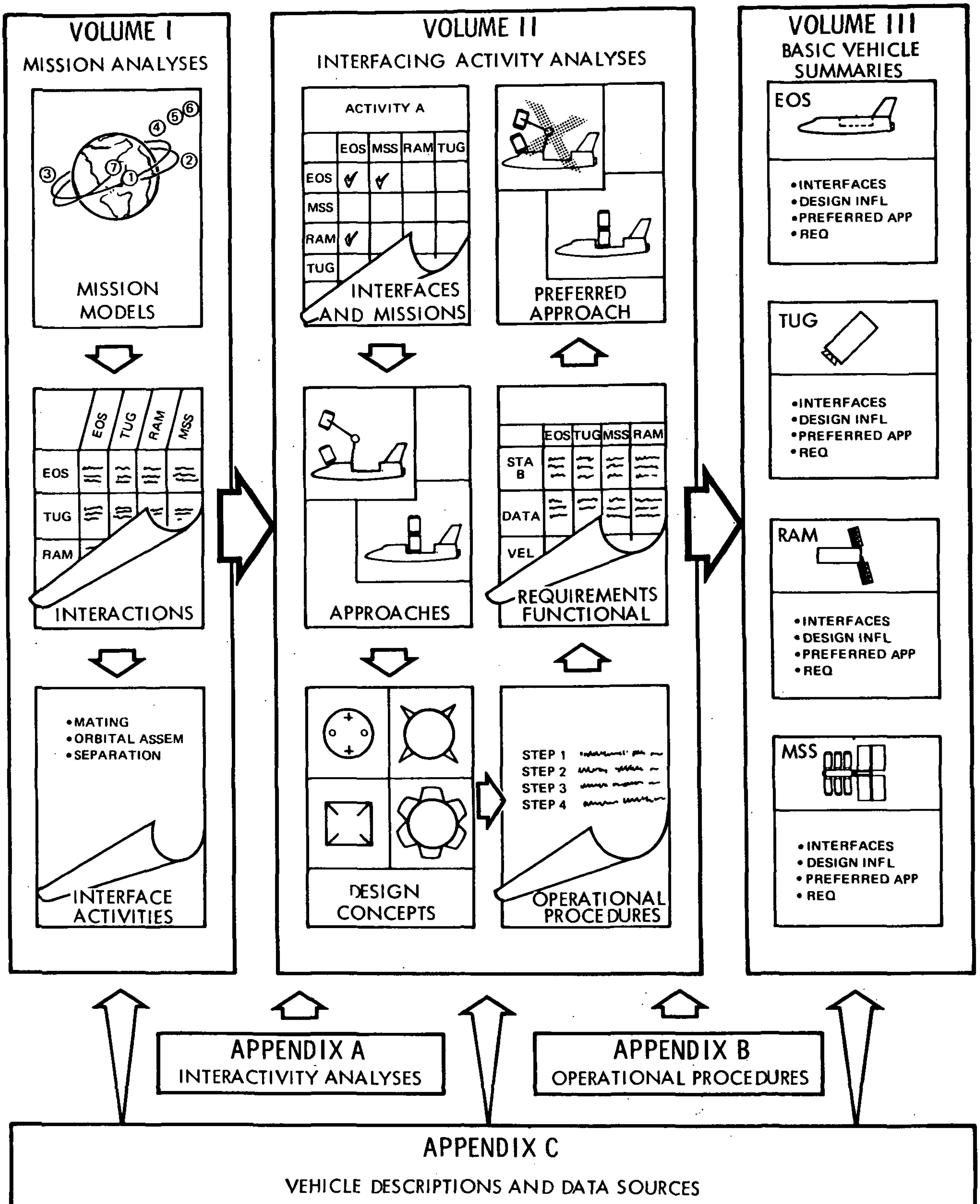
Volume III - BASIC VEHICLE SUMMARIES, contains a condensed summary of the study data pertaining to the following elements:

- 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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TABLES

SECTION 1. INTRODUCTION

SYNOPSIS OF ANALYSIS

The technical approach followed during the conduct of this orbital operations study was designed to cope with the ever present problem of breadth versus depth. Initially, a broad spectrum of data was accumulated encompassing all the potential interactions of the program elements considered in this study. Appropriate evaluation and selection criteria narrowed the scope and increased the depth of the analysis. Figure 1-1 illustrates this top level analysis flow.

The center portion of Figure 1-1 illustrates the Interfacing Activities analysis (Volume II) effort. In this portion of the study the results of the Mission Analysis (Volume I) effort were evaluated for the applicability of alternate approaches and design concepts. From this analysis operational procedures and functional requirements were synthesized for fourteen interfacing activities. These were then analyzed and a preferred approach selection was made. Volume II contained the following data for each interfacing activity: (1) Definition of Activity, (2) Mission Model Applicability, (3) Alternate Approaches/Procedures, (4) Approach Selection Summary and (5) Functional Requirements.

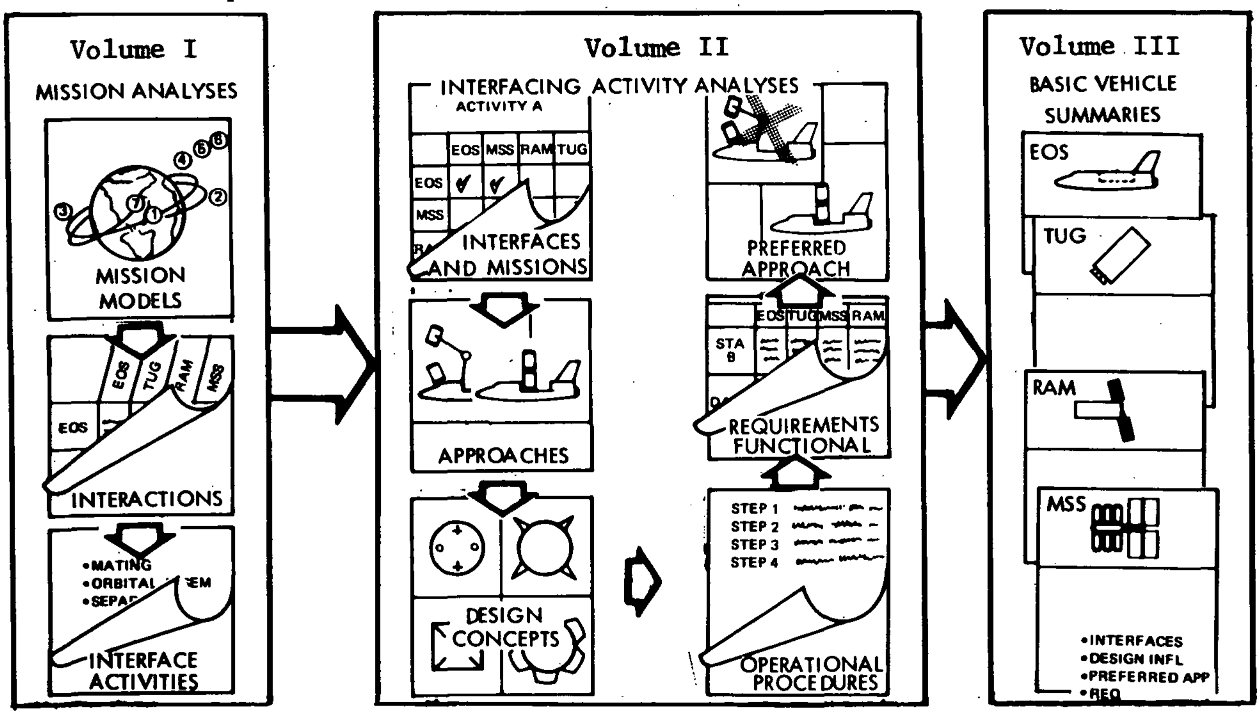


Figure 1-1. Orbital Operations Top Level Flow

This volume (III) provides the basic vehicle summaries for four vehicles; (1) Earth Orbital Shuttle, (2) Space Tug, (3) Research and Applications Module, and (4) Modular Space Station. Volume III consists only of an extraction of data from Volumes I and II. The data base for volume III includes the following:

- Mission Models & Interfacing Elements
- Interfacing Activities
- Alternate Approaches
- Design Influences & Approach Selections

Mission Models and Interfacing Elements

One of the primary purposes of mission models was to identify all element-to-element interfaces that can occur in earth orbit involving any reasonable combination of elements in the study inventory. A second and equally important purpose was to identify all interfacing activities that can occur between interfacing elements in earth orbit and to relate these to each element-to-element interface.

Based upon analysis of previous individual element studies approximately 40 design reference missions were identified. Regrouping and collating the potential uses of the various elements permitted the reduction of mission models to a generic set of eleven. The titles of the 11 mission models are listed on Figure 1-2 and are grouped into five categories according to the primary propulsive vehicle involved.

As the mission model titles indicate, similar mission objectives are accomplished by different mission models. The term "emplacement" is used to signify the delivery of a payload to space as opposed to delivery of a payload to another element. The term "retrieval" signifies the picking-up of a payload from space and not from another element. Therefore, "retrieval" is the reverse of "emplacement". The term "logistics" is used to signify the delivery of a payload to another element, picking-up of a payload from another element, or a combination of the two. The term "sortie" applies to a mission in which an experiment's payload remains attached to the supporting vehicle. The term "staged" and "non-staged" refer to two-stage and single-stage propulsive vehicles, respectively. The term "disposal" refers to the removal of expended elements from earth orbit.

VEHICLE	MISSION MODELS		INTERFACING ELEMENTS
EARTH ORBITAL SHUTTLE	MM-1	EMPLACEMENT	RAM; SATELLITE; KICKSTAGE; TUG; FIRST MOD OF MSS, OLS, OPD, CLS
	MM-2	LOGISTICS/RETRIEVAL	MSS; CLS; OLS; RAM; TUG; SATELLITE; EOS; OPD; CARGO, PROPELLANT, LSB MODS
	MM-3	SORTIE	RAM
SPACE BASED TUG	MM-4	RETRIEVAL/EMPLACEMENT	RAM; SATELLITE; CLS; TUG; OPD; EOS; MSS; OLS; OIS
	MM-5	LOGISTICS	LLT; RAM; SAT; MSS; CLS; TUG; EOS; OPD; CARGO MODS
	MM-6	DISPOSAL	CLS; OIS; OPD; MSS; OPD
GROUND BASED TUG	MM-7	EMPLACEMENT/SORTIE	TUG; SAT; RAM
	MM-8	LOGISTICS/RETRIEVAL	TUG; CLS; SAT; MSS; RAM; OPD; EOS; PROPEL, CARGO MODS
OIS	MM-9	DELIVERY	CLS; OLS; OPD; TUG
CISLUNAR SHUTTLE	MM-10	STAGED LOGISTICS	OPD; EOS; TUG; OIS; RAM; OLS; LSB; MSS; SAT; PROPEL, CARGO MODS
	MM-11	NONSTAGED LOGISTICS	OPD; EOS; TUG; OIS; RAM; OLS; LSB; MSS; SAT; PROPEL, CARGO MODS

Figure 1-2. Mission Models and Interfacing Elements

Figure 1-3 shows a generic grouping of the 25 study elements. The right hand column indicates the number of actual elements included in each of the categories.

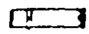
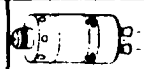
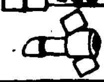
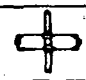
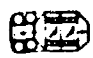
Earth orbital shuttle (EOS) - One element only, referred to throughout this report as EOS, orbiter and shuttle orbiter.		1
Interim tug - Various types of nonreusable nonreturnable, and nonreusable returnable kick stages such as Centaur, Agena, Titan Transtage, and Burner II.		2
Space tug - Reusable unmanned and manned ground-based tug, and unmanned and manned space-based tug.		2
Chemical propulsion stage (CPS) - The orbital insertion stage (mounted on the EOS booster at launch), the earth orbit-to-orbit shuttle, and the cislunar shuttle. The CPS can be modular or nonmodular, and single-stage or two-stage.		3
Reusable nuclear shuttle (RNS) - Both the earth orbit-to-orbit shuttle and the cislunar shuttle application. The RNS can be modular or nonmodular and is single-stage only.		1
Modular space station (MSS) - The low earth orbital station and the geosynchronous station.		2
Research and applications module (RAM) - Both attached and detached RAM's, supported by the EOS and by either of the two MSS's (see above).		4
Satellite - Satellites deliverable to orbit by the EOS and those requiring the EOS plus a third stage for delivery. Also included are satellites requiring retrieval and servicing.		3
Orbital propellant depot (OPD) - The low earth orbital propellant depot located in an orbit optimized to support the RNS or CPS and the space-based tug.		1
Earth orbital resupply module - Cargo and propellant modules for resupply of earth orbiting elements.		1
Orbiting lunar station (OLS) - Both the modular and nonmodular configurations (deliverable to lunar orbit by CPS or RNS).		1
Lunar surface base (LSB) - The modular base only (deliverable to lunar orbit by CPS or RNS).		1
Lunar landing tug (LLT) - Both the unmanned and manned tugs (deliverable to lunar orbit by CPS or RNS).		2
Lunar resupply module - Crew, cargo and propellant modules for delivery to lunar orbit by CPS or RNS.		1

Figure 1-3. Element Inventory

Interfacing Activity Definition

Based upon the extensive mission model activity conducted in this study, a total of 14 interfacing activities were identified. Figure 1-4 groups these activities into the 3 parts of Volume II where the detail analyses data are contained. This report (Volume III) represents an extraction and condensation of the results pertinent to 4 of the study elements.

Volume II, Part 2	
MATING The attachment in earth orbit of any two elements (or modules), including the operations of final closure prior to contact **ORBITAL ASSEMBLY** The joining together of two or more major parts to form a particular configuration of a single operational element in earth orbit, or to facilitate transport to lunar orbit or high-energy earth orbit **SEPARATION** The physical uncoupling of two mated elements and the subsequent maneuvers required to provide adequate clearance between elements	**EOS PAYLOAD DEPLOYMENT** The removal of a payload from the orbiter cargo bay and readying it for operation or separation **EOS PAYLOAD RETRACTION** The insertion of a payload into the orbiter cargo bay subsequent to initial mating of the payload to the orbiter
Volume II, Part 3	
COMMUNICATIONS The transmission of sound, video, and digital/analog data via space links from element-to-element and from element-to-ground **RENDEZVOUS** The operations required to achieve close proximity of one element to another for purposes of stationkeeping and/or mating	**STATIONKEEPING** The maintaining of a predetermined (not necessarily fixed) relative position between two orbiting elements **DETACHED ELEMENT OPERATIONS** The operational support required by a free-flying element from another element and/or ground control
Volume II, Part 4	
CREW TRANSFER The transfer of personnel between two elements in orbit **CARGO TRANSFER** The transfer of solid and fluid cargo between two elements in orbit **PROPELLANT TRANSFER** The transfer of large quantities of liquid hydrogen and liquid oxygen between elements in orbit	**ATTACHED ELEMENT OPERATIONS** Support by one element to another attached element while the latter is operating or being serviced, checked out, or stored **ATTACHED ELEMENT TRANSPORT** Support by a major propulsive element to an attached payload (element or module) during transport from one orbit to another

Figure 1-4. Interfacing Activity Definition

Alternate Approaches

The key function (activities) and approaches that were selected for further analysis are summarized in Figures 1-5, 1-6, and 1-7.

Structural and Mechanical Activity Group Approaches

The approaches illustrated by Figure 1-5 are those selected for in-depth analysis for which the results are summarized in this document and detailed in Volume II, Part 2.

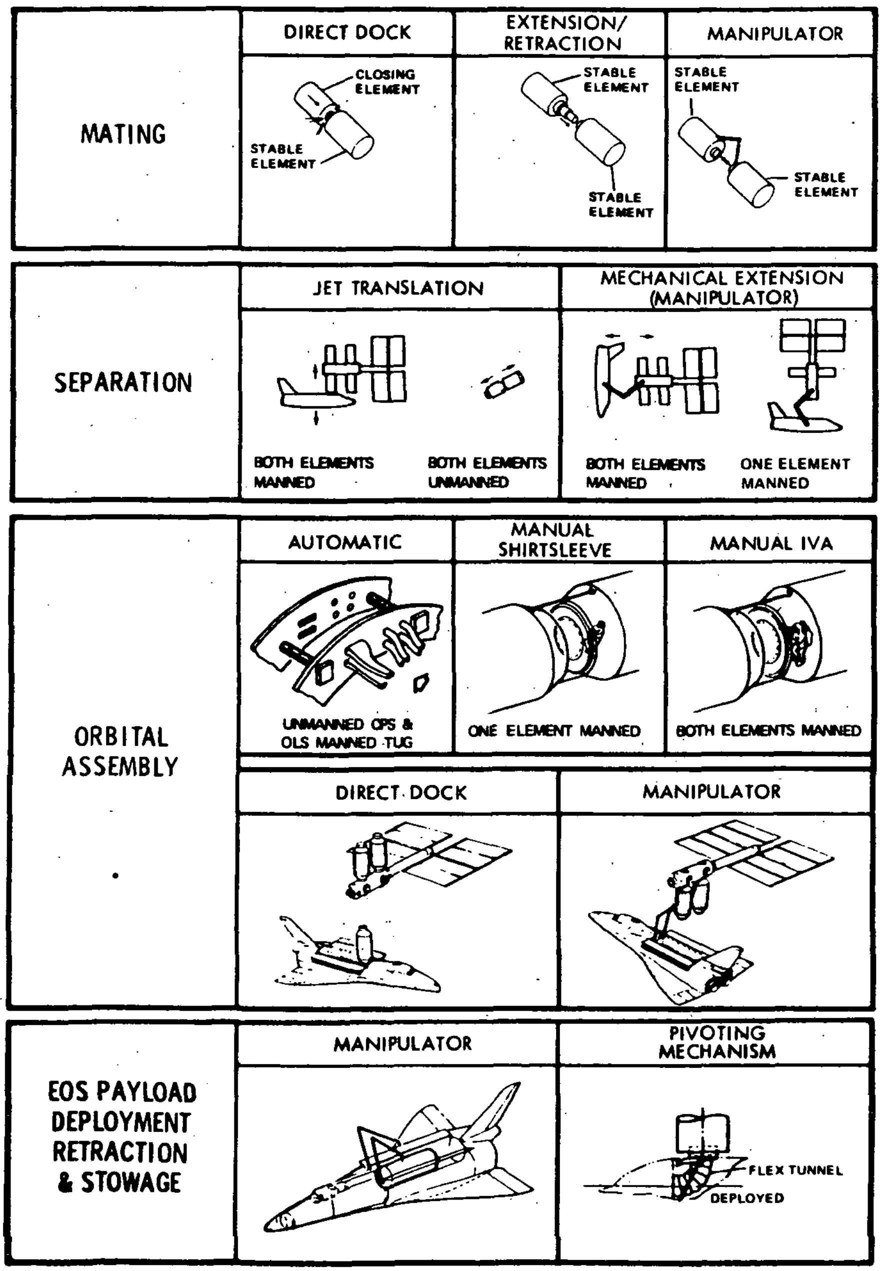


Figure 1-5. Structural and Mechanical Activity Group Approaches

Data Management Activity Group Approaches

The approaches illustrated by Figure 1-6 are those selected for in-depth analysis for which the results are summarized in this document and detailed in Volume II, Part 3.

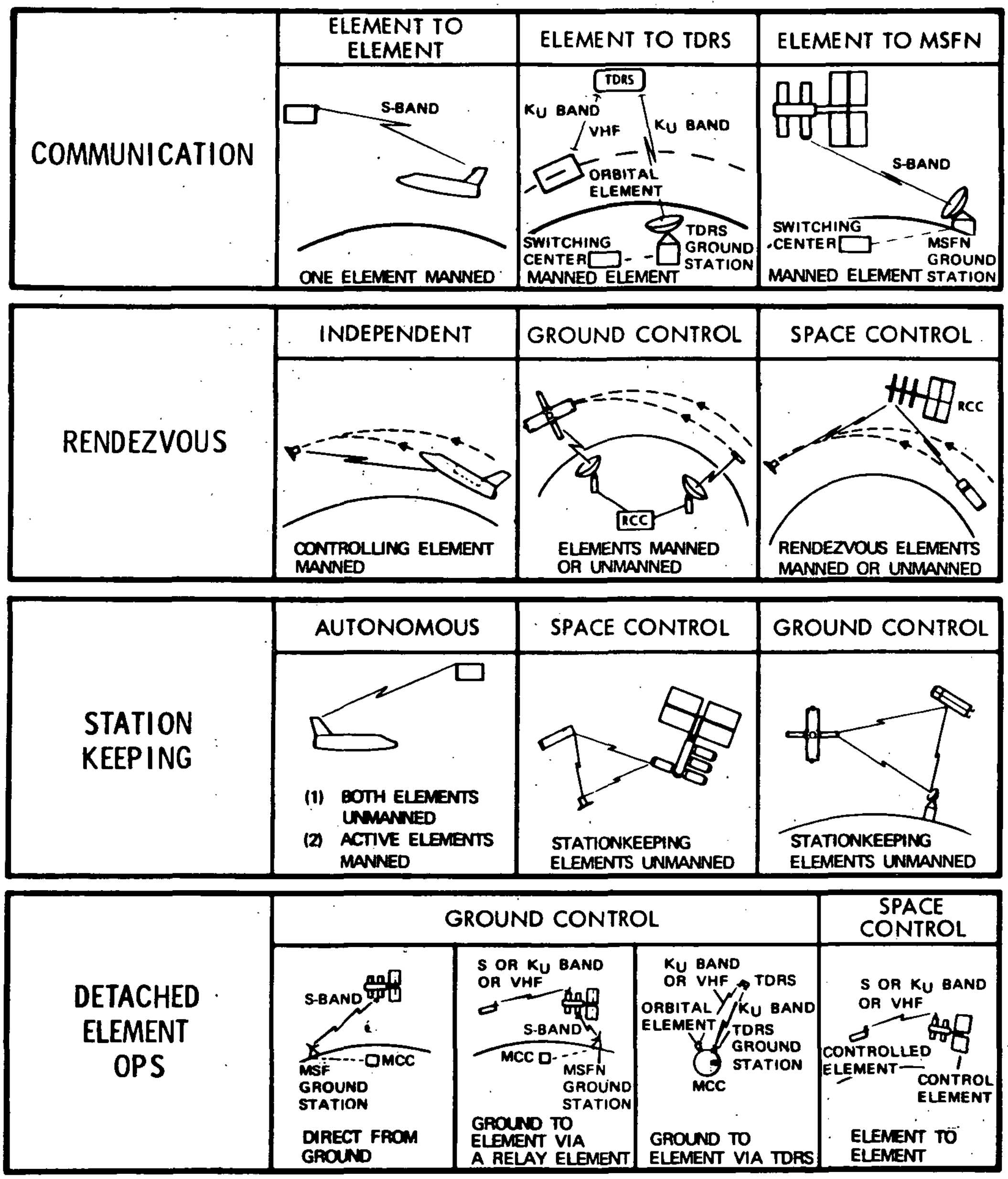


Figure 1-6. Data Management Activity Group Approaches

Support Operations Activity Group Approaches

The approaches illustrated by Figure 1-7 are those selected for in-depth analysis for which the results are summarized in this document and detailed in Volume II, Part 4.

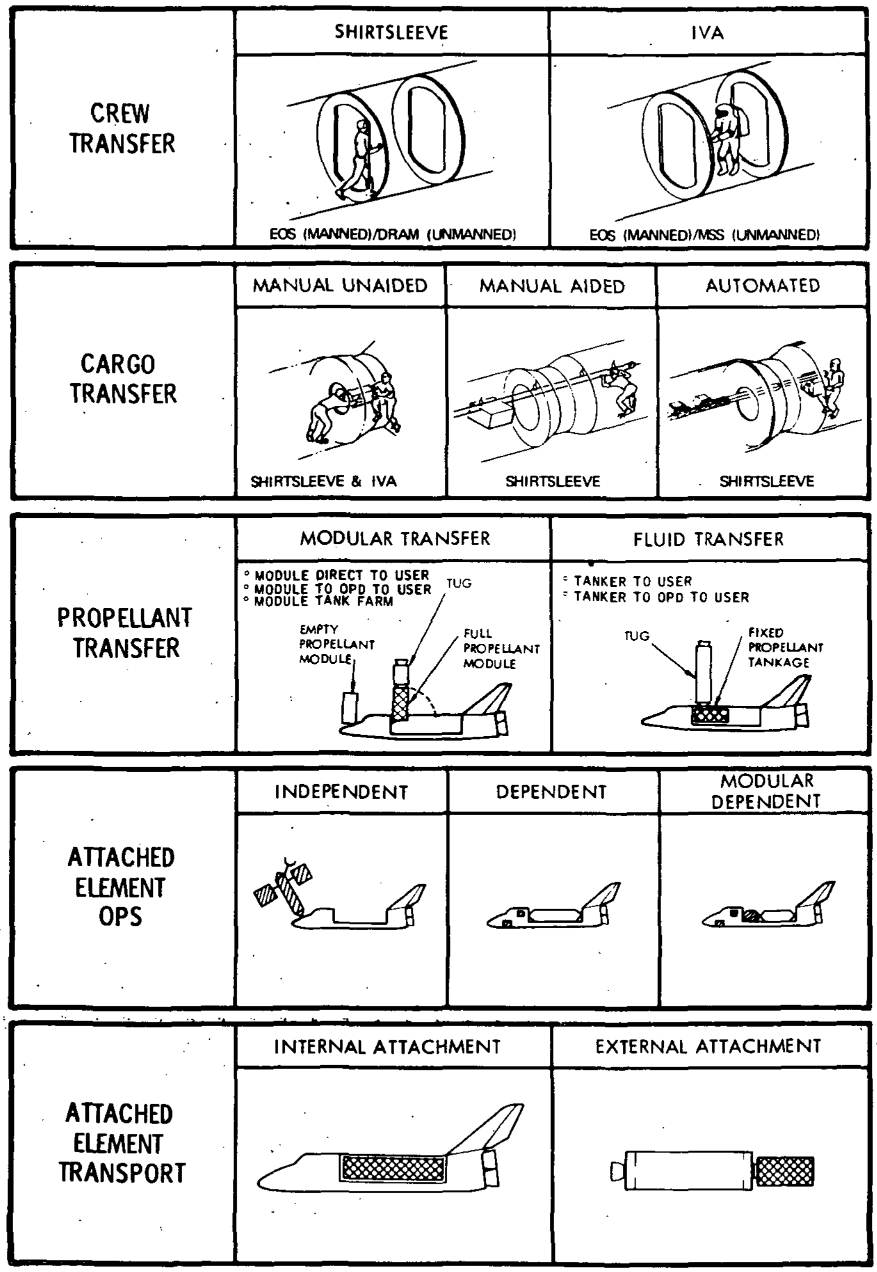


Figure 1-7. Support Operations Activity Group Approaches

Design Influences and Preferred Approach Selections

Each of the 14 separate interfacing activities identified a preferred alternate approach for each of the possible interfacing element pairs. Also included with the detail evaluation is the design influences the recommendation imposes on the remaining elements in the study inventory.

The major recommended approach selections for each of the interfacing activities is as follows:

INTERFACING ACTIVITY	MAJOR RECOMMENDATION
MATING	Direct Automatic Dock - All element pairs except EOS/TUG to small satellites Manipulator - EOS mating with satellites Extention Retraction Device - TUG mating with satellites
ORBITAL ASSEMBLY	Direct Dock - Applicable to CPS, RNS, OPD, and cislunar payloads for MSS Manipulator - EOS assembly of MSS
SEPARATION	Mass Expulsion - Either of the two mated elements active or passive except MSS which is always passive
EOS P/L DEPLOYMENT AND EOS P/L RETRACTION	Pivot Mechanism - Deploy, retract or retrieve and redeploy single payloads Manipulator - Deploy/retract multiple payloads on same mission and mate with small satellites
COMMUNICATIONS	Element-to-Element - S-band primary; Ku-band for MSS-RAM links. Element-to-TDRS - Ku-band for MSS and selected RAMs and satellites Element-to-Ground - S-band primary and VHF backup for all elements

INTERFACING ACTIVITY	MAJOR RECOMMENDATION
RENDEZVOUS	Independent - All manned logistics elements; selected unmanned tugs; terminal phase for all elements Ground Control - At long ranges for unmanned elements. Update and monitor for manned elements Space Control - Only MSS-TUG-RAM operations
STATIONKEEPING	Autonomous - All close proximity operations Ground Control - All long range operations except for MSS operations Space Control - MSS operations
DETACHED ELEMENT OPERATIONS	Ground Operations - Direct to ground Data rates < 1 Mbps, ground network Data rates > 1 Mbps, TDRS Space Operations - MSS-RAM-TUG operations only
CREW TRANSFER	Shirtsleeve - All ground crew rotation between elements IVA - Required operations, non-mannable elements
CARGO TRANSFER	Package Cargo Manually Unaided - All interfaces except those involving an earth orbit resupply module and satellites Manually Aided - MSS, CPS, RNS, OPD and RAM with a resupply module Automatic - Satellite Fluid Transfer Manual Plumbed - All interfaces that are accessible to either shirtsleeve or IVA mode Automatic - Inaccessible interfaces

INTERFACING ACTIVITY	MAJOR RECOMMENDATION
PROPELLANT TRANSFER	Fluid Transfer - Direct from logistics propellant module
ATTACHED ELEMENT OPERATIONS	Independent - Unique RAM support requirements (e.g., astronomy module stability) Dependent - RAMs and TUGS associated with MSS; RAM access only to EOS available capability Modular Dependent - Add-on or kit installations on the EOS (e.g., airlock, RAM support module
ATTACHED ELEMENT TRANSPORT	Internal - EOS load distribution requirements set by launch and entry External - Current docking port concepts adequate for axial loads; multiple payloads on CPS/RNS require special adapter

BASIC VEHICLE DATA

The principal purpose of the vehicle summaries is to collect into four easily accessible subsections the pertinent data, including the major operational or design recommendations that relate specifically to each of the four vehicles. In Volume III the following data were developed for each of the four basic vehicles:

- Element Inventories and Mission Model Interactions. This subsection discusses all of the mission models that are applicable to each vehicle and all of the study elements that it interfaces with.

- Recommended Operational/Design Approaches and Design Influences. Major recommendations were developed for each vehicle. They were derived from a detailed analysis of the 14 interfacing activities. The rationale for and design influence on the total element inventory are identified for each basic vehicle.

- Functional Requirements. This subsection was structured with system level requirements and also with subsystems functional requirements for each of the four vehicles. These functional requirements were defined in Volume II and represent those requirements imposed by the preferred approach and/or the interfacing activities and the elements. These data are the results of the selections and analyses documented in Volume II and the appendices. The rationale for these results are referenced to the appropriate section in the previously mentioned documents. The following subsystems are covered:

    - Structures/Mechanical
    - Environmental Control
    - Electrical Power
    - Guidance and Control
    - Propulsion
    - Communications/Data Management
    - Crew and Habitability

SECTION 2. EARTH ORBITAL SHUTTLE (EOS)

The Earth Orbital Shuttle model used in this study is a two-stage reusable vehicle that will be operational before the end of this decade to serve a broad range of functions. Figure 2-1 illustrates the model furnished by the NASA for use in this study.

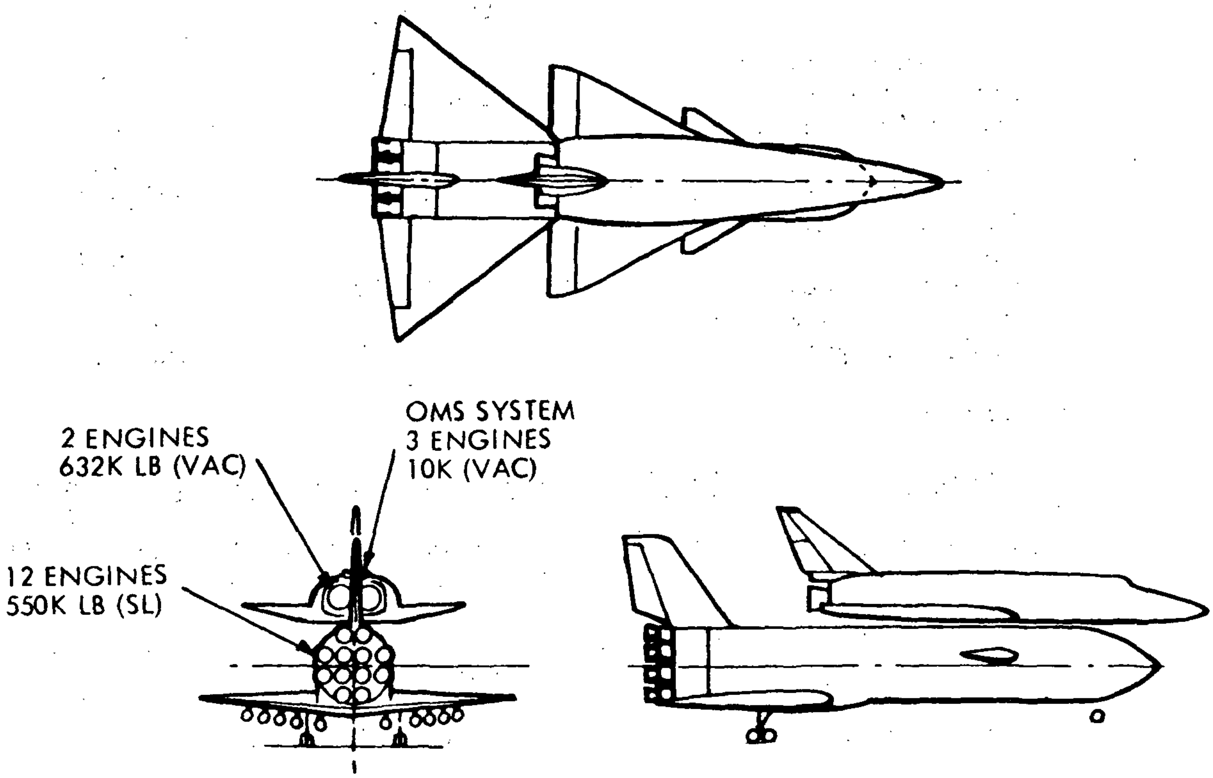


Figure 2-1. Earth Orbital Shuttle Model (EOS)

NOTE: The significant analyses results and recommendations contained in this section were not sensitive to the specific EOS model of Figure 2-1.

The salient characteristics of the EOS model furnished for this study are highlighted in Table 2-1.

Table 2-1. Earth Orbital Shuttle Model Characteristics

- Vehicle Characteristics *

Liftoff gross weight (lb)	5,047,457	
Liftoff thrust to weight	1.308	
	Booster	Orbiter
Gross stage weight (lb)	4,188,223	859,234
Thrust (sea level) (lb)	6,600,000	-------
Thrust (vacuum) (lb)	7,243,500	1,263,810
I_{sp} (vacuum) (lb)	439	459
Main ascent propellant (lb)	3,376,547	555,377
Oms, propellant (lb)	---------	19,526
Oms ΔV, fps	---------	1,000
Booster flyback propellant (lb)	149,427	-------
Booster flyback range (n mi)	417	-------
Landing weight (lb)	630,153	268,007

- Performance

Mission	Inclination	Altitude	Abes	OMS ΔV	Payload
Station Resupply	55°	270 n mi Circular	In	1500 fps	25,000 lbs
Payload Delivery	South Polar	100 n mi Circular	Out	580 fps	40,000 lbs
Satellite Placement and/or Retrieval	28.5°	100 n mi	Out	1030 fps	65,000 lbs

- Payload Bay - 15 ft diameter x 60 ft length
- Development Time
  6 years from start of phase C (to first manned orbital flight)

* Based on 65,000 lb to 100 n mi due east circular orbit with orbiter air breathing engines removed.

SUMMARY

This section of the basic element summaries is structured to provide the key operational/design approaches recommended for incorporation in the EOS model as a direct result of the interfaces between the EOS and associated vehicles. These interfaces were identified and analyzed using 14 interfacing activities as the interface drivers. The 14 activities listed and defined in Figure 2-2 include every type of interaction pertinent to this study that can occur between the EOS and the study inventory of earth orbital space elements.

Volume II, Part 2	
MATING The attachment in earth orbit of any two elements (or modules), including the operations of final closure prior to contact **ORBITAL ASSEMBLY** The joining together of two or more major parts to form a particular configuration of a single operational element in earth orbit, or to facilitate transport to lunar orbit or high-energy earth orbit **SEPARATION** The physical uncoupling of two mated elements and the subsequent maneuvers required to provide adequate clearance between elements	**EOS PAYLOAD DEPLOYMENT** The removal of a payload from the orbiter cargo bay and readying it for operation or separation **EOS PAYLOAD RETRACTION** The insertion of a payload into the orbiter cargo bay subsequent to initial mating of the payload to the orbiter
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Figure 2-2. Interfacing Activity Definition

Three major topics were used to report the EOS related results of the interfacing activity analyses. These major topics are:

- o Element Inventory, Mission Models and Interactions
- o Recommended Operational/Design Approaches and Design Influences
- o System and Subsystem Functional Requirements

ELEMENT INVENTORY, MISSION MODELS AND INTERACTIONS

This subsection discusses all of the mission models that are applicable to the EOS orbiter, and all of the study elements with which the EOS orbiter interfaces with.

The EOS is involved in 9 of the 11 generic mission models identified and developed in the Mission Analyses Volume (Vol. I). Twenty-five elements were identified for potential interactions. The EOS interacts with all elements (including itself) except the Orbital Insertion Stage and the Orbital Propellant Depot. The OPD was deleted from the study inventory as not being practical in light of the EOS payload capability to the preferred orbits of the CPS and RNS user vehicles.

RECOMMENDED OPERATIONAL/DESIGN APPROACHES AND DESIGN INFLUENCES

Nine major recommendation were derived from a detail analysis of the 14 interfacing activities. Table 2-2 summarized these recommendations and provides reference to the specific activity that either drove or supported the recommendation. The rationale for and design influence on the total element inventory resulting from these recommendations is contained in paragraphs subsequent to this summary.

Table 2-2. Major EOS Recommendations

Major Recommendations	Hdw & Oper'l Considerations	Interfacing Activities
1. Direct Automated Dock to all Elements Except Small Satellites - Manual Backup for Contingency	•Common Mating Port •100-400 ft-lb Atten. •$\leq$0.4 ft/sec Closing Velocity •Scanning Laser Radar •TV & Backup Aids	Mating Orbital Assembly
2. Jet Translation for Separation from Mated Elements	•EOS Active •EOS Passive	Separation
3. Deploy, Retract, or Retrieve & Redeploy Single Payloads	•Pivot mechanism	EOS P/L Deploy EOS P/L Retract
4. Deploy/Retract Multiple Payloads on Same Mission & Mate with Small Satellites	•Manipulator •Multiple Payload Attach Point Locations	EOS P/L Deploy EOS P/L Retract Mating Attach Elem Xport
5. Crew/Cargo Transfer to Payload in Cargo Bay & in Deployed Pos. - Shirtsleeve Prime Mode - IVA Backup Mode	•Flexible Tunnel •Airlock •41-in. dia Clear Opening	EOS P/L Deploy EOS P/L Retract Attach Elem Ops Crew Transfer Cargo Transfer
6. Direct EOS-to-Element and EOS-to-Ground Comm Links	•S-Band Equip & Omni •VHF Equip & Omni	Communication Detached Elem Ops
7. Complete Autonomous Control for Rendezvous & Station-keeping - Ground Control of EOS to within $\underset{\sim}{\sim}$50 n mi for Normal Missions	•Horizon Scanners & IMU •Star Trackers •Scanning Laser Radar •VHF & S-Band Omni Antennas •TV (for Inspection)	Rendezvous Stationkeeping Detached Elem Ops Communications
8. Deliver Large Quantity of Propellants to User Via Active Tank Module - EOS Stationkeeping During Subsequent Fluid Transfer	•OPD Not Required •Tug Not Required •Linear Acceleration Provided by Tank Module •Att Control Provided by User Element	Propellant Xfer
9. Attached Elements have Access to Available EOS Subsystem Capabilities	•Comm (S-Band & VHF) •Electrical Power •Habitability •Att Stab & Pointing	Attached Elem Ops

SYSTEM AND SUBSYSTEM FUNCTIONAL REQUIREMENTS

This subsection identifies the pertinent quantitative and qualitative requirements that apply to the EOS during the operations associated with the 14 interfacing activities. These functional requirements are presented in quasi-spec format with reference to the specific activity(s) that generated the requirement.

Two distinct categories have been used to report the functional requirements as follows:

System Level - those functional requirements relating to the overall performance of the entire system, or by their nature they are involved in each subsystem (i.e., safety or general subsystem requirements). This section will also include requirements that form interfaces between subsystems.

Subsystem Level - those functional requirements that relate to one specific subsystem. Again as with the system level requirements, cross reference will be made to the appropriate interfacing activity that initially defined the requirement.

ELEMENT INVENTORY, MISSION MODELS AND INTERACTIONS

This subsection identifies all of the mission models that are applicable to the EOS orbiter, and all of the elements with which the EOS has an interface with for each of the 14 interfacing activities.

ELEMENT INVENTORY

Figure 2-3 shows a generic grouping the 25 study elements. The right hand column indicates the number of actual elements included in each of the categories.

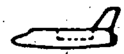
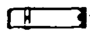
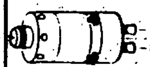
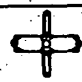
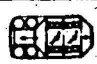
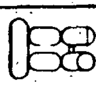
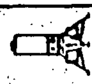
Earth orbital shuttle (EOS) - One element only, referred to throughout this report as EOS, orbiter and shuttle orbiter.		1
Interim tug - Various types of nonreusable nonreturnable, and nonreusable returnable kick stages such as Centaur, Agena, Titan Transtage, and Burner II.		2
Space tug - Reusable unmanned and manned ground-based tug, and unmanned and manned space-based tug.		2
Chemical propulsion stage (CPS) - The orbital insertion stage (mounted on the EOS booster at launch), the earth orbit-to-orbit shuttle, and the cislunar shuttle. The CPS can be modular or nonmodular, and single-stage or two-stage.		3
Reusable nuclear shuttle (RNS) - Both the earth orbit-to-orbit shuttle and the cislunar shuttle application. The RNS can be modular or nonmodular and is single-stage only.		1
Modular space station (MSS) - The low earth orbital station and the geosynchronous station.		2
Research and applications module (RAM) - Both attached and detached RAM's, supported by the EOS and by either of the two MSS's (see above).		4
Satellite - Satellites deliverable to orbit by the EOS and those requiring the EOS plus a third stage for delivery. Also included are satellites requiring retrieval and servicing.		3
Orbital propellant depot (OPD) - The low earth orbital propellant depot located in an orbit optimized to support the RNS or CPS and the space-based tug.		1
Earth orbital resupply module - Cargo and propellant modules for resupply of earth orbiting elements.		1
Orbiting lunar station (OLS) - Both the modular and nonmodular configurations (deliverable to lunar orbit by CPS or RNS).		1
Lunar surface base (LSB) - The modular base only (deliverable to lunar orbit by CPS or RNS).		1
Lunar landing tug (LLT) - Both the unmanned and manned tugs (deliverable to lunar orbit by CPS or RNS).		2
Lunar resupply module - Crew, cargo and propellant modules for delivery to lunar orbit by CPS or RNS.		1

Figure 2-3. Element Inventory

MISSION MODELS

In the Orbital Operations Study a total of 11 mission models have been generated which encompass all of the mission events, element-to-element interfaces (element pairs), and interfacing activities which can occur in earth orbit. Each of the 11 mission models (refer to Volume I) consists of a sequence of mission events, with an identification of related interfacing activities and interfacing elements for each event. The EOS can be involved in nine of the eleven missions (see Table 2-3).

Three of the mission models (MM-1, -2, and -3) utilize the EOS as the primary propulsive vehicle. MM-1 "EOS Emplacement Mission" is applicable to a wide variety of individual missions where the EOS orbiter is used to emplace a free-flying payload in earth orbit. This mission does not include delivery of a payload to another element in space. MM-2 "EOS Logistics/ Retrieval Mission" is applicable to EOS delivery of various payloads from earth to other major elements in earth orbit, retrieval of free-flying elements in orbit for return to earth, and rescue of personnel from a disabled orbiting element. MM-3 "EOS Sortie Mission" encompasses all individual missions where the EOS orbiter delivers an experiments payload (i.e., attached RAM) to earth orbit, followed by orbital operations with attached RAM, and subsequent return to earth.

In addition to the above three missions, the EOS orbiter has a potential involvement in six of the remaining eight missions, i.e., MM-4, -5, -7, -8, -10, and -11. In MM-4 "Space-Based Tug Retrieval/Emplacement Mission" the tug may retrieve a free-flying element, transport it to the EOS for servicing, then return the element to the desired orbit. This same mission is applicable to the tug retrieval of a free-flying payload for delivery to the orbiter for return to earth in the cargo bay. In MM-4 "Space Based Tug Logistics Mission" the tug may transport a payload from the EOS orbiter to another major element, or from another element to the EOS orbiter. In MM-7 "Ground-Based Tug Emplacement/Sortie Mission" the EOS orbiter may deliver a tug and its attached payload to orbit, deploy the tug, wait in orbit for the tug to perform its mission, and then return the tug to earth. MM-8 "Ground-Based Tug Logistics/Retrieval Mission" is similar to mission MM-7 from the standpoint of the EOS orbiter. The difference between these two mission models is associated with the mission flown by the tug while the EOS orbiter is waiting in orbit. In MM-10 "Staged Geosynchronous/Cislunar Shuttle Logistics Mission", and in MM-11 "Nonstaged Geosynchronous/Cislunar Shuttle Logistics Mission" a cislunar shuttle can transport a payload from the EOS orbiter to lunar orbit (or to a high energy earth orbit). The cislunar shuttle can also transport a payload from lunar orbit to the EOS orbiter for return to earth in the orbiter cargo bay.

Table 2-3. Mission Model, Interfacing Activity, and Element Inter-relationships with the EOS

Interfacing Element	Interfacing Activity														Mission Model										
EOS to ↓	1 Mating	2 Orbital Assy	3 Separation	4 Cargo Transfer	5 Crew Transfer	6 Propel. Transfer	7 EOS Payload Deployment	8 EOS Payload Retr. & Stowage	9 Communications	10 Rendezvous	11 Stationkeeping	12 Attached Elem. Operations	13 Detached Elem. Operations	14 Attached Elem. Transport	1 EOS Emplacement	2 EOS Logis/Retriev.	3 EOS Sortie	4 SB Tug Retr/Emplace.	5 SB Tug Logistics	6 SB Tug Disposal	7 Grd-Based Tug Emplace/Sortie	8 Grd-Based Tug Logis/Retriev.	9 OIS Delivery	10 CLS Staged Logistics	11 CLS Nonstaged Logistics
EOS	✓		✓	✓	✓				✓	✓	✓	✓	✓			✓									
Non Rtn Tug			✓				✓		✓		✓	✓	✓	✓	✓										
Rtn Tug	✓		✓				✓	✓	✓	✓	✓		✓	✓	✓	✓					✓				
GB Tug	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓			✓		✓	✓		✓	✓
SB Tug	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓			✓		✓	✓
ARAM, EOS				✓	✓		✓	✓	✓			✓		✓			✓								
DRAM, EOS	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓									
ARAM, MSS	✓	✓	✓				✓	✓						✓		✓			✓			✓		✓	✓
DRAM, MSS	✓	✓	✓				✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓		✓	✓		✓	✓
Sat, EOS Deliv			✓				✓		✓		✓	✓	✓	✓	✓	✓									
Sat, 3rd St			✓				✓		✓		✓	✓	✓	✓	✓			✓			✓				
Sat, Retr	✓		✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓			✓			
EO Resup Mod	✓	✓	✓	✓	✓		✓	✓				✓		✓		✓			✓			✓		✓	✓
Low EO MSS	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓					✓	✓

Table 2-3. Mission Model, Interfacing Activity, and Element Inter-relationships with the EOS (Cont.)

Interfacing Element	Interfacing Activity														Mission Model										
EOS to ↓	Mating	Orbital Assy	Separation	Cargo Transfer	Crew Transfer	Propel. Transfer	EOS Payload Deployment	EOS Payload Retr. & Stowage	Communications	Rendezvous	Stationkeeping	Attached Elem. Operations	Detached Elem. Operations	Attached Elem. Transport	EOS Emplacement	EOS Logis/Retriev.	EOS Sortie	SB Tug Retr/Emplace.	SB Tug Logistics	SB Tug Disposal	Grd-Based Tug Emplace/Sortie	Grd-Based Tug Logis/Retriev.	OIS Delivery	CLS Staged Logistics	CLS Nonstaged Logistics
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11
Geo MSS	✓	✓	✓	✓	✓		✓	✓	✓						✓	✓		✓	✓		✓	✓		✓	✓
CPS, EO	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓			✓		✓	✓
CPS, CLS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓			✓		✓	✓
RNS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓			✓		✓	✓
OLS	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓					✓	✓
Unman LLT	✓	✓	✓			✓	✓	✓	✓	✓		✓	✓	✓	✓	✓			✓			✓		✓	✓
Man LLT	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓			✓		✓	✓
Lun Resup Mod	✓	✓	✓			✓	✓	✓				✓		✓		✓			✓					✓	✓
LSB	✓	✓	✓				✓	✓				✓		✓	✓	✓			✓					✓	✓

ELEMENT INTERACTIONS

The methodical in-depth approach used in the generation of the mission models (see Section 1.0 of Volume I) made possible the identification of all potential element-to-element interfaces (i.e., element pairs) and all interfacing activities that can occur between elements in earth orbit. A summary of the total list of orbital elements considered in this study was presented in Figure 2-3. Those elements with which the EOS orbiter may interface with and those interfacing activities which may occur between the EOS orbiter and these other elements are also identified in Table 2-3.

As can be seen in Table 2-3, the EOS orbiter interfaces with every element in the study inventory with the exception of the orbital insertion stage (OIS). The EOS orbiter is used to deliver all elements to orbit which are capable of being transported in the EOS cargo bay. This includes such elements as the modular MSS, RNS, CPS, OLS, and LSB. The interface with another EOS is for crew rescue purposes only. The orbiter does not interface with the OIS because the latter is used in place of the orbiter for delivery of large elements (such as the non-modular RNS or CPS) to earth orbit. The EOS orbiter interfaces with several elements after they become space based, as discussed in the previous mission model paragraph.

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RECOMMENDED OPERATIONAL/DESIGN APPROACHES AND DESIGN INFLUENCES

Several major operational/design approaches for the EOS were synthesized from the detail analyses conducted for each of the 14 separate interfacing activities. These major recommendations are illustrated by Figure 2-4. The nine recommendations highlighted on the figure are amplified in subsequent paragraphs.

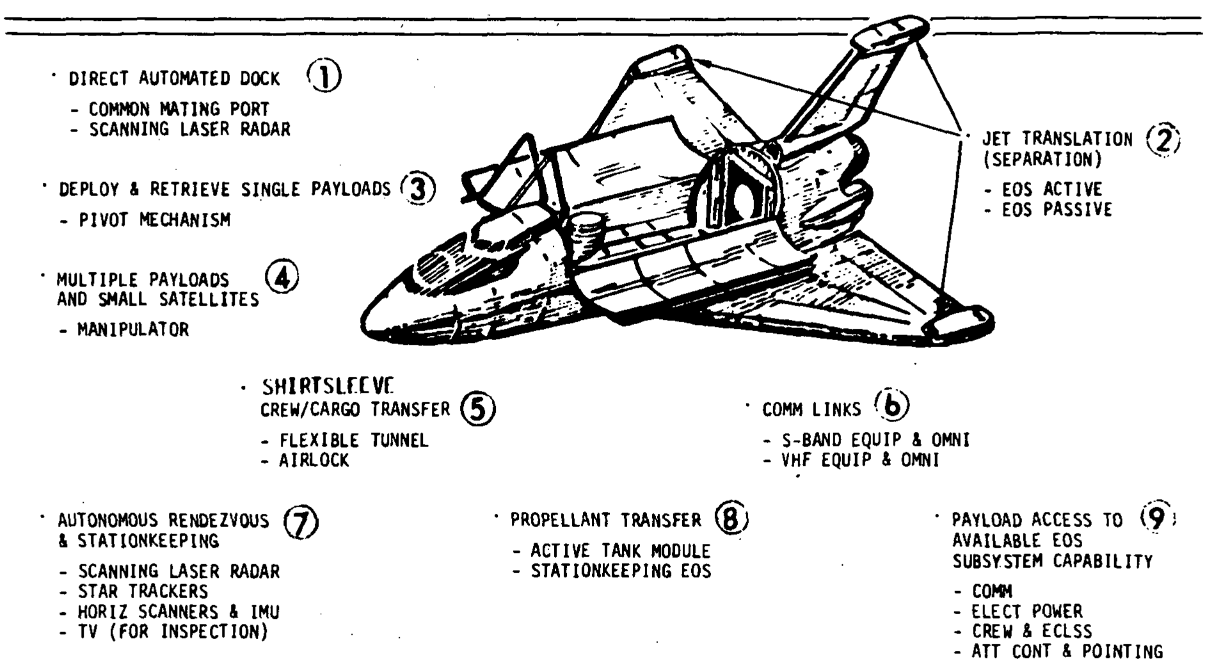

Figure 2-4. Major EOS Recommendations

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DIRECT AUTOMATED DOCK (1)

A fully automated direct dock approach is recommended for EOS mating to all elements except small satellites. In conjunction, a manual direct dock capability is mandatory for contingency purposes.

In addition the orbital assembly of all elements utilizing the EOS shall be compatible with the direct dock approach.

Selection Considerations

The Mating and Orbital Assembly interfacing activities each considered two generic approaches to mating:

1) Direct Dock (automatic and manual)

2) Manipulator Berth (manual only)

Ten separate comparison factors were considered:

- Technology
- Checkout and Maintenance
- Safety
- Reliability
- Commonality
- Relative Cost
- Operational/Design Complexity
- Subsystem Interfaces
- Near Term Bias
- Far Term Bias

An overall evaluation of these comparison factors tends to favor 1) Direct Dock over 2) Manipulator for EOS matings. Also an automated direct dock approach must be developed for the mating of unmanned elements, therefore the automated approach is recommended for commonality across all element pairs.

A prime benefit from this selection is that EOS demonstration of the hardware and software required to accomplish a completely automated direct docking will provide an early development of the approach required for later unmanned-to-unmanned matings.

The manual direct dock approach must also be provided because 1) crew safety dictates manual override and 2) mission success criteria favors a manual backup mode to increase the probability of success.

(1) Refer to Table 2-2 and Figure 2-4

EOS Design/Operational Influences

An automated direct dock approach with a manual backup mode requires the following be incorporated as part of the basic EOS design:

- Common Mating Port. Active attenuation in the 100-400 ft-lb range with closing velocity held to ≤0.4 ft/sec.
- Scanning Laser Radar Transceiver. Provides range, range rate and angular misalignments.
- Passive Laser Reflectors. Enables EOS to be passive during matings (i.e., EOS rescue, Tug to EOS mating).
- Direct Visual Scope. Required for manual backup mode.
- Visual Alignment Target. Required for backup mode during EOS rescue.
- TV Camera. Required for visual inspection and backup to direct visual.

Design/Operational Influences on Interfacing Elements

The EOS can be either the active or passive vehicle during automated direct dockings. All elements that mate with the EOS are required to have passive laser reflectors.

The following matrix represents the recommended mating hardware for the major elements:

Hardware	TUG	RAM	MSS	CPS	RNS
• Common Mating Port	Active	Passive	Passive	Active	Active
• SLR Transceiver	Yes	No	Yes	Yes	Yes
• Passive Laser Reflectors	Yes	Yes	Yes	Yes	Yes
• Visual Alignment Targets	Yes	Yes	Yes	Yes	Yes
• TV Camera	Yes	No	Yes	Yes	Yes

JET TRANSLATION SEPARATION (2)

The preferred mode of EOS separation from mated elements is via mass explusion of RCS engines. The EOS and selected EOS mated elements must be capable of this separation maneuver. Dependent upon operational considerations the EOS may be either active or passive during the separation.

Selection Considerations

Two generic approaches for separation were considered in the Separation interfacing activity:

1) Jet translation (manual or automatic modes)

2) Manipulator extension (manual or automatic modes)

Nine comparison factors were considered in making a selection. These factors are as follows:

- Technology
- Checkout & Maintenance
- Plume Impingement
- Safety
- Reliability
- Relative Cost
- Commonality
- Near Term Bias
- Far Term Bias

An evaluation of the factors showed that both approaches are adequate in either manual or automatic modes. However both approaches offer significant advantages.

1) Jet translation is significantly lower in cost because at least one of the two mated elements will be equipped with a translation capability.

2) Manipulator extension appears to offer a more safe operation in that the elements can be physically separated some distance prior to independent operations.

Jet translation is the recommended approach for all separation operations as it requires little or no additional hardware than is already included in the elements; it has been demonstrated to be safe; and it can be utilized for all element pairs in the study inventory.

(2) Refer to Table 2-2 and Figure 2-4.

EOS Design/Operational Influences

The jet translation separation approach does not impose any additional hardware to the EOS model used during this study. However, a reliable means must be provided to assure that any stored energy that can impart a noticeable thrust to one of the separating elements has been released prior to the jet translation maneuver. Examples of this stored energy are:

- compressed docking attenuation struts
- crew/cargo transfer tunnel pressurization
- spring type capture latches

Design/Operational Influences on Interfacing Elements

Elements will at times be exposed to jet plume contaminations prior to mating, while attached to the EOS, and during the separation maneuver. Elements sensitive to this contamination will be required to provide suitable protection. An operational option is to have the sensitive element perform the translation with the EOS engines inhibited.

The only identified critical alignment separation is for the MSS where a RAM to be separated is adjacent to a station module. A laser radar guidance concept is recommended for this operation.

DEPLOY, RETRACT, OR RETRIEVE AND REDEPLOY SINGLE PAYLOADS (3)

The selected concept for the deployment and retraction of single payloads is the pivot mechanism.

Selection Considerations

The EOS Payload Deployment and EOS Payload Retraction and Stowage interfacing activities considered five alternate approaches as follows:

1) Teleoperator
2) EVA with AMU
3) Lateral translation
4) Manipulator
5) Pivot mechanism

The pivot mechanism (5) was selected primarily because it can accomplish all of the operational and functional requirements with a less expensive, less complex method. This selected approach is compatible with the direct automated dock technique proposed for mating.

The first four alternate approaches were rejected using the following prime rationale:

- Teleoperator - would have to "deploy" itself from cargo bay, reduces the effective cargo bay volume, and requires an additional vehicle development
- EVA with AMU - least safe of the 5 concepts, limited in its ability to handle payloads of any significant volume or mass.
- Lateral Translation device - more complex and expensive than some of the alternatives while offering no significant advantage to either pivot mechanism or manipulator.
- Manipulator - more expensive than pivot mechanism, more complex, and offers a flexibility not required for single payloads.

(3) Refer to Table 2-2 and Figure 2-4.

EOS Design/Operational Influences

The selection of a pivot mechanism for the deployment and retraction of single payloads creates the following influences on the EOS:

- Dictates a direct dock approach for matings
- A single mating port is adequate to support Mating, Orbital Assembly and EOS Payload Deployment/Retraction
- The addition of a flexible tunnel provides crew egress to payload in both stowed and deployed positions
- Limits the ability to adjust the payload c.g. travel within acceptable limits.

Design/Operational Influences on Interfacing Elements

An EOS with a pivot mechanism creates the following influences on the various elements that interface with it:

- Selected payloads will require mating ports at both ends of the modules (i.e., MSS modules)
- Selected attached payloads can have continuous utility connections from stowage through deployment
- The spacing between modules on the MSS will require ≈ 5 ft separation distance.
- Docking attenuation will be required on all orbital facilities receiving modules from the EOS.

DEPLOY/RETRACT MULTIPLE PAYLOADS AND MATE WITH SMALL SATELLITES (4)

A multi-degree of freedom manipulator is the recommended approach for deployment/retraction of multiple payloads on a single EOS mission. This concept is also applicable for mating operations between the EOS and small satellites.

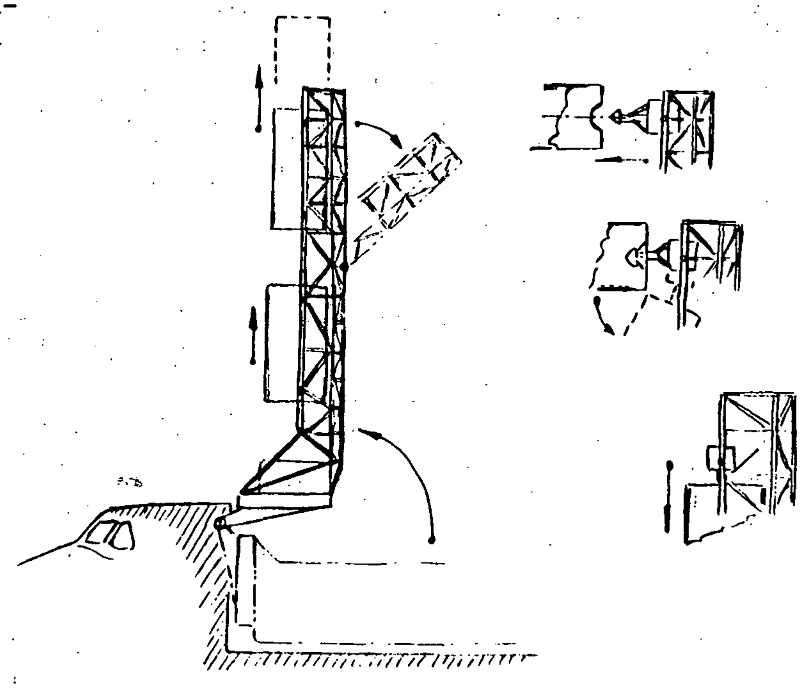
Analysis of various EOS traffic models indicates a wide dispersion in the scheduling of multiple payload missions. Some traffic models introduce multi-payloads into the space program in the first year; others do not identify multi-payloads until several years into the program. Thus, the inclusion of the manipulator in the basic shuttle is an EOS programmatic issue. Detailed EOS mission analyses and development cost evaluation will directly influence the resolution of the baseline deployment/retraction design concept for the EOS.

Selection Considerations

The EOS Payload Deployment, EOS Payload Retraction & Stowage, and the Mating interfacing activities considered two generic approaches for the handling of multiple payloads and mating to small satellites:

1. Manipulator
2. Pivotal mechanism with direct docking

Several pivotal mechanism design concepts were synthesized that could accommodate the handling of multiple payloads by the EOS. The illustration is one concept that essentially consists of a rack that attaches to the pivotal mechanism mounted at the forward bulkhead of the cargo bay. Each payload is mounted on the rack and is sequentially deployed or retracted. The primary drawbacks to this concept are (1) the weight of the truss device and (2) the reduction in useable cargo bay volume because of the rack (maximum payload diameter of 14 feet).



EOS mating with small satellites could also use the illustrated pivotal mechanism with a rack but the weight and cargo bay restrictions make it undesirable.

(4) Refer to Table 2-2 and Figure 2-4

The preferred approach is the manipulator concept. Interactivity analyses (Trade Study A5 Appendix A) indicated that synergistic benefits could be realized from the inclusion of the manipulator. Deployment, retraction and stowage, and mating (with small satellites) can be simplified and performed more efficiently with a manipulator; orbital assembly operations associated with the MSS can also be enhanced with a manipulator; logistics resupply of satellites and some RAM's can be more readily accomplished by means of a manipulator; and on orbit maintenance operations can be accomplished in most cases without EVA operations if a manipulator is available.

Design/Operational Influences

The selection of a multi-degree of freedom manipulator for the EOS has major impact in the operations associated with orbital assembly and on-orbit inspection, service and repair of various payloads and interfacing elements. The following are examples of these influences:

EOS

a. Specialized crew training
b. High degree of crew involvement
c. Ancillary electrical fluid connect/disconnects independent of mating/separation operations

Payloads

a. End effector receptacle on payloads
b. "Plug-in" replacement packages acceptable
c. Impact attenuation device on docking ports only required if mating to elements other than EOS
d. Payload checkout required by microwave link after deployment/prior to separation.
e. Payload utility connects/disconnects made remotely-independent of mating/separation operations.

CREW/CARGO TRANSFER TO EOS PAYLOAD (5)

This study identified the necessity to enter payloads while in the EOS cargo bay and in the deployed position. A shirtsleeve entry is the preferred mode, however IVA provisions are also recommended as a backup mode.

Selection Considerations

The Crew Transfer and Cargo Transfer interfacing activities each considered three generic methods for crew/cargo transfer as follows:

Method	Approaches	
	Crew Transfer	Cargo Transfer
EVA	1) No	1a) Manual unaided
IVA	2) Yes	2a) Manual unaided
Shirtsleeve	3) Yes	3a) Manual unaided 3b) Manual aided 3c) Automated

Shirtsleeve crew transfer (approach 3) was selected due to the high degree of crew movement between the EOS and its various payloads. This selection benefits the EOS by the ease of crew movement offered by the shirtsleeve transfer.

Manually unaided cargo transfer in a shirtsleeve environment (approach 3a) was selected for the transfer of cargo items between the Orbiter crew compartment and the payloads.

The IVA method (approach 2 and 2a) is recommended as a backup for the shirtsleeve mode of crew transfer and manually unaided cargo transfer. Two IVA alternatives were considered:

- Depressurize EOS cabin and enter payload
- Provide an airlock

The use of an airlock is preferred due to the operational restrictions placed on crew and equipment by depressurization.

This IVA backup will benefit some payloads that cannot accept the design penalties associated with a shirtsleeve environment. In addition, an airlock will provide an acceptable alternate mode to increase mission success for selected critical crew/cargo transfer operations.

EVA crew and/or cargo transfer was not selected as all interfacing elements can be accomodated by either shirtsleeve or IVA transfer.

(5) Refer to Table 2-2 and Figure 2-4

Design/Operational Influences

The selection of shirtsleeve and IVA crew/cargo transfer between the EOS and its payload creates the following design influences:

- Flexible tunnel - required for payload entry with the pivot mechanism in both the stowed and deployed positions.
- Airlock - required for IVA

  Note: The airlock can be either part of the basic orbiter design or a kit installation.
- 41" dia clear opening - Although large cargo items are not carried in the orbiter crew compartment; the 41" dia hatch is derived from a commonality analysis across all elements
- Establish, monitor, and maintain a habitable environment for shirtsleeve activities.
- Pressure suits and related provisions for use with IVA airlock.

COMMUNICATION LINKS (6)

Operation in two radio frequency bands, S-band and VHF, is recommended for all EOS communications to ground or to other space elements. S-band equipment compatible with both the communication and ranging signals of the NASA ground network is recommended. VHF can be used for low data rate and voice communication to ground via TDRS to provide greater than 90 percent orbital contact continuity.

When necessary, VHF can be used as a back-up link to other elements. Both S-band and VHF EOS terminals can adequately support the link criteria with omni-directional antennas.

Selection Considerations

Three approaches were considered for both Communications and Detached Element Operations interfacing activities as follows:

1) Element to element

2) Element to ground via TDRS

3) Element to ground direct

Considerations of equipment commonality - with ground network systems and other element systems, continuity of communications contact and reliability were the major drivers that result in the recommendation to utilize all three approaches for the communications interfacing activity.

Element to element and element to ground links are necessary for mission operations. Provision for element to ground via TDRS as well as to ground direct provides backup for emergency purposes as well as continuity of contact when the EOS is out of radio contact with any ground station.

(6) Refer to Table 2-2 and Figure 2-4.

EOS Design/Operational Influence

Implementation of all three approaches requires that the EOS provide the following to meet the approach requirements:

1) An S-band transponder compatible with ground network characteristics and with the following capabilities.

    (a) An omni-directional antenna system that provides radio link coverage to ground or other elements without requiring specific EOS attitude.

    (b) A 30-watt transmitter in S-band capable of transmitting up to 51.2 K bps digital data, a single voice channel and turn-around PRN ranging signals to ground or other elements.

    (c) An S-band receiver with an 800 degree K input system noise temperature capable of receiving and demodulating up to 10 K bps digital data, a single voice channel and PRN ranging signals from ground or other elements.

2) A VHF transponder compatible with TDRS and other element characteristics and with the following capabilities:

    (a) An omni-directional antenna system that provides radio link coverage to TDRS or other elements without requiring specific EOS attitude.

    (b) A 25-watt transmitter in the VHF band capable of transmitting up to 10 K bps digital data and a single voice channel.

    (c) A VHF receiver with an 1200 degree K input system noise temperature capable of receiving and demodulating up to 1 K bps digital data and a single voice channel.

Design/Operation Influences on Interfacing Elements

The EOS can be either a controlling or controlled vehicle and must have the capability to transmit and receive TT&C signals to and from other elements and ground. All interfacing elements, i.e., Tug, RAM, MSS, CPS, RNS, OPD and satellites should have as a minimum, complementary S-band hardware. This would be similar to that described under (1) above. VHF capability is not a necessity on the interfacing elements, but if implemented it would provide an emergency backup link.

AUTONOMOUS CONTROL FOR RENDEZVOUS AND STATIONKEEPING (7)

A fully autonomous Rendezvous and Stationkeeping capability is recommended for these EOS operations when EOS separation from its target vehicle is less than approximately 50 n miles.

The EOS should be capable of performing the control of target elements and all necessary communications, target tracking and ranging, self-navigation and flight control to proceed with Rendezvous and Stationkeeping operations with the accuracy needed for a safe and successful mission.

Selection Consideration

Rendezvous, Stationkeeping and Detached Element Operations interfacing activities supported by the Communications activity considered three basic alternate approaches for control, as follows:

1. Autonomous or independent
2. Ground control
3. Space control

Since the EOS is a manned vehicle with all necessary capability for rendezvous and/or stationkeeping at ranges to 50 feet, the autonomous control mode (No. 1) was considered the most efficient and effective alternate approach for successful mission accomplishment.

Emergency operations are available, if necessary, by utilizing ground/EOS communications links. The autonomous mode, however, provides EOS-to-element continuous contact during these maneuvers.

Ground control (No. 2), by direct link, would suffer from lack of contact continuity during orbital operations. Even TDRS could not guarantee 100 percent orbital coverage.

Space control (No. 3) from another vehicle could not in any case provide the accuracy of tracking and ranging necessary to assure safety and mission success at separation of ranges less than 50 nautical miles.

(7) Refer to Table 2-2 and Figure 2-4

Design/Operational Influence

Operation in an autonomous control mode requires that the EOS and its interfacing element provides the following to meet the autonomous control requirements:

	EOS	Interfacing Element TUG, RAM, MSS, CPS, RNS
1. For separation distances >50 n miles S-band PRN Ranging equipment	Measure	Transpond
2. For separation distances <50 n miles Scanning laser Radar	Active SLR to Measure	Passive Optical Reflectors
3. Communication link at S-band or VHF to provide EOS to target command operation and to provide target to EOS vehicle status as well as command verification.	S-band or VHF Transmitter and Receiver with Omni directional antenna	S-band or VHF Transmitter and Receiver with Omni directional antenna
4. A TV camera for inspection purposes.	Under EOS pilot control.	Not Applicable.
5. An attitude reference with an accuracy of $\pm$ 0.5 degree	Yes	Yes
6. An attitude control capable of $\pm$ 0.5 degree stabilization	Yes	Yes
7. Delta-V maneuver capability	Yes	For orbital makeup only.
8. Onboard computation capability	Yes for total mission operation	For attitude determination and control only

PROPELLANT TRANSFER (8)

A separatable logistic tank module delivered to the user is recommended for EOS transfer of large quantity propellants.

The gross sequence of events is as follows:

(a) EOS delivery of loaded propellant logistic tank to orbit
(b) EOS deployment of logistic tank
(c) Direct dock of logistic tank and user vehicle
(d) Separation of EOS and mated logistic tank/user vehicle
* (e) Linear acceleration and fluid transfer to user vehicle provided by logistic tank module (EOS stationkeeping)
(f) EOS redock to logistic tank and mated user vehicle
(g) Separation of user vehicle from EOS and mated logistic tank
(h) EOS retraction and stowage of logistic tank in cargo bay
(i) EOS deorbit and earth return with empty logistic tank

Selection Considerations

The Propellant Transfer interfacing activity considered three alternate approaches for EOS delivery of large quantity propellants to the user vehicle as follows:

1) Orbiter stowed tank - (linear and rotational acceleration)
2) Orbiter deployed tank - (linear and rotational acceleration)
3) Orbiter separated tank - (linear acceleration only)

Approach 3) orbiter separated tank was selected for the following reasons:

- Enables a common EOS operational procedure
- Minimizes design/operational impacts on EOS
- Increased mission planning flexibility by having the EOS available during fluid transfer operation.
- Minimizes quantity of propellant required to provide acceleration for liquid vapor interface control.

*Capillary transfer concepts are currently being studied but as yet must be considered an advanced technology item.

(8) Refer to Table 2-2 and Figure 2-4.

EOS Design/Operational Influences

The selection of a separate logistic tank module for EOS delivery of large quantity propellants to the user vehicles creates the following influences on the EOS:

- Different logistic tank module lengths for Tug/CPS and RNS resupply requiring multiple attachment points in cargo bay

- Provide the following interconnects with logistics tank(s)

  - Electrical including power, command and control, and hazard monitoring

  - Insulation purge and pressurization (helium)

  - Propellant vent and dump

Design/Operational Influences on Interfacing Elements

The following influences are applicable to the various user vehicles that will mate with the logistic tank and receive the propellants:

- Provide compatible mating port
- Provide propellant transfer line interconnects
- Provide electrical power interconnects
- Provide for the monitor of hazardous conditions
- Provide command and control of linear acceleration jets on logistic tank
- Provide attitude control during propellant transfer
- Provide control and monitoring of propellant transfer operations

ATTACHED ELEMENT SUBSYSTEM SUPPORT (9)

This study recommends that the EOS provide interfaces to the payload to utilize the "available" subsystem capability.

NOTE: "Available" means that quantity of capability inherently required for normal EOS mission sizing that is not fully utilized on any specific flight.

Selection Considerations

The Attached Element Operations interfacing activity considered three generic approaches for attached element support from the EOS:

(1) Payload Dependent on EOS
(2) Payload Independent of EOS
(3) Payload Dependent on added modules or kits

The following matrix represents the selected approach for the major subsystem functions:

<table>
<tr><th>Function</th><th>1) Dependent</th><th>2) Independent</th><th>3) Modular Dependent</th></tr>
<tr><td>Tracking and voice</td><td>✓</td><td>-</td><td>-</td></tr>
<tr><td>Data</td><td>< 1 Mbps</td><td>10-50 Mbps</td><td>1 - 10 Mbps</td></tr>
<tr><td>Electrical power</td><td>≤ 500 W ave and 20 KW hr max</td><td colspan="2">← > 500 W ave and 20 KW hr max →</td></tr>
<tr><td>Attitude stability</td><td>≥ 0.5 deg and 0.05 deg/sec</td><td>-</td><td>< 0.5 deg and 0.05 deg/sec</td></tr>
<tr><td>Environmental control</td><td>—</td><td>✓</td><td>—</td></tr>
<tr><td>Thermal control</td><td>—</td><td>✓</td><td>—</td></tr>
<tr><td>Habitability</td><td>Pre & Post orbit</td><td>-</td><td>On-orbit Hygiene and Food Prep.</td></tr>
</table>

(9) Refer to Table 2-2 and Figure 2-4

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FUNCTIONAL REQUIREMENTS

The vehicle functional requirement for the Earth Orbital Shuttle (EOS) were developed from the functional requirements defined for each of the 14 interfacing activities. This subsection will contain the requirements that relate principally to the EOS and are necessary for performing the interfacing activities. Along with the functional requirement there will be a cross-reference made to the interfacing activitiy that established the requirement. There are eight categories of functional requirements. The initial category contains the system level (i.e., those that apply to more than one subsystem or relate to the performance of the entire system as a whole) functional requirements. The remaining seven categories contain the functional requirements by subsystem, again with references to the appropriate interfacing activity where the requirement was established.

A separate numerical designator has been established for each of the eight functional requirement categories as follows:

Category	Designator
EOS Orbiter System	1-X
Structures/Mechanical Subsystem	2-X
Environmental Control Subsystem	3-X
Electrical Power Subsystem	4-X
Guidance and Control Subsystem	5-X
Propulsion Subsystem	6-X
Communication/Data Management Subsystem	7-X
Crew/Habitability Subsystem	8-X

SYSTEM FUNCTIONAL REQUIREMENTS

1-1. A credible accident to, or a credible failure of an interface function or adjacent function shall not cause the loss of redundantly provided functions or compound the accident or failure by creating additional hazards (explosion, fire). In this sense, the following criteria apply:

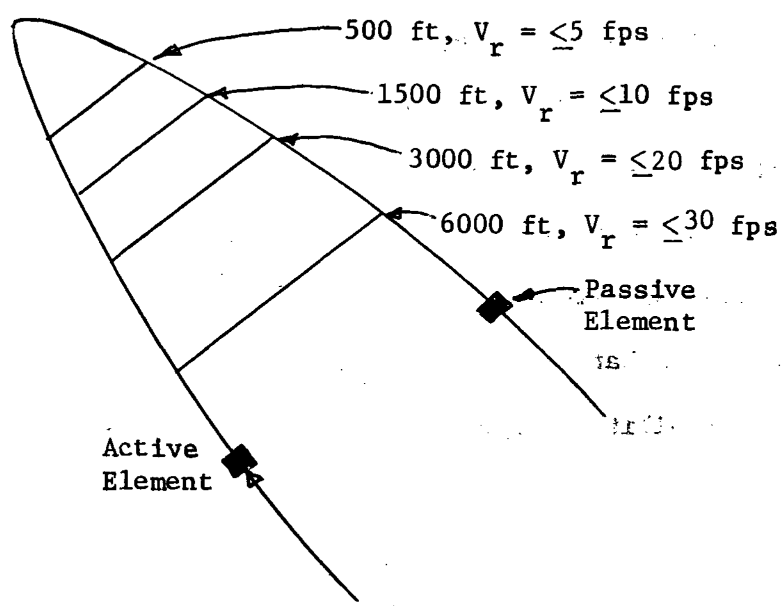
(a) Hazardous fluid lines shall be barriered or physically separated from power wires and each other (O_2 lines shall be considered hazardous in interface areas (DS-208)).

(b) Redundant fluid lines shall be separated a minimum of 45 degrees (DS-208).

(c) Redundant connectors shall be separated a minimum of 45 degrees (DS-208). (Mating - 37, Orbital Assembly - 28, Cargo Transfer - 31)

1-2. During terminal rendezvous a braking gate similar to that shown below, where the relative velocity (V_r) varies with the relative distance between elements must be satisfied. (Rendezvous - 11)

Braking Gate Criteria



1-3. Manual connections shall be located, designed, and mounted such that a worker can mate the connectors in a pressurized suit. (Mating - 32, Cargo Transfer - 34)

1-4. Deployment Time Constraint--The orbiter must be capable of deploying any single payload within a given period of time. The most rapid deployment requirement currently identified is five minutes (Reference Section 6.0, SD-136). A 10-minute deployment criteria also has been identified as a result of safety analyses. (Deployment - 2)

1-5. Interface assemblies that contain plugs, receptacles, and couplings shall be equipped with compatible guides such that alignment will be achieved prior to engagement of the connectors. (Mating - 30, Orbital Assembly - 23)

1-6. Hazardous fluid interconnects that are to be disconnected shall be purged with a non-hazardous (inert) gas and shall be pressure vented prior to separation. (Separation - 18)

1-7. Prior to initiation of the separation routine those subsystems that will be utilized during the separation activity shall be verified. Where backup paths are available, these shall also be statused. (Separation - 20)

1-8. Atmospheric contamination levels shall be monitored within habitable areas for 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 accpetable levels per the following tables: Crew Transfer - 19, Cargo Transfer - 26).

1-9. The capability shall be provided to ensure that passageways/hatchways to a normally uninhabited element are free of obstructions so that crew can enter safely and cargo movement will not be inhibited. This may include direct visual inspection through a view window or remotely monitored sensors or closed circuit television. (Crew Transfer - 21, Cargo Transfer - 28).

1-10. A method shall be provided whereby fluid interfaces can be verified to be free of residuals that may contaminate the surrounding environment prior to disconnect. (Cargo Transfer - 33).

1-11. Leak-detection sensors shall be provided when transferring any contaminable fluid. Venting is required to protect against contamination for plumbed transfer. (Cargo Transfer - 35).

STRUCTURES/MECHANICAL SUBSYSTEM FUNCTIONAL REQUIREMENTS

2-1. The EOS shall be capable of attaching to a payload and transferring the payload to the cargo bay. (Retraction and Stowage - 2)

2-2. Separation of plumbing and wiring connections shall leave them in a state such that, if needed they can be reconnected to and function with either the deployed payload or another payload retrieval on the same msision. There shall be a positive, safe separation of any plumbing and/or wiring connections between the payload and the orbiter. This separation may occur at any time after the initial check indicating that the payload is ready for deployment. Different connections may be separated at different times during the deployment sequence. (Deployment - 14, Retraction/Stowage - 15)

2-3. Alignment aids shall provide relative positional information between the EOS and the mating elements. The information shall include centerline miss distance and angular misalignment to the accuracy as follows:

Automatic systems, such as laser radar: +/-1 degree
Direct visual systems: knowledge to identify when the vehicles are off aligned with the mating port centerlines greater than 3 degrees (Mating - 5)

2-4. Residual attitude misalignments remaining after capture shall be corrected prior to rigidizing (Mating - 16)

2-5. The mating interfaces shall be drawn together by the mating concept to remove residual attenuation stroke and seat the interfaces. The rate at which the vehicles are drawn together must be controlled to within the structural capability of the docking ports. (Mating - 17)

2-6. Throughout mated operations, the mated element shall be capable of being separated upon command. This requirement naturally applies only after the interface between the EOS and the element has been properly isolated/sealed for safe separation or before the interface hatches have been opened. (Mating - 25)

2-7. The separation technique shall be such that the mating ports will be left in a condition ready for a subsequent mate, unless remote control configuring of the mating port is available. (Separation -13)

2-8. The interface between the EOS and a mated element must be designed to be closed and sealed without performing a prolonged demating of interface connectors. (Mating - 39)

2-9. Prior to separation alignment aids must be active and aligned. (Separation - 3)

2-10. A backup means for release and separation of the EOS and mated elements shall be provided. (Separation - 14, Deployment - 6, Retraction and Stowage - 7)

2-11. Deploy/Retrieve Multiple Payloads--The EOS shall be capable of deploying multiple payloads during a single mission.

Maximum Weight: 65,000 pounds (including cargo bay provisions)

Maximum Size: 15 foot diameter by 58 foot length (including retention/storage mechanisms)

(Deployment - 1, Retraction/Stowage - 1)

2-12. Provide Venting--The EOS shall provide service panels for GSE umbilicals and in-flight fluid venting and dumping.

During the on-orbit phase of the mission the shuttle/payload vent interfaces will need to be safely broken prior to release of a deployed payload, and connections remade and verified, with retrieved payloads, if residuals are on board. This implies a need for automatic, remotely controlled connecting hardware to preclude EVA activity. (Deployment - 8, Retraction/Stowage - 9)

2-13. Protection of eyes and video visual device from reflected or high intensity light damage shall be provided. (Mating - 2)

2-14. Mating port mechanisms shall be designed to the following criteria:

(a) The design shall be applicable to direct docking and manipulator berthing operations. The concept may be of a design that will perform one type of mating, but with an adapter added can perform the other type.

(b) The design shall be inherently dynamically stable when fully engaged to an associated mating port.

(c) The design shall provide redundant features where active mechanisms are involved.

(d) The design shall incorporate means to automatically reduce angular misalignment and lateral miss distance between the mating interfaces to permit initial capture on first structural connection.

(e) A method of monitoring the status of capture mechanism (latch position) shall be provided.

(f) The capture mechanism shall be capable of quick release and recycle to its initial state at any phase of the capture operation.

(g) The mating port shall be capable of rotational oriented berthings of 180-degree intervals minimum, with 90-degree intervals or less preferred.

(h) The mating port shall be capable of successfully capturing and hard docking to an opposing mating port with a miss distance and misalignment tolerance as follows:

Miss distance: ±6 inches minimum

Misalignment: ±3 degrees minimum (pitch, yaw, roll)

(i) Mating port design shall be capable of accommodating the full complex of study vehicles identified. Vehicle masses up to 8000 slugs. (Mating - 12)

2-15. The EOS mating interfaces shall be structually connected either automatically or manually to provide the required intervehicular stiffness for combining EOS-Element vehicle maneuvering. (Mating - 20)

2-16. Mechanical radial position and roll indexing shall be provided at the mated interface to prevent interface slippage and damage to pressure seals during combined vehicle maneuvering. (Mating - 2)

2-17. The capability to inspect, maintain, and manually recycle both capture and rigidizing latches in a shirtsleeve environment shall be provided. (Mating - 23)

2-18. The tunnel leak rate between the EOS and a mated element shall be no greater than the leak rate of the worst case hatch seal of the mated pair. (Mating - 36)

2-19. Separation velocities and angular rates caused by the extension of shock attenuation system or other energy storage system shall be controlled by delaying release until the extension dynamics cease.

2-20. Stability--The deployment mechanism must hold the payload stable until it is physically released from the orbiter. (Deployment - 13)

2-21. The EOS Orbiter shall provide the capability for shirtsleeve access to the interior of the pressurized payloads (Attitude Element Operations - 19)

2-22. Attachment Integrity Verification--The manipulator shall be capable of verifying attachment integrity by applying and sensing forces prior to release of the retention mechanisms. (Retraction and Stowage - 18)

2-23. Payload Retraction--The retraction mechanism must be capable of handling any pallet, shield or supporting structure that must be retracted along with the payload. In some cases, the operational payload (e.g., an experiment module) is permanently attached to a pallet that provides the handling points for the retraction mechanism. Only one payload shall be moved at a time during any one sequence of operations. (Retraction and Stowage - 19)

2-24. The retention assembly holding the two elements together during transport must be capable of withstanding any dynamic loads imposed by maneuvers performed by the transporting element. (Attached Element Transport - 1)

2-25. 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 to keep operators hands free. (Cargo Transfer - 3)

2-26. All hatches utilized for cargo 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. (Cargo Transfer - 22 (see Crew Transfer - 12))

2-27. The retention assembly shall be capable of accommodating payloads of various configurations and dimensions. (Attached Element Transport - 2)

2-28. The EOS control center shall have the means to verify the attachment of the two elements prior to initiation of any thrust maneuver. (Attached Element Transport - 5)

2-29. Extension and connection of automatic utility interface connectors and couplings shall be delayed until after the mating rigidizing mechanism has engaged and locked up. (Orbital Assembly - 17; Mating - 31)

2-30. Rigidizing techniques shall be designed such that during the application of the rigidization, the module structural fabrication cannot be over-stressed. (Orbital Assembly - 39)

2-31. Pressure equalization capability and leak rate verification shall be provided on each side of each mating interface hatch of any docking vehicle combination requiring shirtsleeve environment for assembly operations. (Orbital Assembly - 40)

ENVIRONMENTAL CONTROL SUBSYSTEM FUNCTIONAL REQUIREMENTS

3-1. Propulsive venting (other than attitude control of the EOS shall be inhibited or controlled during the Mating, Separation and Attached Element Operations. During mated operations venting must be controlled, particularly venting of condensable gases to minimize exterior contamination of susceptible elements (Mating - 19, Separation - 12, Attached Element Operations - 9)

3-2. Prior to separation of an element from the EOS pressure integrity of both elements shall be verified. (Separation - 21)

3-3. Prior to separation of an element from the EOS, if a pressurized tunnel is used between them it must be pumped down or vented to space. The pressure remaining in the tunnel shall be low enough such that when separation occurs no noticeable delta velocity, due to the remaining pressure, will be imparted to the separating elements. (Separation - 9; Attached Element Operations - 22)

3-4. Prebreathing equipment shall be provided for use with the 3.7 psig suits to provide means for which crew can prebreathe oxygen for a sufficient length of time to accomplish denitrogenation. Use of the 8.0 psig suit may avoid any need for prebreathing equipment operations, or time. The time involved for prebreathing for the 3.7 psig suit normally ranges from two to four hours. (Cargo Transfer - 29 (IVA/EVA only))

3-5. The EOS shall provide the necessary interfaces to dump, purge, and fill the payload atmosphere.

The preferred service and checkout mode is shirtsleeve. However, various payloads are not pressurized while in orbit. In addition, cryogenic liquids used to cool scientific sensors and other trace gases may result in a hostile atmosphere.

(a) Means shall be provided for air circulation from support equipment to the payload during ground checkout and pad operations to provide payload air conditioning for equipment operation and crew access if required.

(b) The orbiter shall provide atmosphere pressure control of the orbiter and selected attached payloads.

(c) The orbiter shall provide ducting and fans sufficient to remove heat, humidity, CO_2 and trace contaminants generated by two crew members located in an attached payload for a mission duration of seven days. Additional capability requirements shall be provided by the payload. (Attitude Element Operations - 23)

(d) The payload shall provide oxygen and nitrogen atmospheric gases to support payload manned operation, pressurization and leakage makeup. Metabolic O_2 consumption shall be based on a usage rate of 1.84 pounds per man per day.

(e) Means shall be provided for support equipment cooling lines to the payload to maintain subsystem equipment temperature control during ground checkout and pad operations.

(f) The orbiter shall provide an airlock capability and oxygen pre-breathing for suited operations. Umbilical connects and liquid cooling garments shall be provided in the orbiter airlock. Orbiter provisions for EVA capability shall contain TBD pressure garment assemblies and portable life support systems (PLSS). Capability to recharge the PLSS's shall also be provided.

(Deployment - 9; Retraction and Stowage - 10)

3-6. There shall be a means of pressurizing the docking interlock volume from the EOS. Pressurization to 14.7 psia atmosphere will be required. Volumetric requirements are of the order of 100 to 300 ft^3. Air composition shall be that of the EOS. (Attached Element Operations - 26)

ELECTRICAL POWER SUBSYSTEM FUNCTIONAL REQUIREMENTS

4-1. Electrical cables and fluid lines that traverse crew and cargo passages shall be suitably enclosed or otherwise protected to minimize hazards to the crew and provide protection for the hardware.

Routing electrical cables along fluid lines or near high temperature sources shall be avoided. (Mating - 34)

4-2. For mating operations, the EOS shall provide self-illumination. The lighting shall provide the mating vehicle with the capability to determine EOS orientation at a minimum range of 1000 feet. (Mating - 1; Separation - 15)

4-3. All electrical and signal interfaces shall be deadfaced prior to being connected or disconnected. The possibility of connecting "hot" connectors is very likely if deadfacing is not part of the interface design. (Mating - 27; Separation - 16)

4-4. When electrical or fluid interfaces are to be mated between elements, a ground connection between the element structures shall be established to provide a consistent measured low impednace bond between the elements rather than rely on the mating interface for structural ground. (Mating - 38; Orbital Assembly - 29)

4-5. Adequate lighting shall be provided along all personnel crew transfer routes. General illumination criteria for shirtsleeve operations are presented below. (Crew Transfer - 11)

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

4-6. Adequate lighting shall be provided to ensure visibility in the immediate area of cargo handling and along the cargo transfer path. General illumination criteria for shirtsleeve operations are also presented in the above matrix. (Cargo Transfer - 5)

4-7. Illumination shall be provided to permit easy visual detection of the location and orientation of handgrips, rails, tether points, and restraint devices along transfer paths and at the work site. Fixtures shall be designed and located to provide even lighting on the surfaces to be illuminated, generate minimum stray light, minimum glare, and minimum reflections. IVA operations in direct sunlight may require that the orbiter be oriented such that glare, direct and specular, does not hinder visual acuity. Minimum lighting should range as follows:

Direct diffused lighting, 30-50 foot-candles

Supplementary local, 50-70 foot-candles

(Orbital Assembly - 8)

4-8. Prior to activating electrical interface circuits or closing deadface switches, proper mate of the interface connectors shall be verified. (Mating - 28)

GUIDANCE AND CONTROL SUBSYSTEM FUNCTIONAL REQUIREMETNS

5-1. For docking, the EOS must align its mating port with respect to the mating port of the other vehicle in both translation and rotation. Alignment shall be as follows:

Lateral miss distance: ±6 inches

Pitch/yaw/roll misalignment: ±3 degrees

(Mating - 4)

5-2. During direct docking alignment and closure to docking contact, a narrow attitude deadband of 0.2 degree and 1 degree, respectively, shall be maintained by the independent vehicles. (Mating - 6)

5-3. Prior to separation, the EOS will be maintaining attitude hold control of the mated pair. At separation, both elements will have attitude control capability (Separation - 1).

5-4. Prior to final separation, the attitude control logic of each element will be nulled, such that individual devices will not oppose each other when both systems are activated. (Separation - 11)

5-5. The EOS will be required to perform attitude maneuvers with a payload attached and activated to verify proper response of attitude control and orientation devices, and provide illumination for viewing. Illumination of the cargo bay for selected steps in the retrieval operation may require shuttle maneuvers as a backup to floodlights. (Deployment - 3; Retraction and Stowage - 3)

5-6. Both the EOS and mating elements must contain an attitude reference device, either horizon sensor or star-tracker capable of determining the element attitude in relation to the element coordinates and orbital or earth coordinates. For these requirements the attitude reference device shall be capable of measuring attitude to an accuracy of ±0.5 degrees. (Rendezvous - 4)

5-7. The EOS must have a computer capable of computing state-vectors and orbital parameters from range, range-rate data or other data supplied from element on-board sensors. It shall also have the capability to compute delta-velocity maneuvers from stored data for the makeup of orbital parameters.

At the time of a state-vector update, the one-sigma uncertainty in element position and velocity shall not exceed the limits of the type presented below:

Element Position and Velocity Uncertainty:

Parameter:

Component	Position	Velocity
Downrange	±3 n mi	±3 ft/sec
Cross range	±1 n mi	±10 ft/sec
Vertical	±1 n mi	±20 ft/sec

During initial rendezvous operations when the EOS is tracking a cooperative target, the one-sigma tracking uncertainties shall not exceed the limits of the type presented below. Terminal rendezvous tracking inaccuracies are covered in Rendezvous Interfacing Activity (Volume II, part 3).

Cooperative Target Tracking Uncertainty:

	Uncertainty
Parameter	At 30 n mi
Range	±100 feet
Range Rate	±1.0 ft/sec

(Rendezvous - 1; Stationkeeping - 9; Detached Element Operations - 10)

5-8. The EOS or the control center must have the capability to calculate the relative positional state (position and velocity) of the rendezvous elements and then determine, based on a knowledge of the ephemerides of both elements, the maneuvers (vectorial velocity changes) which the EOS must execute to effect rendezvous with the passive element. (Rendezvous - 2)

PROPULSION SUBSYSTEM FUNCTIONAL REQUIREMENTS

6-1. Prior to contact between the mating interfaces, the relative closing rate (axial velocity) must be reduced to a velocity that is compatible with both vehicles structure and mating port energy absorption capabilities. The range of closing velocities for the noted concepts are as follows:

Longitudinal velocity:

with attenuation, 0.2 fps to 0.5 fps

without attentuation, 0.04 fps to 0.17 fps

Lateral velocity:

with attenuation, 0.09 fps to 0.5 fps

without attenuation, 0.03 fps to 0.17 fps

Angular velocity:

0.06 d/s to 0.3 d/s

Other rendezvous techniques are possible with corresponding different rates. (Mating - 14)

6-2. Translation jets utilized for separation shall be selected and propellants utilized so as to minimize the effects of exhaust plume impingement on sensitive areas of interfacing elements. This applies where more than one set of jets can be selected. Solar arrays and experiment sensors are particularly vulnerable to structural damage from direct jet exhaust and degradation through contamination by the reactants. (Separation - 6)

6-3. The EOS must have attitude control capability enabling implementation of a change in attitude. It shall be capable of holding attitude within 0.5 degrees of desired. (Rendezvous - 5)

6-4. The EOS and mating element must have propulsive capability for performing delta-velocity maneuvers in accordance with the computed requirements for orbital makeup. (Stationkeeping - 10)

6-5. 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. (Attached Element Operations - 25)

COMMUNICATIONS/DATA MANAGEMENT SUBSYSTEM FUNCTIONAL REQUIREMENTS

7-1. Range and range rate data shall be displayed during mating operations. This capability must also exist during other data transfer. (Mating -9; see Rendezvous - 8 and 9)

7-2. Electronic acquisition for automated docking maneuver control shall have remote backup for manual override of the docking operations. (Mating - 10)

7-3. After mating, one of the vehicle control devices shall be inhibited to permit combined vehicle maneuvering and prevent inadvertent control system activity resulting in plume impingement damage. (Mating - 22)

7-4. Throughout a docking or separation maneuver the control devices of both vehicles shall be monitored for indications of control failures such as reaction jet "stuck-on" and "stuck-off" conditions. (Mating - 26; Separation - 5)

7-5. EOS shall be equipped with RF communications devices. The minimum extent of the devices shall be as follows:

(a) When mating/separating EOS to manned elements a duplex voice link between the elements shall be provided. Element status and voice command information must be transmitted between the elements.

(b) When mating/separation EOS to unmanned elements a data link shall be provided between the elements. The manned elements will continuously monitor and status the unmanned element and will transmit commands to the unmanned element. (Mating - 40; Separation - 8)

7-6. Sensing shall be provided to ascertain positive capture has occurred at the mating port or for positive separation prior to initiating a jet separation or mechanical extension by a manipulator. (Separation - 7; Mating - 12; Attitude Element Operations - 5; Orbital Assembly - 19)

7-7. The EOS and payload shall collectively provide the capability to monitor the health and safety status of the payload. A data bus tie for commands and responses shall be provided. Two-way voice shall be provided to support all manned operations.

Voice and alarm status is a mandatory crew safety requirement for all activities requiring ingress into a payload. (Deployment - 10; Retraction and Stowage - 11)

Audio alarms could be tone and/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. (Crew Transfer - 20, Cargo Transfer - 27).

7-8. The EOS shall be capable of establishing a RF link and transmitting command signals to condition the payloads for normal operations. Selected payloads will require single or multiple RF commands to initiate the following responses:

(a) Initiate spin

(b) Enable and/or change attitude control modes

(c) Extend external appendages (solar arrays, antennas)

(d) Enable orientation of sensors

(e) Activate protective doors and shutters

(Deployment - 11; Retraction and Stowage - 12)

7-9. Means shall be provided for monitoring the various steps in the deployment sequence (e.g., clearance of the cargo bay, separation of wiring and plumbing stability of payload, and either direct or television viewing of the operations). The information obtained from this monitoring must be available to the operator and/or controller of the deployment mechanism.

The orbiter shall provide the following monitoring capability via the payload information management interface:

(a) Payload total pressure

(b) Payload oxygen partial pressure

(c) Pressure of payload pressure vessels and temperature and pressure of cryogenic vessels

(d) Payload internal temperatures

(e) Monitor for explosive atmosphere for pressurized payloads

(f) Monitor for toxic atmosphere for pressurized payloads

(g) Provide fire detection and control of pressurized payloads

(Deployment - 12; Retraction and Stowage - 13)

7-10. The following data parameters shall be provided to the RAM by the orbiter: 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 synchronising the payload systems with the orbiter computer clock. (Attached Element Operations - 3)

7-11. The EOS shall provide attitude pointing, crientation maneuvering, attitude hold deadband (limit cycle), and attitude rate capability to some payloads. (Attached Element Operations - 7)

7-12. The EOS shall receive experiment data across the interface with subsequent recording and storage. (Attached Element Operations - 14)

7-13. A measurement system must be available that is capable of determining rendezvous elements relative range and range rate. These data must be available at the location of the controlling unit. It shall be capable of providing these measurements to the following nominal accuracies:

Range	Range Accuracy	Range Rate
10 to 50 feet	±6 in.	±0.1 ft/sec
50 ft to 30 n mi	±5 ft	±0.5 ft/sec
30 to 60 n mi	±100 ft	±1.0 ft/sec
60 n mi and over	±1 n mi	±10 ft/sec

(Rendezvous - 7)

7-14. A monitor and display system shall be available at the controlling (RCC) element that is capable of providing simultaneous real-time display of:

(a) Relative rendezvous elements range

(b) Range-rate between rendezvous elements

(c) Bearing angles from active to target elements

(d) Rate of change of bearing angles

(Rendezvous - 8)

7-15. The EOS must have a sequence timer or computer scheduled timing activation system that can automatically activate or wake up specified subsystems utilized in stationkeeping of two unmanned near-earth orbital elements. (Stationkeeping - 1)

The EOS must have a computer memory capable of storing attitude reference data and predicted attitudes for all stationkeeping operations. The computer must be programmed and a look-up routine available that can perform a computation to determine the difference between actual and predicted attitudes and to calculate the attitude control maneuvers to correct the attitude within prescribed limits. (Stationkeeping - 3)

7-16. The EOS shall have an on-board autonomous navigation capability for determining its own state vectors and orbital parameters. A combination of a star tracker and an earth horizon sensor satisfies this requirement. (Stationkeeping - 13)

7-17. Relay switching capability:

Receive/transmit, 1 kbps commands, 10 Kbps data, voice

7-18. Communications capability shall be provided for transfer crew members. Two-way voice communications must be maintained to the IVA/EVA crewmen at all times. (Crew Transfer - 16; Cargo Transfer - 17; Orbital Assembly - 10)

7-19. A means shall be provided in the controlling element (ground or space) to command and control the collection, storage, and transfer of dumped or real-time data by the detached element. (Detached Element Operations - 5)

7-20. Monitoring and checkout of detached element condition, operations, and equipments by continuous or periodic interrogation shall be provided for determining element status, isolating faults, processing and displaying such data for evaluation and possible correction. (Detached Element Operations - 8)

7-21. A means shall be provided for inspection of the detached element by direct visual observation or by a television system.

This may be accomplished by means of a black-and-white television camera system. This can be used for both self-inspection and inspection of other elements. The TV system will transmit approximately 2.9 MHz baseband analog signals for direct or relayed pictures of the detached element to the ground or space controlling element.

Video visual systems (TV) shall provide a minimum of 300 lines resolution at video monitor; provide a lens field of view limited to 70 degrees, and the video presentation to the pilot shall be the "fly-to" convention. (Detached Element Operations - 11; Mating - 3)

7-22. The EOS shall be equipped with RF communications devices. The minimum extent of the systems shall be as defined in the following three matrices. (Mating - 40, Separation - 8, Rendezvous - 6, Stationkeeping - 4,6,7,8,11, Detached Element Operations - 1,4, Communications - 1 through 11, Comm/Data Mgmt Rqmts table.

Communications/Data Management/EOS Element Pair Requirements Matrix

	EOS (Controlling)	EOS	TUG	RAM	MSS	GROUND
1	Command Data Transmission to					
	Digital BER 1×10^{-6}	2 kbps	→	→	2 kbps	NA
	Voice (4 kHz)	Yes	Yes	NA	Yes	
2	Command Verification					
	Digital from BER 1×10^{-6}	2 kbps	→	→	2 kbps	NA
	Receive/verify	Yes	→	→	Yes	
3	Data Storage					
	Digital storage per day	NA	→	→	→	NA
	Later dump per day	NA	→	→	→	NA
	Film or tape delivery	NA	NA	15 reels per day trans-port (max)	1 reel of mag tape in 2 days	NA
4	Digital Data Transfer					
	Receive from	10 kbps	4 kbps	5 kbps	51.2 kbps	2 kbps
	Transmit to	See cmds	→	→	See cmds	51.2 kbps
5	Analog Data Transfer					
	Voice (4 kHz) Channels	1	1	NA	1	2
	Television	NA	→	→	→	NA
	Facsimile	NA	→	→	→	NA
	Other	NA	→	→	→	NA
6	Tracking/Ranging					
	PRN range capability	Meas.	→	→	Meas.	Respond
	±1 n mi range ±5 ft/sec range rate	Resp.	→	→	Resp.	
7	Computer capability to determine ephemerides	Yes	→	→	Yes	NA
8	Visual Inspection	Yes, TV	→	→	→	Yes, TV
9	Analog Data Transmission to					
	Voice (4 kHz) Channels	1	1	NA	1	1
	Television	NA	→	→	→	NA
	Others	NA	→	→	→	NA

Shuttle Link Requirements Matrix

Signal	Q	Mode	Data Rate	Modulation	SCO	Quality	Deviation	Carrier (MHz)	Remarks
A. Uplink									VHF antenna is simi-directional (G = 4 db)
Voice	1	FDX	300 to 3000 Hz	FM-FM	30 kHz ±7.5 kHz	46db-Hz	$\beta = 1$	148-150	S-band antenna is omni-direc'l (0 db)
	1	FDX	300 to 3000 Hz	FM-PM	30 kHz ±7.5 kHz	46db-Hz	1.34 rad	2106.5	
Data	1	SPX	2 kb/s	FM-FM	70 kHz ±5 kHz	BeR = 10^{-5}	$\beta = 1$	148-150	Receiver T_{sys} ≈2000°K, S-band
	1	SPX	2 kb/s	FM-PM	70 kHz ±5 kHz	BeR = 10^{-5}	1.85 rad	2106.5	Receiver T_{sys} ≈1800°K, VHF
Range, range rate	1	Turnaround	100 kHz (tones)	VHF-FM	-	BeR = 10^{-5}	TBD	148-150	(Simultaneous signals)
	1	Turnaround	0.5 Mb/s	PM	-	BeR = 10^{-5}	1.2 rad.	2106.5	
B. Downlink									
Voice	1	FDX	300 to 3000 Hz	FM-FM	30 kHz ±7.5 kHz	46db-Hz	$\beta = 1$	136-138	
	1	FDX	300 to 3000 Hz	FM-PM	1.25 MHz ±7.5 kHz	46db-Hz	0.7 rad.	2287.5	S-band transmitter power output = 10 watts each (one special data and one voice, data, range)
Data	1	SPX	2 kb/s	FM-FM	70 kHz ±5kHz	Ber = 10^{-5}	$\beta = 1$	136-138	
	1	SPX	51.2 kb/s	PSK-PM	1.024 MHz	Ber = 10^{-5}	1.2 rad.	2287.5	VHF transmitter power output = 80 watts
Range, range rate	1	Turnaround	0.5 Mb/s	FM		Ber = 10^{-5}	TBD	136-138	(Simultaneous signals)
	1	Turnaround	0.5 Mb/s	PM		Ber = 10^{-5}	1.2 rad.	2287.5	
Special data	1	SPX	51.2 kb/s	PSK-PM	1.024 MHz	Ber = 10^{-5}	600 kHz	2272.5	

Element Characteristics Matrix

EOS

Operation with
EOS_2, Tug, RAM, Sat, MSS, CPS, RNS, OPD, Ground Station and TDRS

Frequency Band		Ku	S	VHF
Frequency	Ret.	14.4 - 15.35 gHz	2200 - 2300 MHz	136 - 144 MHz
	Fw.	13.4 - 14.2 gHz	2025 - 2120 MHz	126 - 130 MHz
Data - Transmit		Not Used		
Analog - voice			1 channel	1 channel
Analog - TV			--	--
Digital			51.2 kbps	10 kbps
Data - Receive				
Analog - voice			1 channel	1 channel
Analog - TV			--	--
Digital			10 kbps	1 kbps
Antenna Type			Omni	Omni
Gain			0 db	0 db
Size				
Receiver Noise Figure			800 K	1200 K
Transmitter Power Output			30 watts	25 watts
Tracking/Ranging				
Measure			X	--
Respond			X	--
Active SLR and passive optical reflectors for rendezvous and docking				

CREW AND HABITABILITY SUBSYSTEM FUNCTIONAL REQUIREMENTS

8-1. A means shall be provided to perform visual tracking of the other element during the terminal phase at a separation of less than 5 miles. (Rendezvous - 10)

8-2. All IVA, EVA and hazardous shirtsleeve operations shall be conducted with a minimum of two crew members (buddy system). One crew member acting as a backup, monitors the operations of the active crew member providing a rescue capability. (Crew Transfer - 1, Orbital Assembly - 9, Cargo Transfer - 12)

8-3. The backup crew member during IVA and hazardous shirtsleeve operations shall be positioned to observe the other crew member at all times and, in the case of IVA activities, will be required to control the other crew member tether or umbilical to prevent entanglement. A third crew member shall be available for voice communication and C&W monitoring. (Crew Transfer - 2, Cargo Transfer - 13)

8-4. Crew mobility aids and restraint devices shall be provided along all crew transfer routes and worksites in order to facilitate crew translation and stabilization in zero-g environment. (Crew Transfer - 3)

8-5 Crew mobility aids shall be capable of use by a 5 to 95 percentile crew member in either a shirtsleeve or pressurized suited mode of operation. (Crew Transfer - 4, Cargo Transfer - 11)

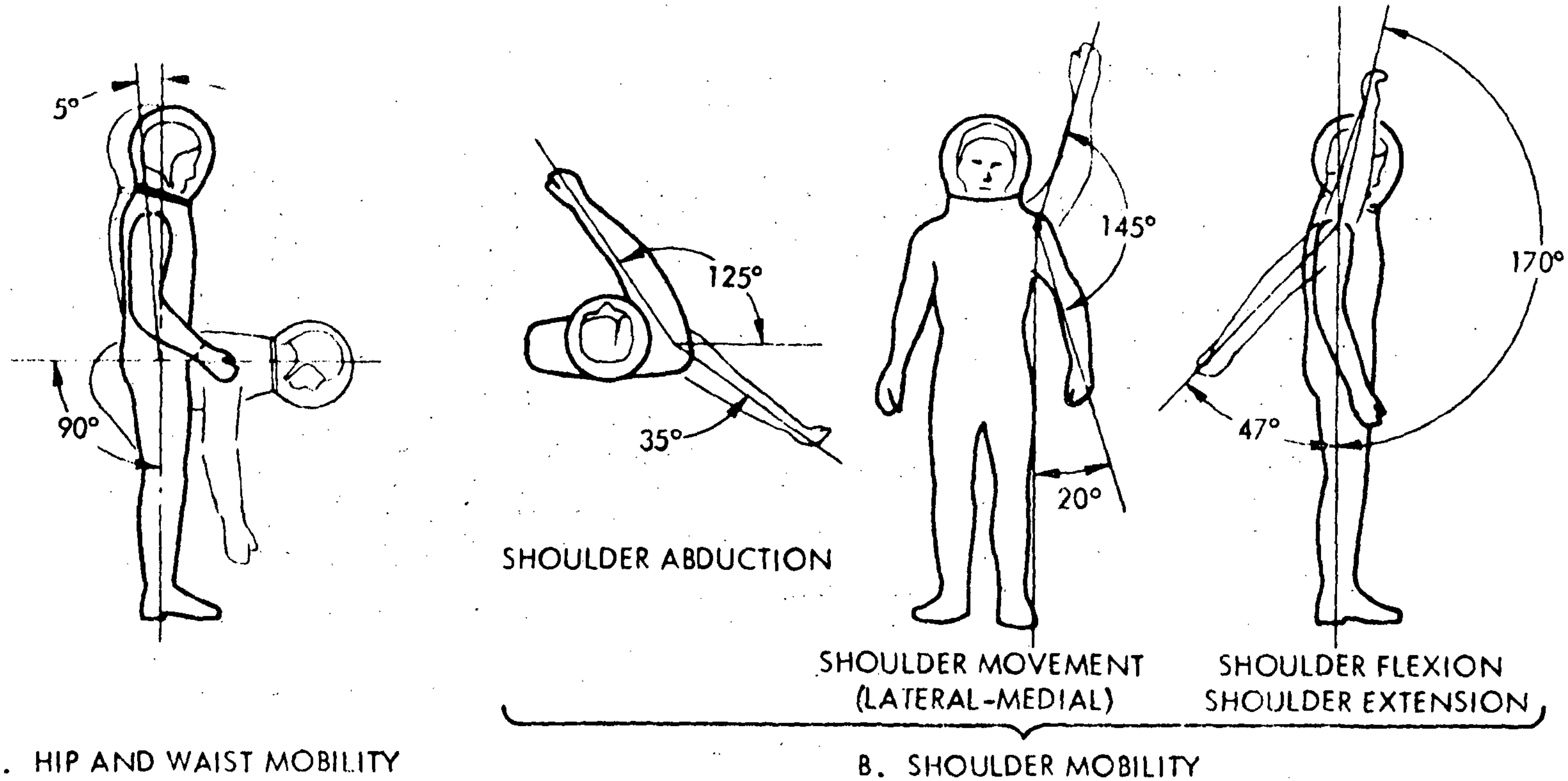
8-6. Crew restraint devices shall be capable of use by a 5 to 95 percentile crew member in either a shirtsleeve or pressurized suited mode of operation. Development of worksite crew restraint device requirements will be dependent upon the reach capability of the 5 to 95 percentile crew population while restrained. Illustrations on pages 2-56 and 2-57 define anthropometric data. (Crew Transfer - 6)

8-7. Crew restraint devices shall be easily operable, not restrictive of required crew motions, and possess a high degree of crew acceptability. (Crew Transfer - 7)

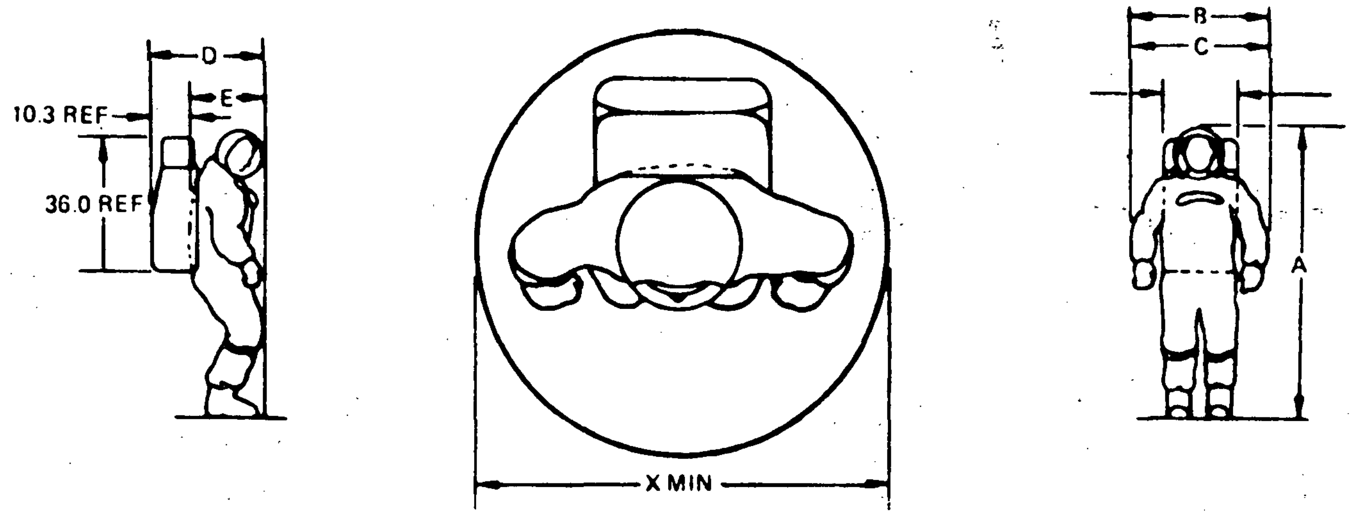
8-8. Crew restraint devices shall be designed to allow crew members to apply various combinations of loads at 1 g equivalent force values with or without a pressurized space suit. (Crew Transfer - 8), Cargo Transfer - 16)

8-9. Cargo restraint devices shall be capable of single hand attachment operations by a crewman in a pressurized space suit. (Cargo Transfer - 4)

8-10. Crew restraint devices shall be provided along the cargo transfer path and at cargo transfer worksites to provide capability for crewman positioning and stabilization. (Cargo Transfer - 15)



. PGA Mobility



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

. Envelope Dimensions for a Suited Pressurized Male Crew Member

8-11. 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. (Cargo Transfer - 18)

8-12. Manual interface connections shall be located, designed, and mounted such that a worker can mate the connectors in a pressurized IVA suit. (Mating - 32, Cargo Transfer - 34)

8-13. Accessible surfaces shall be capable of being touched by a crewman in a shirtsleeve or spacesuit. Surface materials shall be selected to ensure that high and low temperatures and conductivity are not limiting factors in crew or cargo transfer. (Crew Transfer - 5, Cargo Transfer - 14)

8-14. All equipment installations within crew mobility areas shall be capable for use for push-off. Installations shall be capable of withstanding multi-directional application of crewman impact loads. (Crew Transfer - 9, Cargo Transfer - 20)

8-15. Equipment susceptible to damage or that is hazardous to crew and cargo transfer operations shall be separated from mobility areas and color-coded or placarded. (Crew Transfer - 9, Cargo Transfer - 21)

8-16. Acceptable noise levels shall be maintained during crew and cargo transfer operations to prevent discomfort to crew members and interference with verbal communications at normal voice levels. (Crew Transfer - 14, Cargo Transfer - 24)

8-17. Passageways/aisles shall be capable of accommodating crew and cargo transfer operational requirements. The criteria is shown in the sketch below. (Cargo Transfer - 18, Cargo Transfer - 25, Attached Element Operations - 30)

8-18. The weight (mass) of cargo/resupply items requiring manual handling will be limited by crewman maneuvering capabilities. All cargo transfer approaches, except 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 with 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 the table below. For two men, a 250-pound mass is considered the upper limit at zero-g. (Cargo Transfer - 1)

Cargo Mass Handling Limits (180-lb Crewman)

g level	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	.10
% 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

8-19. A window or other viewing method shall be provided through each pressure hatch that is capable of being closed for either normal or emergency operations. This permits crew observation of IVA operations and viewing prior to ingress whenever hatches are closed. (Crew Transfer - 13, Cargo Transfer - 28, Attached Element Operations - 15)

SECTION 3. SPACE TUG

The space tug is a propulsive stage capable of being carried into orbit in the EOS cargo bay. Once in orbit, it will be capable of performing missions ranging from placing spacecraft into orbits different from that of the EOS to the insertion of spacecraft into geosynchronous orbit, or injection into escape trajectories. Although the ultimate performance objectives for this propulsive stage include manned applications, spacecraft retrieval, and reusability of the propulsive stage itself, the early capability may be somewhat more restricted. Studies are currently underway both in the United States and in Europe to define the performance and operating requirements of the space tug and to identify and evaluate alternate design approaches. It is envisioned that a space tug with limited capability could be available by the early 1980's (European tug) and that a system embodying the full performance objectives could be in operation by the mid-1980's.

Figure 3-1 illustrates the full capability space tug model furnished by the NASA for use in this study.

In the interim before the space tug becomes operational it is possible that a derivative of an existing stage, such as Centaur, Agena, Titan Transtage or Burner II, could be adapted to fulfill the functions of inserting spacecraft into orbits different from that of the shuttle, into geosynchronous orbit, and injection into escape trajectories. This vehicle is identified as an interim tug and could become operational concurrently with the EOS.

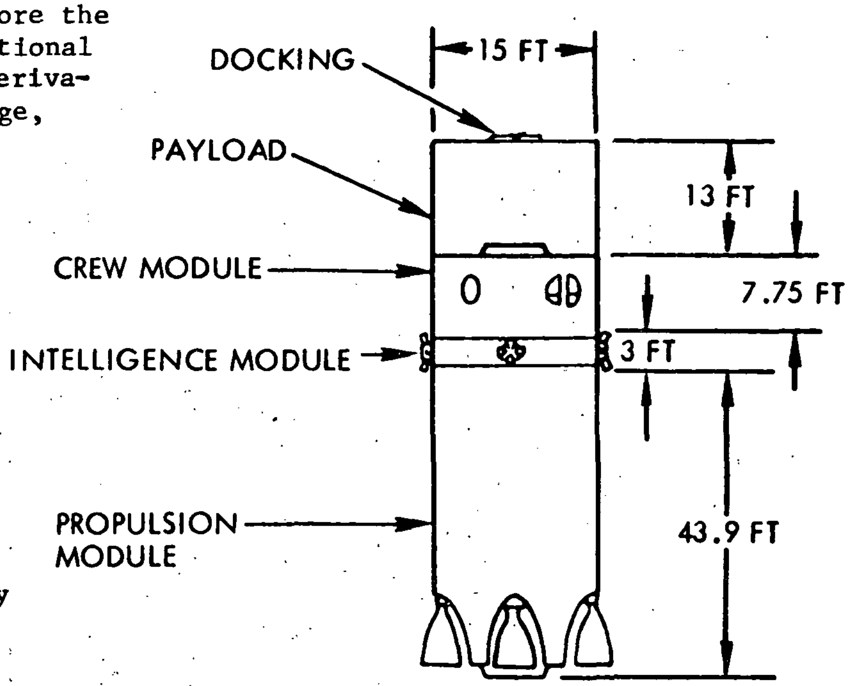


Figure 3-1. Full Capability Space Tug Model

NOTE: The significant analyses results and recommendations contained in this section were not sensitive to the specific TUG model of Figure 3-1.

Orbital inclination requirements for identifiable tug payloads tend to be grouped at or near equatorial, 30-degree, 55-degree, or polar orbits. When launched from either the Eastern or Western Test Range, the EOS is limited to an operational orbit of 28.5 degrees or greater inclination. Gross weight limits of 65,000, 55,000, and 40,000 pounds are representative of the EOS payload capabilities to a 100 nautical mile circular orbit at inclinations of 28.5, 55, and 90 degrees, respectively (payload capability decreases as orbital inclination increases).

The salient characteristics of the TUG model furnished for this study are highlighted in Table 3-1.

Table 3-1. Space Tug Model Characteristics

• WEIGHT STATEMENT

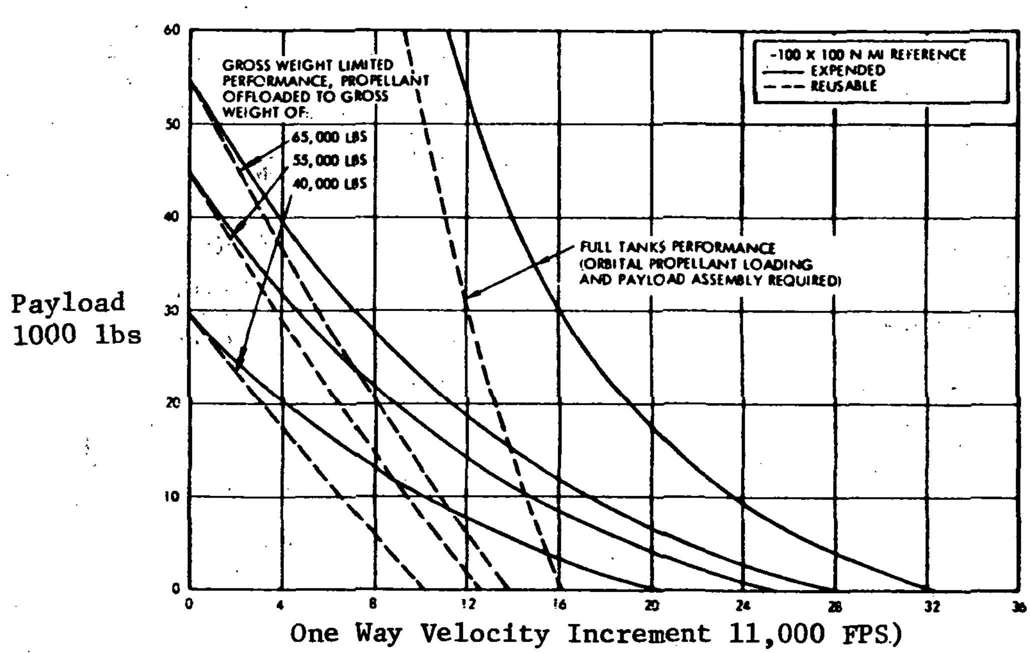
ITEM	GEOSYNCHRONOUS APPLICATION WEIGHT (LBS)		MINI-TUG APPLICATION WEIGHT (LBS)
PROPULSION MODULE			
INERT WEIGHT	6,670		
PROPELLANT	78,946		
GROSS		85,610	---
INTELLIGENCE MODULE		3,440	3,440
CREW MODULE		--	9,500
MANIPULATOR MODULE		--	2,200
RCS PROPELLANT MODULE		--	1,460
TOTAL		89,050	16,460

• PROPULSION CHARACTERISTICS

ENGINE TYPE	RL10A-3-8A
NUMBER OF ENGINES	4
NOZZLE TYPE	2 POSITION
AREA RATIO	250/100
SPECIFIC IMPULSE	461/450 SEC
MAX THRUST (EACH)	23,400 LBS
FUEL	LH_2
OXIDIZER	LO_2

• DEVELOPMENT TIME - 9 YEARS FROM START OF PHASE C

• PERFORMANCE



SUMMARY

This section of the basic element summaries is structured to provide the key operational/design approaches recommended for incorporation in the TUG model as a direct result of the interfaces between the TUG and associated vehicles. These interfaces were identified and analyzed using fourteen interfacing activities as the interface drivers. The 14 activities listed and defined in Figure 3-2 include every type of interaction pertinent to this study that can occur between the TUG and the study inventory of earth orbital space elements.

Volume II, Part 2	
MATING The attachment in earth orbit of any two elements (or modules), including the operations of final closure prior to contact **ORBITAL ASSEMBLY** The joining together of two or more major parts to form a particular configuration of a single operational element in earth orbit, or to facilitate transport to lunar orbit or high-energy earth orbit **SEPARATION** The physical uncoupling of two mated elements and the subsequent maneuvers required to provide adequate clearance between elements	**EOS PAYLOAD DEPLOYMENT** The removal of a payload from the orbiter cargo bay and readying it for operation or separation **EOS PAYLOAD RETRACTION** The insertion of a payload into the orbiter cargo bay subsequent to initial mating of the payload to the orbiter
Volume II, Part 3	
COMMUNICATIONS The transmission of sound, video, and digital/analog data via space links from element-to-element and from element-to-ground **RENDEZVOUS** The operations required to achieve close proximity of one element to another for purposes of stationkeeping and/or mating	**STATIONKEEPING** The maintaining of a predetermined (not necessarily fixed) relative position between two orbiting elements **DETACHED ELEMENT OPERATIONS** The operational support required by a free-flying element from another element and/or ground control
Volume II, Part 4	
CREW TRANSFER The transfer of personnel between two elements in orbit **CARGO TRANSFER** The transfer of solid and fluid cargo between two elements in orbit **PROPELLANT TRANSFER** The transfer of large quantities of liquid hydrogen and liquid oxygen between elements in orbit	**ATTACHED ELEMENT OPERATIONS** Support by one element to another attached element while the latter is operating or being serviced, checked out, or stored **ATTACHED ELEMENT TRANSPORT** Support by a major propulsive element to an attached payload (element or module) during transport from one orbit to another

Figure 3-2. Interfacing Activity Definition

Three major topics were used to report the TUG related results of the interfacing activity analyses. These major topics are:

- o Element Inventory, Mission Models and Interactions
- o Recommended Operational/Design Approaches and Design Influences
- o System and Subsystem Functional Requirements

ELEMENT INVENTORY, MISSION MODELS AND INTERACTIONS

This subsection discusses all of the mission models that are applicable to the Space Tug, and all of the study elements with which the Space Tug interfaces with:

The TUG is involved in 9 of the 11 generic mission models identified and developed in the Mission Analyses Volume (Vol. I). Twenty-five elements were identified for potential interactions. The TUG-to-element interactions are as follows:

Ground Based TUG to

- o Earth Orbital Shuttle
- o Ground Based Tug
- o Space Based Tug
- o MSS Attached RAM
- o MSS Detached RAM
- o Satellite + 3rd Stage Delivery
- o Satellite Retrieval/Resupply
- o Earth Orbital Resupply Modules
- o Geosynchronous MSS

Space Based TUG to

- o Earth Orbital Shuttle
- o Ground Based Tug
- o Space Based Tug
- o MSS Attached RAM
- o MSS Detached RAM
- o Satellite + 3rd Stage Delivery
- o Satellite Retrieval/Resupply
- o Earth Orbital Resupply Modules
- o Geosynchronous MSS
- o Low Earth Orbital MSS
- o Orbital Insertion Stage

RECOMMENDED OPERATIONAL/DESIGN APPROACHES AND DESIGN INFLUENCES

Nine major recommendations were derived from a detail analysis of the 14 interfacing activities. Table 3-2 summarized these recommendations and provides reference to the specific activity that either drove or supported the recommendation. The rationale for and design influence on the total element inventory resulting from these recommendations is contained in paragraphs subsequent to this summary.

Table 3-2. Major TUG Recommendations

Major Recommendations	Hdw & Oper'l Considerations	Interfacing Activities
1. Direct Automated Dock to all Elements Except Small Satellites - Manual Backup for Contingency	• Common Mating Port • 100-400 ft-lb Atten. • ≤0.4 ft/sec Closing Velocity • Scanning Laser Radar • TV & Backup Aids	Mating Attached Elem Xport
2. Mate with Small Satellites using Adapter	• Extention/Retraction Device	Mating
3. Jet Translation for Separation from Mated Elements	• TUG Active • TUG Passive	Separation
4. Orbital Assembly to Payload Modules via EOS with Direct Dock Approach - Manipulator Assist where Reach is Practical	• Mating Ports at both Ends of all Modules • Manipulator Attach Points	Orbital Assembly
5. Specialized EOS Payload Retention for all TUG's	• Hinge or Clamp Device to Retain TUG	EOS P/L Deploy EOS P/L Retract
6. Crew/Cargo Transfer between TUG and MSS or EOS - Shirtsleeve Prime Mode - IVA Backup Mode	• 41 in. dia Clear Opening • • Manually Unaided Cargo Transfer	Crew Transfer Cargo Transfer Attached Elem Ops
7. Direct TUG-to-Element & Direct TUG-to-Ground Comm Links	• S-Band Equip & Omni • VHF Equip & Omni	Communications Detached Elem Ops
8. Autonomous Control for Stationkeeping of Manned TUG & Close Proximity Unmanned TUG - Ground Control of all TUG Rendezvous to within ≈50 nm for Normal Missions - Autonomous Control for Special "Fast Response" Unmanned Rendezvous	• Horiz Scanners & IMU • Star Trackers • Scanning Laser Radar • VHF & S-Band Equip & Omni Antennas • TV (for Inspection)	Rendezvous Stationkeeping Detached Elem Ops Communications
9. Transfer Large Quantity Propellants from Tank Mod via Fluid Transfer - EOS Stationkeeping during Operations	• Linear Acceleration provided by Tank Mod • Att Control provided by TUG	Propellant Transfer

SYSTEM AND SUBSYSTEM FUNCTIONAL REQUIREMENTS

This subsection identifies the pertinent quantitative and qualitative requirements that apply to the TUG during the operations associated with the 14 interfacing activities. These functional requirements are presented in quasi-spec format with reference to the specific activity(s) that generated the requirement.

Two distinct categories have been used to report the functional requirements as follows:

System Level - those functional requirements relating to the overall performance of the entire system, or by their nature they are involved in each subsystem (i.e., safety or general subsystem requirements). This section will also include requirements that form interfaces between subsystem.

Subsystem Level - those functional requirements that relate to one specific subsystem. Again as with the system level requirements, cross-reference will be made to the appropriate interfacing activity that initially defined the requirement.

ELEMENT INVENTORY, MISSION MODELS AND INTERACTIONS

This subsection identifies all of the mission models that are applicable to the Space Tug, and all of the elements with which the TUG has an interface with for each of the 14 interfacing activities.

ELEMENT.INVENTORY

Figure 2-3 shows a generic grouping the 25 study elements. The right hand column indicates the number of actual elements included in each of the categories.

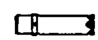
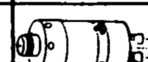
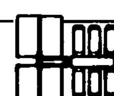
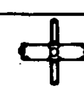
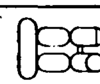
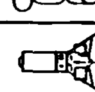
Earth orbital shuttle (EOS) - One element only, referred to throughout this report as EOS, orbiter and shuttle orbiter.		1
Interim tug - Various types of nonreusable nonreturnable, and nonreusable returnable kick stages such as Centaur, Agena, Titan Transtage, and Burner II.		2
Space tug - Reusable unmanned and manned ground-based tug, and unmanned and manned space-based tug.		2
Chemical propulsion stage (CPS) - The orbital insertion stage (mounted on the EOS booster at launch), the earth orbit-to-orbit shuttle, and the cislunar shuttle. The CPS can be modular or nonmodular, and single-stage or two-stage.		3
Reusable nuclear shuttle (RNS) - Both the earth orbit-to-orbit shuttle and the cislunar shuttle application. The RNS can be modular or nonmodular and is single-stage only.		1
Modular space station (MSS) - The low earth orbital station and the geosynchronous station.		2
Research and applications module (RAM) - Both attached and detached RAM's, supported by the EOS and by either of the two MSS's (see above).		4
Satellite - Satellites deliverable to orbit by the EOS and those requiring the EOS plus a third stage for delivery. Also included are satellites requiring retrieval and servicing.		3
Orbital propellant depot (OPD) - The low earth orbital propellant depot located in an orbit optimized to support the RNS or CPS and the space-based tug.		1
Earth orbital resupply module - Cargo and propellant modules for resupply of earth orbiting elements.		1
Orbiting lunar station (OLS) - Both the modular and nonmodular configurations (deliverable to lunar orbit by CPS or RNS).		1
Lunar surface base (LSB) - The modular base only (deliverable to lunar orbit by CPS or RNS).		1
Lunar landing tug (LLT) - Both the unmanned and manned tugs (deliverable to lunar orbit by CPS or RNS).		2
Lunar resupply module - Crew, cargo and propellant modules for delivery to lunar orbit by CPS or RNS.		1

Figure 3-3. Element Inventory

MISSION MODELS

In the Orbital Operations study a total of 11 mission models have been generated which encompass all of the mission events, element-to-element interfaces (element pairs), and interfacing activities which can occur in earth orbit. Each of the 11 mission models (refer to Volume I) consists of a sequence of mission events, with an identification of related interfacing elements for each event. The space-based tug can be involved in nine of the 11 missions, and the ground-based tug can be involved in six of the missions (see Table 3-3).

Three of the mission models (MM-4, -5, and -6) utilize the space-based tug as the primary propulsive vehicle. In MM-4 "Space-Based Tug Retrieval/ Emplacement Mission" the tug separates from the element at which it is based, retrieves a free-flying payload, delivers the payload to a major element for servicing or propellant transfer, returns the free-flying payload to the desired orbit, and then returns to its space base. In MM-5 "Space-Based Tug Logistics Mission" the tug separates from its space base, picks up a payload from a major orbiting element, transports the payload to another major element, then returns to its space base. In MM-6 "Space-Based Tug Disposal Mission" the tug separates from its space base, flies to and mates with the element to be disposed of (such as non-modular RNS or CPS), performs a retrograde maneuver, separates from the element (which continues on an earth intersecting trajectory), performs a posigrade maneuver, then returns to its space base.

In addition to the above three missions, the space-based tug has a potential involvement in six of the remaining eight missions; i.e., MM-1, -2, -8, -9, -10, and -11. In MM-1 "EOS Emplacement Mission" the EOS orbiter can perform the initial delivery of the tug to orbit. In MM-2 "EOS Logistics/ Retrieval Mission" the EOS orbiter can deliver a payload to the tug in orbit, or can retrieve a tug and return it to earth. In MM-8 "Ground-Based Tug Logistics/Retrieval Mission" the ground-based tug could be a tanker which is delivered to orbit by the EOS orbiter. In this application the tanker could then fly to a space-based tug, transfer propellant to the latter vehicle (by fluid transfer), then return to the orbiter. In MM-9 "Orbital Insertion Stage Delivery Mission" the OIS (used as a second stage on the EOS booster) can deliver a large payload (too large for EOS orbiter delivery) to a space-based tug. In MM-10 "Staged Geosynchronous/Cislunar Shuttle Logistics Mission" and MM-11 "Non-Staged Geosynchronous/Cislunar Logistics Mission" the cislunar shuttle can pick up a payload from the space-based tug for delivery to lunar orbit. The cislunar shuttle can also be refueled from a tug tanker or from a tug-delivered propellant module. Also in MM-10 the tug can be used to remate stages of a two-stage cislunar shuttle.

Table 3-3. Mission Model, Interfacing Activity, and Element Inter-relationships with Tugs

Interfacing Element	Interfacing Activity														Mission Model										
GROUND-BASED TUG to ↓	Mating	Orbital Assy	Separation	Cargo Transfer	Crew Transfer	Propel. Transfer	EOS Payload Deployment	EOS Payload Retr. & Stowage	Communications	Rendezvous	Stationkeeping	Attached Elem. Operations	Detached Elem. Operations	Attached Elem. Transport	EOS Emplacement	EOS Logis/Retriev.	EOS Sortie	SB Tug Retr/Emplace.	SB Tug Logistics	SB Tug Disposal	Grd-Based Tug Emplace/Sortie	Grd-Based Tug Logis/Retriev.	OIS Delivery	CLS Staged Logistics	CLS Nonstaged Logistics
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11
EOS	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓			✓		✓	✓		✓	✓
GB TUG	✓		✓	✓	✓				✓	✓	✓		✓	✓								✓			
SB TUG	✓		✓	✓	✓	✓			✓	✓	✓	✓	✓	✓					✓			✓			
MSS ARAM	✓		✓						✓					✓							✓	✓			
MSS DRAM	✓		✓						✓		✓	✓	✓	✓							✓	✓			
Sat, 3rd St			✓									✓		✓							✓				
Sat, Retr.	✓		✓	✓					✓	✓	✓	✓	✓	✓							✓	✓			
EO Resup Mod	✓		✓	✓	✓							✓		✓							✓	✓			
Geo MSS	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓							✓	✓			

Table 3-3. Mission Model, Interfacing Activity, and Element Inter-relationship with Tug (Cont.)

Interfacing Element	Interfacing Activity														Mission Model										
SPACE-BASED TUG to	Mating	Orbital Assy	Separation	Cargo Transfer	Crew Transfer	Propel. Transfer	EOS Payload Deployment	EOS Payload Retr. & Stowage	Communications	Rendezvous	Stationkeeping	Attached Elem. Operations	Detached Elem. Operations	Attached Elem. Transport	EOS Emplacement	EOS Logis/Retriev.	EOS Sortie	SB Tug Retr/Emplace.	SB Tug Logistics	SB Tug Disposal	Grd-Based Tug Emplace/Sortie	Grd-Based Tug Logis/Retriev.	OIS Delivery	CLS Staged Logistics	CLS Nonstaged Logistics
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11
EPS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓			✓		✓	✓
G.B. TUG	✓		✓	✓	✓	✓				✓	✓	✓	✓	✓					✓			✓			
S.B. TUG	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓		✓		✓	✓					✓	✓
MSS ARAM	✓	✓	✓						✓					✓		✓			✓					✓	✓
MSS DRAM	✓	✓	✓						✓	✓	✓	✓	✓	✓		✓		✓	✓					✓	✓
SAT. 3RD ST.	✓		✓									✓		✓		✓		✓	✓					✓	✓
SAT, RETR.	✓		✓	✓					✓	✓	✓	✓	✓	✓		✓		✓	✓					✓	✓
EO RESUP. MOD.	✓	✓	✓	✓	✓	✓						✓		✓		✓			✓			✓		✓	✓
LO EO MSS	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓		✓		✓	✓	✓					
GEO MSS	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓				✓	✓	✓					✓
OIS	✓		✓						✓	✓	✓		✓	✓				✓	✓	✓			✓		

Two of the mission models (MM-7 and MM-8) utilize the ground-based tug as the primary propulsive vehicle. In MM-7 "Ground-Based Tug Emplacement/ Sortie Mission" the tug (which is delivered to orbit in the EOS orbiter with payload attached) transports a payload to a high energy orbit, where the payload is either emplaced in space or remains attached to the tug for experiment operations. The tug then returns to the EOS orbiter with or without a payload, followed by return to earth. In MM-8 "Ground-Based Tug Logistics/Retrieval Mission" the tug (as in MM-7) is delivered to orbit with an attached payload in the orbiter cargo bay. However, in this mission the tug can deliver a payload to another element in a high energy orbit and/or pick-up a payload from this element. Also the tug can retrieve a free-flying payload and return it to the orbiter for subsequent return to earth.

In addition to the above two missions, the ground-based tug has a potential involvement in three of the remaining nine missions; i.e., MM-2, -10, and -11. In MM-2 "EOS Logistics/Retrieval Mission" the ground-based tug can be retrieved by the EOS orbiter and returned to earth. In MM-10 "Staged Geosynchronous/Cislunar Shuttle Logistics Mission" and MM-11 "Non-Staged Geosynchronous/Cislunar Logistics Mission" the ground-based tug can be a tanker for refueling of the cislunar shuttle or it can be a vehicle for transporting a payload (including a propellant module) to a cislunar shuttle from the EOS orbiter.

ELEMENT INTERACTIONS

The methodical in-depth approach used in the generation of the mission models (see Section 1.0 of Volume I) made possible the identification of all potential element-to-element interfaces (i.e., element pairs) and all interfacing activities that can occur between elements in earth orbit. A summary of the total list of orbital elements considered in this study was presented in Figure 3-3. Those elements with which the ground-based and space-based tugs may interface are listed in Figure 3-2. Those interfacing activities which may occur between the tugs and these other elements are also identified in Table 3-3.

It has been determined in this study that the baseline EOS orbiter is capable of interfacing directly with those elements which are in earth parking orbits below approximately 300 nautical miles altitude and at orbital inclinations of 28.5 to 31.5 degrees (refer to paragraph 3.3, Part 4 of Volume II for a detailed discussion and rationale for this conclusion). This is accomplished by using the EOS orbiter OMS abort propellant to increase the on-orbit delta velocity capability. Hence there is no requirement at this time for the tug to serve as an intermediate transport vehicle between the orbiter and the CPS or RNS, or the lunar program systems which are delivered to lunar orbit by the CPS or RNS. The space-based (S.B.) tug may interface with another S.B. tug for rescue purposes, payload transfer, or for propellant transfer. The S.B. tug may also interface with RAM's satellites, cargo modules, and MSS modules in connection with payload delivery from the EOS orbiter to higher energy orbits. The S.B. tug interfaces with the OIS for the purpose of transporting the OIS payload from low earth orbit to its ultimate destination.

The primary role of the unmanned ground-based (G.B.) tug is to transport payloads from the EOS orbiter to higher energy orbits for emplacement in space (emplacement as distinguished from delivery to another element). Transport of a payload by an unmanned tug to a low earth orbit MSS is not considered a viable delivery mode. Hence the unmanned G.B. tug's primary interfaces are with the various satellites (in high energy orbits) for emplacement, retrieval, and resupply purposes. In the event that there should be a manned G.B. tug there would be additional interfaces with both of the manned MSS's, and with MSS related RAM's and resupply modules. In addition one tug can interface with another tug for crew rescue (if both tugs are manned) or for vehicle rescue only. Additional discussion of interfacing elements is included in the previous section on mission models.

RECOMMENDED OPERATIONAL/DESIGN APPROACHES AND DESIGN INFLUENCES

Several major operational/design approaches for the tug were synthesized from the detail analyses conducted for each of the 14 separate interfacing activities. These major recommendations are illustrated by Figure 3-4. The nine recommendations highlighted on the figure are amplified in subsequent paragraphs.

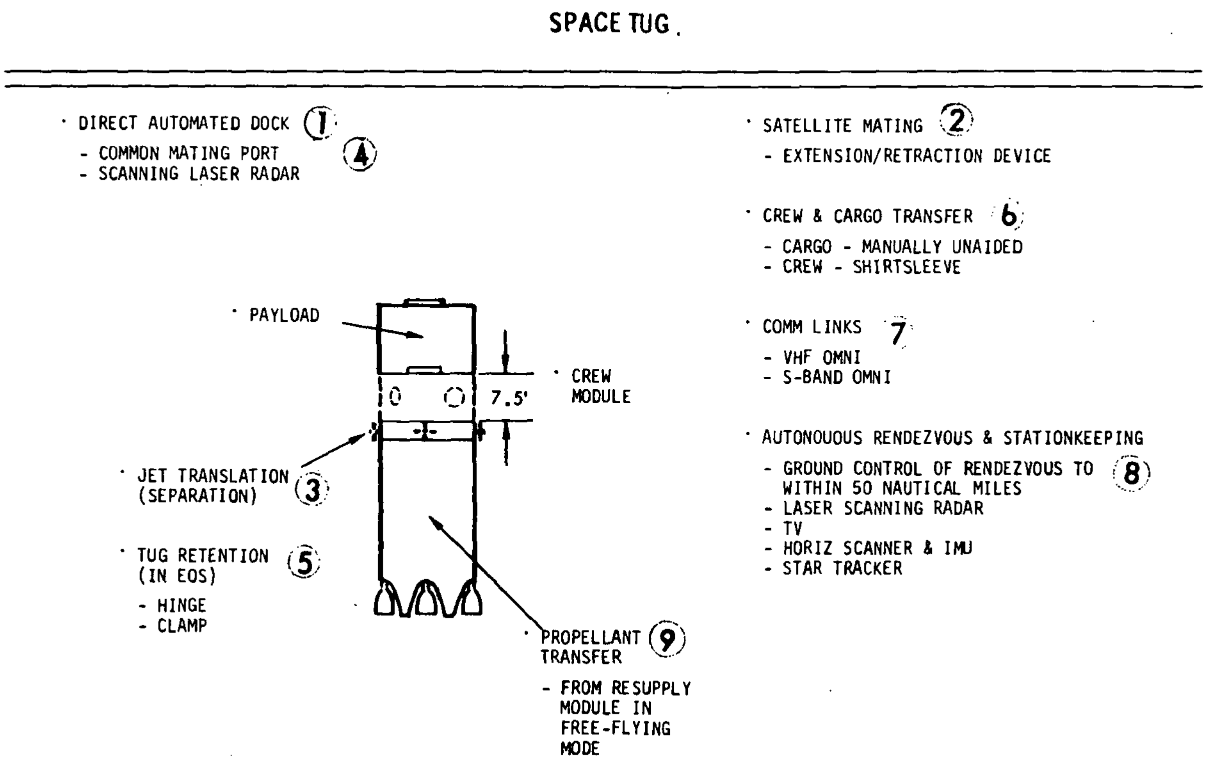


Figure 3-4. Major Tug Recommendations

DIRECT AUTOMATED DOCK (1)

A fully automated direct dock approach is recommended for both manned and unmanned TUG mating to all elements except small satellites. In conjunction, a manual direct dock capability (manned TUG) is mandatory for contingency purposes.

Selection Considerations

The Mating and Orbital Assembly interfacing activities each considered two generic approaches to mating:

1) Direct Dock (automatic and manual)

2) Manipulator Berth (manual only)

Ten separate comparison factors were considered:

- Technology
- Checkout and Maintenance
- Safety
- Reliability
- Commonality
- Relative Cost
- Operational/Design Complexity
- Subsystem Interface
- Near Term Bias
- Far Term Bias

An overall evaluation of these comparison factors tends to favor 1) Direct Dock over 2) Manipulator for manned TUG matings. Also an automated direct dock approach must be developed for the mating of unmanned elements, therefore the automated approach is recommended for commonality across all element pairs.

The manual direct dock approach must also be provided because 1) crew safety dictates manual override and 2) mission success criteria favors a manual backup mode to increase the probability of success.

(1) Refer to Table 3-2 and Figure 3-4

TUG Design/Operational Influences

An automated direct dock approach with a manual backup mode requires the following be incorporated as part of the basic TUG design:

- Common Mating Port. Active attenuation in the 100-400 ft-lb range with closing velocity held to ≤ 0.4 ft/sec.
- Scanning Laser Radar Transceiver. Provides range, range rate and angular misalignments.
- Passive Laser Reflectors. Enables TUG to be passive during matings (i.e., EOS to TUG matings).
- Direct Visual Scope. Required for manual backup mode.
- Visual Alignment Target. Required for backup mode.
- TV Camera. Required for visual inspection and backup to direct visual.

Design/Operational Influences on Interfacing Elements

The TUG can be either the active or passive vehicle during automated direct dockings. All elements that mate with the TUG are required to have passive laser reflectors.

The following matrix represents the recommended mating hardware for the major elements:

Hardware	EOS	RAM	MSS	CPS	RNS
. Common Mating Port	Active	Passive	Passive	Active	Active
. SCR Transceiver	Yes	No	Yes	Yes	Yes
. Passive Laser Reflectors	Yes	Yes	Yes	Yes	Yes
. Visual Alignment Targets	Yes	Yes	Yes	Yes	Yes
. TV Camera	Yes	No	Yes	Yes	Yes

TUG MATING TO SMALL SATELLITES (2)

An "adapter" added to the standard TUG docking port is recommended for TUG mating to small satellites.

This adapter can be an extention/retraction probe device used as a kit installation to the standardized docking port.

Selection Considerations

It would be impractical to penalize small satellites with a docking concept that could represent a major portion of the total vehicle weight.

The Mating interfacing activity considered three generic approaches for satellite matings:

1) Extention/Retraction

2) Multi-degree of freedom manipulator

3) Direct Docking

The extention/retraction approach (No. 1) was preferred primarily due to the small impact to the design of satellites.

The multi-degree of freedom (mdf) manipulator approach was not selected primarily because the capability of the approach was far in excess of the requirements of the mating of a TUG and satellites. The mdf manipulator also had the undesireable features of high cost, and inaccessibility for maintenance on a complex system. It was also the highest cost of the three alternates evaluated.

The direct dock approach was rejected primarily for its impact on the design of the satellites. Direct dock would require that the satellites have two mating ports. One for the EOS interface, the other for the TUG interface. This additional weight penalty (≈700 pounds) would be restrictive for satellite TUG combinations with geosynchronous orbit requirements.

(2) Refer to Table 3-2 and Figure 3-4

TUG Design/Operational Influences

The selection of the extension/retraction probe device for use by the TUG when mating to small satellites has a minimum design or operational impact. It can be installed as a kit to a standard docking port. This device would weigh approximately the same as the attenuation mechanisms it would replace. Thus the net effect on the TUG is minimized while the desirable effects for the small satellites are retained.

Design/Operational Influences on Interfacing Elements

To be compatible with the extension/retraction probe device the satellites must be equipped with a receptical compatible with the end effector on the probe.

JET TRANSLATION SEPARATION (3)

The preferred mode of TUG separation from mated elements is via mass expulsion of RCS engines. The TUG and selected TUG mated elements must be capable of this separation maneuver. Dependent upon operational considerations the TUG may be either active or passive during the separation.

Selection Considerations

Two generic approaches for separation were considered in the Separation interfacing activity:

1) Jet translation (manual or automatic modes)

2) Manipulator extension (manual or automatic modes)

Nine comparison factors were considered in making a selection. These factors are as follows:

- Technology
- Checkout & Maintenance
- Plume Impingement
- Safety
- Reliability
- Relative Cost
- Commonality
- Near Term Bias
- Far Term Bias

An evaluation of the factors showed that both approaches are adequate in either manual or automatic modes. However both approaches offer significant advantages.

1) Jet translation is significantly lower in cost because at least one of the two mated elements will be equipped with a translation capability.

2) Manipulator extension appears to offer a more safe operation in that the elements can be physically separated some distance prior to independent operations.

Jet translation is the recommended approach for all separation operations as it requires little or no additional hardware than is already included in the elements; it has been demonstrated to be safe; and it can be utilized for all element pairs in the study inventory.

(3) Refer to Table 3-2 and Figure 3-4

TUG Design/Operational Influences

The jet translation separation approach does not impose any additional hardware to the TUG model used during this study. However, a reliable means must be provided to assure that any stored energy that can impart a noticeable thrust to one of the separating elements has been released prior to the jet translation maneuver. Examples of this stored energy are:

- compressed docking attenuation struts
- crew/cargo transfer tunnel pressurization
- spring type capture latches

Design/Operational Influences on Interfacing Elements

Elements will at times be exposed to jet plume contaminations prior to mating, while attached to the TUG, and during the separation maneuver. Elements sensitive to this contamination will be required to provide suitable protection. An operational option is to have the sensitive element perform the translation with the TUG engines inhibited.

The only identified critical alignment separation is for the MSS where a RAM to be separated is adjacent to a station module. A laser radar guidance concept is recommended for this operation.

ORBITAL ASSEMBLY OF TUG AND PAYLOAD MODULES (4)

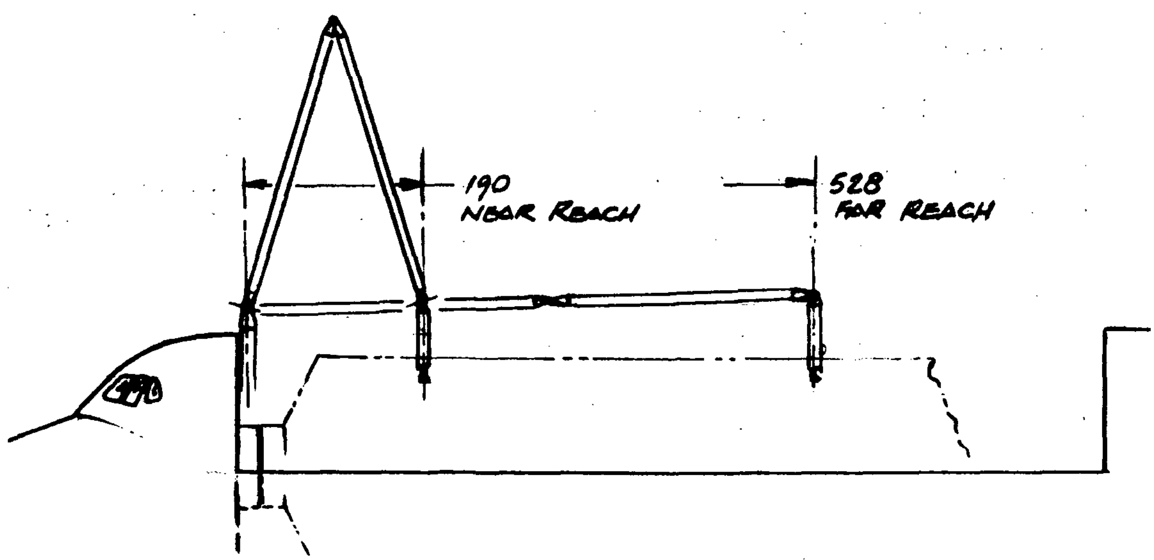
The selected concept for the orbital assembly of payload modules to a Tug is the direct dock approach. However, when the length of the tug and payload are within the reach capability of the EOS manipulator it will be used to assist in the assembly.

Selection Considerations

The Orbital Assembly Interfacing Activity considered: 1) direct dock and, 2) manipulator berth for the attachment of TUGS to EOS payloads. The primary constraints considered in the comparison of the two approaches are:

Direct Dock	Manipulator Berth
. Alignment tolerance	. Reach criteria
. Appendage clearance	. Module length
	. End effector location

An evaluation of these factors shows that, except for those payload/tug combinations that are longer than the manipulator reach capability (see sketch below), both approaches are adequate and no clear cut operational preference can be established for either approach. The far reach capability of the manipulator is 528 inches (44 ft). Any TUG/payload approaching this



length will have to be designed for the direct dock mode (mating ports at both ends). These longer payloads can utilize the manipulator for deployment out of the cargo bay, but the mating to the tug will be by the direct dock mode. The smaller payloads will utilize the manipulator assist both for deployment and orbital assembly.

(4) Refer to Table 3-2 and Figure 3-4

Tug Design/Operational Influences

The decision to use both a direct dock mode and an EOS manipulator assist when possible has the following design and operational influences on the TUG:

- Common mating port - with active attenuation in the 100-400 ft-lb range with closing velocity held to ≤ 0.4 ft/sec.
- Scanning Laser Radar transceiver. (For range, range rate and angular misalignment).
- Passive Laser Reflectors. To be utilized in a contingency mode if the TUG were required to be the passive element in a mating.
- Visual Alignment target - required for backup mode.
- TV Camera - required for visual inspection and for backup ground control of mating.
- Manipulator End effector receptacle to be utilized during a manipulator assisted orbital assembly.

Design/Operational Influences on Interfacing Elements

The elements that interface with the TUG will have the following hardware/operational influences:

- Direct dock mode-mating ports at both ends of modules
- Manipulator assist mode-manipulator end effector receptacles, mating port at one end of module can be eliminated if not required for other operational activities.
- EOS provide a common mating capable of accepting a module and the docking loads of a direct dock

TUG/EOS RETENTION CONCEPT (5)

The recommended approach for TUG/EOS retention is the utilization of either a rotating hinge mechanism or a large clamp device. The selection of one of these two concepts is dependent on the final TUG tank design.

Selection Considerations

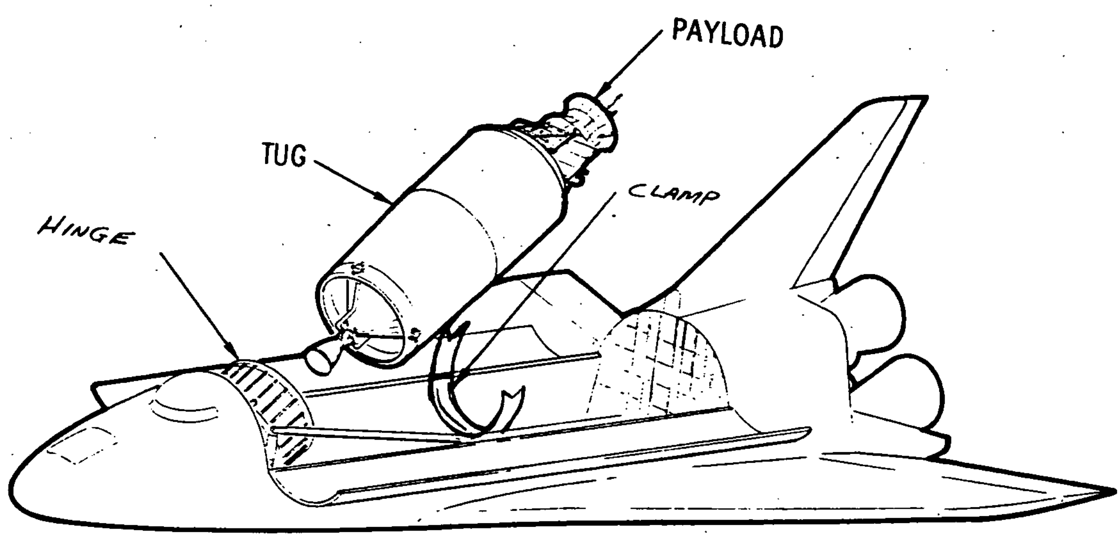
The EOS Payload Deployment and Retraction/Stowage interfacing activities considered three approaches for prossible selection as the TUG retention concept:

1) EOS 3 and 4 point trunnion retention concept
2) A rotating hinge mechanism
3) A large clamp device

If the baseline EOS/Payload retention (3 point) concept were selected for TUG use the penalty would be significant. First there would be a 200 pound penalty to the TUG structure, secondly there would be a 1000 pound payload penalty for an adapter that would tie the TUG trunnion to the EOS retention locations. The 8:1 mass ratio target for TUG design means a 200 pound structural penalty equates to an 1600 pound reduction in equivalent TUG payload capability. (See Volume II, Part 2, Section 4.0 Payload Deployment)

Utilizing the selected EOS 4 point coplaner concept would reduce both of these penalties in half. The resulting figures are still unacceptable. Therefore, attempts were made to incorporate payload retention concepts that would significantly reduce or eliminate the penalty to the TUG structure.

Two alternate concepts 1) hinge and 2) clamp are illustrated in the sketch. These mechanisms will accomplish TUG retention with a minimum weight penalty.



(5) Refer to Table 3-2 and Figure 3-4

TUG Design/Operational Influences

The selection of either 1) rotating hinge or 2) clamp for TUG retention in the EOS cargo bay is greatly influenced by the main propulsion LOX tank location as follows:

LOX Tank Location	Retention Concept	
	Clamp	Hinge
Aft	1) X	2) Preferred
Forward	3) Preferred	4) X

1) Aft LOX Tank and Clamp Mechanism. Not selected due to unfavorable dynamic response created by large cg to retention location moment arm.

2) Aft LOX Tank and Hinge Mechanism. Preferred because the rotating hinge mechanism is located close to combined TUG/Payload cg thereby reacting the principal ±X axis loads. The ±Y and ±Z axis loads can be reacted using the universal retentions.

3) Forward LOX Tank and Clamp Mechanism. Minimizes the dynamic response by locating the retention device on the LOX tank support. The resultant loads are reacted near the cg and using an existing structural member.

4) Forward LOX Tank & Hinge Mechanism. Not selected primarily due to the large separation between retention device and TUG/Payload cg.

The selection between items 2) and 3) will be determined in the current DOD Upper Stage/Shuttle System study.

CREW/CARGO TRANSFER TO EOS PAYLOAD (6)

This study identified the necessity to ingress/ingress the TUG while in the EOS cargo bay, in the deployed position and attached to the MSS. Shirt-sleeve trousers is the preferred mode for the manned TUG, however, IVA provisions are recommended for use with unmanned TUG.

Selection Considerations

The Crew Transfer and Cargo Transfer interfacing activities each considered three generic methods for crew/cargo transfer as follows:

Method	Approaches	
	Crew Transfer	Cargo Transfer
EVA	1) No	1a) Manual unaided
IVA	2) Yes	2a) Manual unaided
Shirtsleeve	3) Yes	3a) Manual unaided 3b) Manual aided 3c) Automated

Shirtsleeve crew transfer (approach 3) was selected for the manned TUG. This selection benefits the TUG by the ease of crew movement offered by the shirtsleeve transfer.

Manually unaided cargo transfer in a shirtsleeve environment (approach 3a) was selected for the transfer of cargo items due to the infrequency of the transfer operations.

The IVA method (approach 2 and 2a) is recommended as a backup for the shirtsleeve mode of crew transfer and manually unaided cargo transfer. Two IVA alternatives were considered:

- Depressurize TUG cabin
- Provide an airlock

The addition of an airlock is not recommended for the manned TUG due to the infrequent operations and relative ease of cabin depressurization.

This IVA backup will benefit some payloads that cannot accept the design penalties associated with a shirtsleeve environment.

EVA crew and/or cargo transfer was not selected as all interfacing elements can be accommodated by either shirtsleeve or IVA transfer.

(6) Refer to Table 3-2 and Figure 3-4

Design/Operational Influences

The selection of shirtsleeve and IVA crew/cargo transfer between the TUG and the EOS/MSS creates the following design influences:

- Flexible tunnel - required for payload entry with the EOS pivot mechanism in both the stowed and deployed positions.
- 41 inch diameter clear opening - Although large cargo items are not carried in the TUG crew compartment; the 41 inch diameter hatch is derived from a commonality analysis across all elements.
- Establish, monitor, and maintain a habitable environment for shirtsleeve activities.
- Pressure suits and related provisions for use with IVA.
- EOS and MSS airlock - required for entry into an unmanned TUG.

COMMUNICATION LINKS (7)

Operation in two radio frequency bands, S-band and VHF, is recommended for all TUG communications to ground or to other space elements. S-band equipment compatible with both the communication and ranging signals of the NASA ground network is recommended. VHF can be used for low data rate and voice communication to ground via TDRS to provide greater than 90 percent orbital contact continuity.

When necessary, VHF can be used as a back-up link to other elements. Both S-band and VHF TUG terminals can adequately support the link criteria with omni-directional antennas.

Selection Considerations

Three approaches were considered for both communications and detached element operations interfacing activities as follows:

1. Element to element
2. Element to ground via TDRS
3. Element to ground direct

Considerations of equipment commonality - with ground network systems and other element systems, continuity of communications contact and reliability were the major dirvers that result in the recommendation to utilize all three approaches for the communications interfacing activity.

Element to element and element to ground links are necessary for mission operations. Provision for element to ground via TDRS as well as to ground direct provides backup for emergency purposes as well as continuity of contact when the TUG is out of radio contact with any ground station.

(7) Refer to Table 3-2 and Figure 3-4

TUG Design/Operational Influence

Implementation of all three approaches requires that the TUG provide the following to meet the approach requirements:

1. An S-band transponder compatible with ground network characteristics and with the following capabilities.

    a. An omni-directional antenna system that provides radio link coverage to ground or other elements without requiring specific EOS attitude.

    b. A 30-watt transmitter in S-band capable of transmitting up to 51.2 K bps digital data, a single voice channel and turn-around PRN ranging signals to ground or other elements.

    c. An S-band receiver with an 800 degree K input system noise temperature capable of receiving and demodulating up to 10 K bps digital data, a single voice channel and PRN ranging signals from ground or other elements.

2. A VHF transponder compatible with TDRS and other element characteristics and with the following capabilities:

    a. An omni-directional antenna system that provides radio link coverage to TDRS or other elements without requiring specific EOS attitude.

    b. A 25-watt transmitter in the VHF band capable of transmitting up to 10 K bps digital data and a single voice channel.

    c. A VHF receiver with an 1200 degree K input system noise temperature capable of receiving and demodulating up to 1 K bps digital data and a single voice channel.

Design/Operation Influences on Interfacing Elements

The TUG can be either a controlling or controlled vehicle and must have the capability to transmit and receive TT&C signals to and from other elements and ground. All interfacing elements, i.e., EOS, RAM, MSS, CPS, RNS, OPD and satellites should have as a minimum, complementary S-band hardware. This would be similar to that described under (1) above. VHF capability is not a necessity on the interfacing elements, but if implemented it would provide an emergency backup link.

AUTONOMOUS CONTROL FOR RENDEZVOUS AND STATIONKEEPING (8)

A fully autonomous Rendezvous and Stationkeeping capability is recommended for these TUG operations when manned TUG separation from its target vehicle is less than approximately 50 n miles.

The manned TUG should be capable of performing the control of target elements and all necessary communications, target tracking and ranging, self-navigation and flight control to proceed with Rendezvous and Stationkeeping operations with the accuracy needed for a safe and successful mission.

When an unmanned TUG is operating with a manned element, it shall be cooperative with the manned element so it can be controlled as the target vehicle.

Selection Consideration

Rendezvous, Stationkeeping and Detached Element Operations interfacing activities supported by the Communications activity considered three basic alternate approaches for control, as follows:

1. Autonomous or independent
2. Ground control
3. Space control

All TUG's should utilize the autonomous control mode for rendezvous and/or stationkeeping when operating at close range because of potential communication gaps with the control centers. These gaps and the non-dedicated communication links have accuracies that are unacceptable at relative ranges or less than 1 n.mi.

Emergency operations are available, if necessary, by utilizing ground/TUG communication links. The autonomous mode, however, provides TUG-to-element continuous contact during these maneuvers.

For long range operations, ground control is performed because of the potential hardware complement required or orbital elements. In almost all cases it is feasible to schedule communication links with remote control centers. The sensitivity to communication gaps is reduced for long range operations.

Space control (No. 3) from another vehicle could not in any case provide the accuracy of tracking and ranging necessary to assure safety and mission success at separation of ranges less than 50 nautical miles.

(8) Refer to Table 3-2 and Figure 3-4

Design/Operational Influence

Operation in an autonomous control mode requires that the manned TUG and its interfacing element provides the following to meet the autonomous control requirements:

		TUG	Interfacing Element EOS, RAM, MSS, CPS, RNS
1.	For separation distances >50 n miles S-band PRN Ranging equipment	Measure	Transpond
2.	For separation distances <50 n miles Scanning laser Radar	Active SLR to Measure	Passive Optical Reflectors
3.	Communication link at S-band or VHF to provide TUG to target command operation and to provide target to TUG vehicle status as well as command verification.	S-band or VHF Transmitter and Receiver with Omni directional antenna	S-band or VHF Transmitter and Receiver with Omni directional antenna
4.	A TV camera for inspection purposes.	Under EOS pilot control.	Not Applicable
5.	An attitude reference with an accuracy of $\pm$ 0.5 degree	Yes	Yes
6.	An attitude control capable of $\pm$ 0.5 degree stabilization	Yes	Yes
7.	Delta-V maneuver capability	Yes	For orbital makeup only.
8.	Onboard computation capability	Yes for total mission operation	For attitude determination and control only

PROPELLANT TRANSFER (9)

In orbit refueling of cryogenic propellants by direct fluid transfer from a mated logistic tank module is recommended for TUG propellant transfer operations. Linear acceleration (provided by logistic tank) is the preferred approach for propellant settling.

The gross sequence of events is as follows:

(a) EOS delivery of loaded propellant logistic tank to orbit
(b) EOS deployment of logistic tank
(c) Direct dock of logistic tank and TUG
(d) Separation of EOS and mated logistic tank/TUG
(e)* Linear acceleration and fluid transfer to TUG provided by logistic tank module (EOS stationkeeping)
(f) EOS redock to logistic tank and mated TUG
(g) Separation of TUG from EOS and mated logistic tank
(h) EOS retraction and stowage of logistic tank in cargo bay
(i) EOS deorbit and earth return with empty logistic tank

Selection Considerations

The Propellant Transfer interfacing activity considered three alternate approaches for EOS delivery of large quantity propellants to the user vehicles as follows:

1) Orbiter stowed tank - (linear and rotational acceleration)
2) Orbiter deployed tank - (linear and rotational acceleration)
3) Orbiter separated tank - (linear acceleration only)

Approach 3) orbiter separated tank was selected for the following reasons:

- Enables a common EOS operational procedure
- Minimizes design/operational impacts on EOS
- Increased mission planning flexibility by having the EOS available during fluid transfer operation
- Minimizes quantity of propellant required to provide acceleration for liquid vapor interface control

*Capillary transfer concepts are currently being studied but as yet must be considered an advanced technology item.

(9) Refer to Table 3-2 and Figure 3-4

TUG Design/Operational Influences

The selection of direct fluid transfer from a mated logistic tank module creates the following design influences on the TUG:

- Provide compatible mating port
- Provide propellant transfer line interconnects
- Provide electrical power interconnects
- Provide for the monitor of hazardous conditions
- Provide command and control of linear acceleration jets on logistic tank module
- Provide attitude control during propellant transfer
- Provide control and monitoring of propellant transfer operations

Design/Operational Influences on Interfacing Elements

The selection of a separate logistic tank module for EOS delivery of large quantity propellants to the user vehicles creates the following influences on the EOS:

- Different logistic tank module lengths for TUG, CPS and RNS resupply requiring multiple attachment points in cargo bay
- Provide the following interconnects with logistics tank(s)
    - Electrical including power, command and control, and hazard monitoring
    - Insulation purge and pressurization (helium)
    - Propellant vent and dump

TUG FUNCTIONAL REQUIREMENTS

The vehicle functional requirements for the space-based and ground-based tugs were developed from the functional requirements defined for each of the 14 interfacing activities. This subsection will contain the requirements that relate principally to the tug and are necessary for performing the interfacing activities. Along with the functional requirement there will be a cross-reference made to the interfacing activity that established the requirement. There are eight categories of functional requirements. The initial category contains the system level (i.e., those that apply to more than one subsystem or relate to the performance of the entire system as a whole) functional requirements. The remaining seven categories contain the functional requirements by subsystem, again with references to the appropriate interfacing activity where the requirement was established.

A separate numerical designator has been established for each of the eight functional requirement categories as follows:

Category	Designator
Tug System	1-X
Structures/Mechanical Subsystem	2-X
Environmental Control Subsystem	3-X
Electrical Power Subsystem	4-X
Guidance and Control Subsystem	5-X
Propulsion Subsystem	6-X
Communication/Data Management Subsystem	7-X
Crew/Habitability Subsystem	8-X

SYSTEM FUNCTIONAL REQUIREMENTS

1-1. Alignment aids shall provide relative positional information between the tug and mating elements. The information provided shall be centerline miss distance and angular misalignment.

Accuracy shall be as follows:

automatic systems, such as laser radar:
+/-1 degree

direct visual systems: knowledge to identify when the vehicles are off aligned with the mating port centerlines greater than 3 degrees. Mating (5)

1-2. Residual attitude misalignments remaining after capture shall be corrected by the active vehicle prior to rigidizing. Mating (16)

1-3. The mating interfaces shall be drawn together by the TUG mating devices to remove residual attenuation stroke and seat the interfaces. The rate at which the vehicles are drawn together must be controlled to within the structural capability of the docking ports. Mating (17)

1-4. Propulsive venting (other than attitude control devices) shall be inhibited or controlled during the mating and separation operations. Mating (19), Separation (12), (see Attached Element Operations - 9).

1-5. Throughout mated operations, the mated element shall be capable of being separated upon command. This requirement naturally applies only after the interface between the elements has been properly isolated/sealed for safe separation or before the interface hatches have been opened. Mating (25), (see Separation - 14).

a. Once separation occurs, one or both of the elements shall maneuver to a safe distance prior to resuming operations. A minimum safe distance can be determined by computing a passive vehicle worst trajectory assuming jet "stuck-on" failure giving both translation and rotation. A minimum time to a safe distance during jettison shall be established by "hardover" rotational control system failure of either vehicle. Separation (4)

b. The separation hardware shall be capable of being inhibited after mating operations are secure and before the interface hatches are opened.

1-6. Throughout a docking or separation maneuver the control systems of both vehicles shall be monitored for indications of control failures such as reaction jet "stuck-on" and "stuck-off" conditions. Mating (26), Separation (5).

1-7. Prior to activation of fluid interfaces, seal integrity should be verified. Deviation is not permitted where liquids or hazardous gases are involved. For non-hazardous gases, the lines shall be activated individually with the interface integrity verified prior to activation of the next line. Mating (29), Orbital Assembly (16)

1-8. Interface assemblies that contain plugs, receptacles, and couplings shall be equipped with compatible guides such that alignment will be achieved prior to engagement of the connectors. Individual connectors and fluid couplings shall be provided with independent mechanical guides such that alignment is achieved prior to engagement of connector pins of fluid coupling interface seals. Mating (30), Orbital Assembly (23), Propellant Transfer (5)

1-9. Extension and connection of automatic utility interface connectors and couplings shall be delayed until after the mating rigidizing mechanism has engaged and locked up. Mating (31), Orbital Assembly (17)

1-10. Manual interface connections shall be located, designed, and mounted such that a worker can mate the connectors in a pressurized IVA suit. Mating (32), Cargo Transfer (34)

1-11. Manual interconnects shall be located to permit visual inspection of the connection. Where possible, provision shall be made to permit inspection of automatic couplings. Mating (33), Orbital Assembly (22)

1-12. Electrical cables and fluid lines that traverse crew and cargo passages shall be suitably enclosed or otherwise protected to minimize hazards to the crew and provide protection for the hardware. Mating (39), Orbital Assembly (24)

1-13. A credible accident to, or a credible failure of an interface function or adjacent function shall not cause the loss of redundantly provided functions or compound the accident or failure by creating additional hazards (explosion, fire). In this sense, the following criteria apply: Mating (37), Orbital Assembly (28), Cargo Transfer (31, 32)

a. Hazardous fluid lines shall be barriered or physically enclosed from power wires and each other (O_2 lines shall be considered hazardous in interface areas). Propellant Transfer (6)

b. Redundant fluid lines and connectors shall be separated a minimum of 45 degrees.

1-14. The interface between mated elements must be designed to be closed and sealed without performing a prolonged demating of interface connectors. Mating (39), Attached Element Operations (18).

1-15. For a jet translation separation where alignment is critical and alignment aids are utilized, the alignment aids must be active and aligned before separating. Separation (3)

1-16. The separation technique shall be such that no damage will occur to the mating ports such that succeeding matings and separations cannot occur. The mating ports shall be left in condition ready for a subsequent mate, unless remote control configuring of the mating port is available. Separation (13)

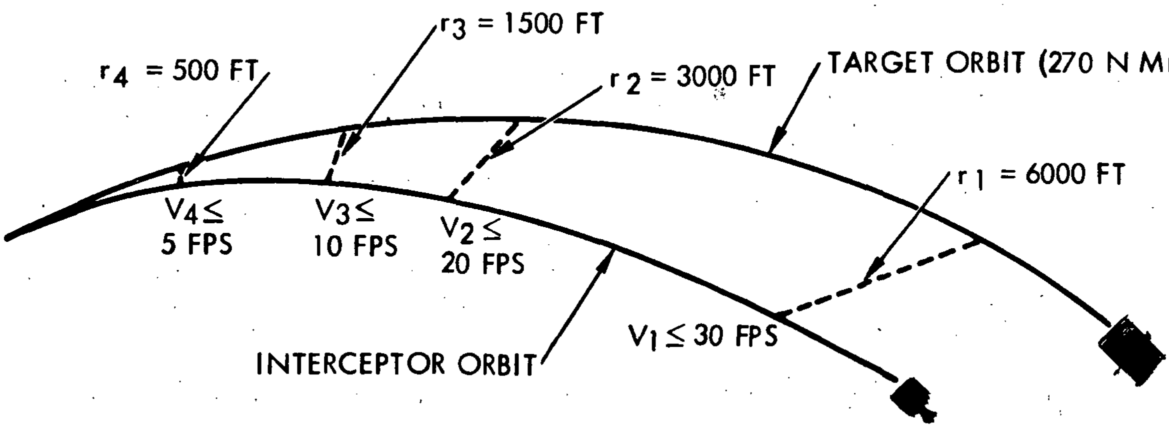
1-17. A backup means for release and separation of mated elements in case of failure of the primary method shall be provided. If the backup scheme is a manual disengagement, the technique shall be designed for IVA or shirtsleeve operations rather than requiring EVA. Separation (14), Deployment (16), Retraction and Stowage (7), (see Mating- 25).

1-18. Hazardous fluid interconnects that are to be disconnected shall be purged with a non-hazardous (inert) gas and shall be pressure vented prior to separation. Separation (18), Propellant Transfer (7)

1-19. Prior to initiation of the separation routine those subsystems that will be utilized during the separation activity shall be verified. Where backup systems are available, these shall also be statused. Separation (19)

1-20. When hatches between elements are closed such that separation can occur, the hatch seal integrity shall be verified. Separation (20)

1-21. During terminal rendezvous a braking gate similar to that shown below, where the relative velocity (V_r) varies with the relative distance between elements must be satisfied. Rendezvous (11)



NOTE: BRAKING GATE ΔV'S APPLIED ALONG LINE OF SIGHT

1-22. Accessible surfaces shall be capable of being touched by a crewman in shirtsleeve or spacesuit. Surface materials shall be selected to ensure that high and low temperatures and conductivity are not limiting factors in crew or cargo transfer. Crew Transfer (5), Cargo Transfer (14)

1-23. All equipment installations within crew mobility areas shall be capable for use for push-off. Installations shall be capable of withstanding multi-directional application of crewman impact loads. Crew Transfer (9), Cargo Transfer (20).

1-24. Equipment susceptible to damage or that is hazardous to crew and cargo transfer operations shall be separated from mobility areas and color-coded or placarded. Crew Transfer (10), Cargo Transfer (21).

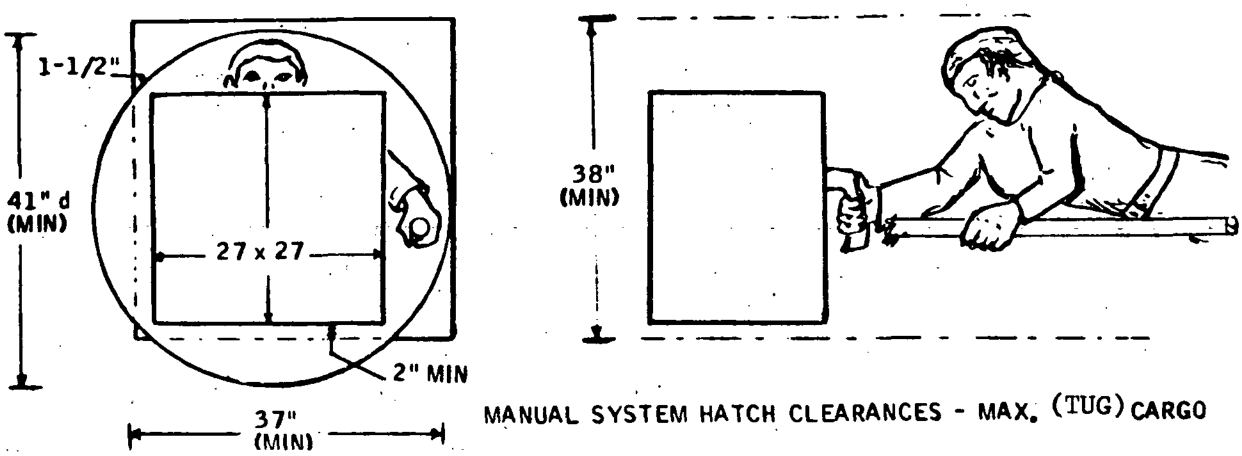
1-25. All hatches between elements shall be capable of operation from either side of the hatch, including a capability for pressure equalization across the hatch. Also included is the capability for pressure monitoring and leak rate checks. Crew Transfer (12), Cargo Transfer (22), Attached Element Operations (21), Orbital Aseembly (40).

1-26. Acceptable noise levels shall be maintained during crew and cargo transfer operations to prevent discomfort to crew members and interference with verbal communications at normal voice levels. Crew Transfer (14), Cargo Transfer (24).

1-27. Passageways/aisles shall be capable of accommodating crew and cargo transfer operational requirements. Page 3-38 illustrates primary passageway criteria. Crew Transfer (18), Cargo Transfer (25), Attached Element Operations (30).

1-28. Atmospheric contamination levels shall be monitored within habitable areas for verification of habitable atmosphere prior to shirtsleeve entry into a previously non-habitable environment. This includes verification of equalized total pressure, adequate P_p0_2, radiation and toxicity within acceptable levels per the following table: Crew Transfer (19), Cargo Transfer (26).

Humidity	Water vapor partial press: 8-13 mm Hg
Temperature	65 to 85 degrees F
Air velocity	15 (min) to 100 (max) ft per minute. 40 ft per minute nominal
Oxygen	P_p 3.1 psi
Odor	Controlled
Carbon Dioxide	Less than 7.6 mm Hg
Microbiological, bacteriological contaminants	Controlled
Radiation Level	Safe Level



Cargo Transfer Sizing

1-29. The capability shall be provided to ensure that passageways/hatchways to a normally uninhabited element are free of obstructions so that crew can enter safely and cargo movement will not be inhibited. This may include direct visual inspection through a view window or remotely monitored sensors or closed circuit television. Crew Transfer (21), Cargo Transfer (28)

1-30. The weight (mass) of cargo/resupply items requiring manual handling will be limited by crewman maneuvering capabilities. All cargo transfer approaches, except 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 the table below. For 2 men, a 250-pound mass is considered the upper limit at zero-g. Cargo Transfer (1)

Cargo Mass Handling Limits (180-lb Crewman)

g level	0	.1	.2	.2	.4	.5	.6	.7	.8	.9	.10
% 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

1-31. 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. Cargo Transfer (2)

1-32. Individual cargo items within a general container shall be packaged to prevent movement or damage during transfer. Cargo Transfer (6)

1-33. Containers that enclose pressure vessels shall be connected to vents prior to and after transfer. Cargo Transfer (7)

1-34. All fluid lines shall be secured to the requirements of the fluids being transferred. Cargo Transfer (30), Propellant Transfer (6)

1-35. A method shall be provided whereby fluid interfaces can be verified to be free of residuals that may contaminate the surrounding environment prior to disconnect. Cargo Transfer (33)

1-36. Leak-detection sensors shall be provided when transferring any contaminable fluid. Vent systems are required to protect against contamination for plumbed transfer. Cargo Transfer (35)

STRUCTURES/MECHANICAL SUBSYSTEM FUNCTION REQUIREMENTS

2-1. Protection of eyes and video visual system from reflected or high intensity light damage shall be provided. Mating (2)

2-2. Mating port mechanisms shall be designed to the following criteria: Mating (12)

a. The design shall be applicable to direct docking and manipulator berthing operations. The concept may be of a design that will perform one type of mating, but with an adapter added can perform the other type.

b. The design shall be inherently dynamically stable when fully engaged to an associated mating port.

c. The design shall provide redundant features where active mechanisms are involved.

d. Both active and passive mating systems shall incorporate in their design the means to automatically reduce angular misalignment and lateral miss distance between the mating interfaces to permit initial capture on first structural connection (i.e., the capture mechanisms shall be automatically triggered and self-locking). The duration of time between triggering and capture latch engagement shall be minimized to prevent the latch from missing if an element rebounds out of the mechanism.

e. A method of monitoring the status of capture mechanism (latch position) shall be provided.

f. The capture mechanism shall be capable of quick release and recycle to its initial state at any phase of the capture operation.

g. The mating port shall be capable of successfully capturing and hard docking to an opposing mating port with a miss distance and misalignment tolerance as follows:

Miss distance: $\pm$ 6 inches min.
Misalignment: $\pm$ 3 degrees min.
(pitch, yaw, roll)

h. Mating port design shall be capable of accommodating the full complex of study vehicles identified. Vehicle masses range between 1000 slugs and 2000 slugs.

2-3. Elements shall be designed with a common androgynous mating port system or with a passive system that mates with the androgynous system. Mating (13)

2-4. The mating interfaces shall be structurally connected either automatically or manually to provide the required intervehicular stiffness for combined vehicle maneuvering. The engaged and locked rigidizing latches shall be preloaded such that the fundamental bending/torsional mode of the mated pairs is determined by the primary structures of the mated pairs, i.e., latch spring stiffness shall not affect vehicle control systems that depend on structural modes. Mating (20)

2-5. Mechanical radial position and roll indexing shall be provided at the mated interface to prevent interface slippage and damage to pressure seals during combined vehicle maneuvering. Mating (21)

2-6. The capability to inspect, maintain, and manually recycle both capture and rigidizing latches in a shirtsleeve environment shall be provided. Mating (23) (Assumes mated condition)

2-7. The tunnel leak rate between the mated elements shall be no greater than the leak rate of the hatch seal of the individual elements. Mating (36)

2-8. Separation velocities and angular rates caused by the extension of shock attenuation system or other energy storage system shall be controlled by delaying release until the extension dynamics cease. Separation (2)

2-9. A window or other viewing method shall be provided through each pressure hatch that is capable of being closed for either normal or emergency operations. This permits crew observation of IVA operations and viewing prior to ingress whenever hatches are closed. Crew Transfer (13), Cargo Transfer (23), Attached Element Operations (15)

2-10. Cargo transfer devices shall be capable of maintaining full control of cargo items at all times. For manual, unaided cargo transfer thethers and/or restraints will be required to affix the cargo item to the operator. Cargo Transfer (3)

2-11. The retention assembly must be capable of accommodating expected thermal and structural deflections of the transported element. Attached Element Transport (4)

2-12. The control center shall have the means to verify the attachment the two elements prior to initiation of any thrust maneuver. Attached Element Transport (5).

ENVIRONMENTAL CONTROL LIFE SUPPORT SUBSYSTEM FUNCTION REQUIREMENTS

3-1. Pressure equalization capability and leak rate verification transducers shall be provided on each side of each docking interface hatch requiring shirtsleeve environment for manned mated operations. Mating (24)

3-2. Prior to separation, the pressurized tunnel between the elements must be pumped down or vented to space. The pressure remaining in the tunnel shall be low enough such that when separation occurs no noticeable delta velocity, due to the remaining pressure, will be imparted to the separating elements. Separation (9), Attached Element Operations (22)

ELECTRICAL POWER SUBSYSTEM FUNCTIONAL REQUIREMENTS

4-1. For mating operations tug shall provide self-illumination. The lighting shall provide the capability to identify the orientation of a tug at a minimum range of 200 feet. Colored lighting or light patterns should be used to aid in visual acquisition and proper geometric orientation between the two vehicles. The lights should present a narrow beam output, be spectrally tailored to the most sensitive visual threshold. Mating (1)

a. Lighting shall artificially illuminate the mating ports to the extent that they can be inspected utilizing closed circuit television or optical aids at ranges of 20 feet to 100 feet or direct visual at a range less than 20 feet.

b. Passive mating aids that require direct viewing (targets) shall be artifically illuminated. Illumination criteria is as follows:

The aids shall stand out and not be obscured by other lighting on the vehicle (colored lighting is acceptable).

The illumination does not blur characteristics of the aid (cross hairs).

Active vehicle lighting does not cause reflections on the aids that will obscure characteristics.

The aids can be utilized at distances up to 100 feet.

4-2. All electrical and signal interfaces shall be deadfaced prior to being connected or disconnected. Mating (27), Separation (16), Orbital Assembly (14)

4-3. Prior to activating electrical interface circuits or closing deadface switches, proper mate of the interface connectors shall be verified. Mating (28), Orbital Assembly (15)

4-4. When electrical or fluid interfaces are to be mated between elements, a ground connection between the element structures shall be established to provide a consistent measured low impedance bond between the elements rather than rely on the mating interface for structural ground. Mating (28), Orbital Assembly (29)

4-5. Illumination of the separating element(s) is required for separations where man is involved or when remote television coverage is required for unmanned elements. Illumination shall be such that appendages of associated elements are visible and element attitude and stabilization can be ascertained. The illumination can be provided independently by each element or one of the elements can illuminate the opposing element utilizing floodlights. Floodlight usage shall be designed such that it does not blind alignment sensors or opposing pilots. Separation (15)

4-6. Adequate lighting shall be provided along all personnel crew transfer routes. General illumination criteria for shirtsleeve operations are presented below: Crew Transfer (11), Cargo Transfer (5)

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

GUIDANCE AND CONTROL SUBSYSTEM FUNCTIONAL REQUIREMENTS

5-1. For docking, the Tug must align its mating port with respect to the mating port of the other vehicle in both translation and rotation. Mating (4)

Alignment shall be as follows:

Lateral miss distance - ±6 inches
Pitch/yaw/roll misalignment - ±3 degrees

5-2. During direct docking alignment and closure to docking contact, a narrow attitude deadband on the order of 0.2 degree shall be maintained by the tug. Mating (6)

5-3. For inspection routines, the target vehicle shall maintain an attitude hold of ±5 degrees and a rate deadband no greater than 0.5 degree/second. Stand-off distance between the elements for the inspection will depend on the configuration of the elements, the inspection aids available, and the inspection detail required. Mating (8)

5-4. Prior to separation, the Tug will be maintaining attitude hold control of the mated pair. At separation, both elements will have attitude control capability. Separation (1)

For a jet translation separation, one element will be only holding attitude. The other element will perform the translation maneuver holding a deadband attitude during the separation.

5-5. Prior to final separation, the tug attitude reference systems will be aligned with its attached element. Separation (11)

5-6. The Tug, either as an active or target element, must contain an attitude reference system capable of determining attitude in relation to Tug coordinates and orbital or earth coordinates. Either a horizon sensor or a star-tracker would satisfy this requirement. In addition, a manned Tug must have autonomous navigation capable of determining its own state vectors, which would be satisfied by a horizon sensor and a star tracker. Rendezvous (4), Stationkeeping (2) and (13)

For these requirements the attitude reference system shall be capable of measuring attitude to an accuracy of ±0.5 degrees.

5-7. The control center must have the capability to calculate the relative positional state (position and velocity) of the rendezvous elements and then determine, based on a knowledge of the ephemerides of both elements, the maneuvers (vectorial velocity changes) which the active element must execute to effect rendezvous withthe passive element. Rendezvous (2)

5-8. A manned tug must have a computer system capable of computing state vectors and orbital parameters from range, range rate data, or other data supplied from element on-board sensor systems. It shall also have the capability to compute delta-velocity maneuvers from stored data for the makeup of orbital parameters. Rendezvous (1), Stationkeeping (9)

At the time of a state-vector update, the one-sigma uncertainty in element position and velocity shall not exceed the limits of the type presented below:

Element Position and Velocity Uncertainty

Component	Position	Velocity
Downrange	± 3 n mi	± 3 ft/sec
Crossrange	± 1 n mi	± 10 ft/sec
Vertical	± 1 n mi	± 20 ft/sec

5-9. During initial rendezvous operations when the controlling element is tracking a cooperative target, the one-sigma tracking uncertainties shall not exceed the limits of the type presented below. Terminal rendezvous tracking inaccuracies are covered in functional requirement no. 7.5.

Cooperative Target Tracking Uncertainty

Parameter	Uncertainty at 30 n mi
Range	± 100 feet
Range rate	± 1.0 ft/sec

PROPULSION SUBSYSTEM FUNCTIONAL REQUIREMENTS

6-1. Prior to contact between the mating interfaces, the relative closing rate (axial velocity) must be reduced to a velocity that is compatible with both vehicles structure and mating port energy absorption capabilities. Mating (14)

The range of closing velocities for the Tug are as follows:

Longitudinal velocity -
with attenuation, 0.3 fps to 0.4 fps
without attenuation, 0.07 fps to 0.1 fps

Lateral velocity -
with attenuation, 0.2 fps to 0.3 fps
without attenuation, 0.07 fps to 0.1 fps

Angular velocity -
0.15 d/s to 0.2 d/s

6-2. Translation jets utilized for separation shall be selected and propellants utilized so as to minimize the effects of exhaust plume impingements on sensitive areas of interfacing elements. This applies where more than one set of jets can be selected. Separation (6)

6-3. The tug must have attitude control systems enabling implementation of a change in attitude. It shall be capable of holding attitude within 0.5 degree of desired. Rendezvous (5), Stationkeeping (3)

6-4. Control of propellant transfer shall be established in the Tug as a control center and exercised on both sides of the interface. Propellant Transfer (8)

6-5. A means shall be provided for measuring or gauging the amount of propellant transferred or stored at any time. Propellant Transfer (9)

6-6. 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. Propellant Transfer (10)

COMMUNICATIONS/DATA MANAGEMENT SUBSYSTEM FUNCTIONAL REQUIREMENT

7-1. Range and range rate data shall be displayed during mating operations. This capability is required at the same time as other data transfer. Mating (9), Rendezvous (9), (9)

7-2. Electronic acquisition for automated docking maneuver control shall have remote backup for manual override of the docking operation. If the manual override is to continue the docking rather than abort the functions, visual capability must be provided through a video system to the remote control site. Mating (10)

7-3. After mating, one of the vehicle control systems shall be inhibited to permit combined vehicle maneuvering and prevent inadvertent control system activity resulting in plume impingement damage. Mating (22)

7-4. Sensing shall be provided to ascertain positive capture at the mating port or for positive separation prior to initiating a jet separation or mechanical extension by a manipulator. Separation (7), Mating (12), Attached Element Operations (5), Orbital Assembly (19)

7-5. A measurement system must be available that is capable of determining rendezvous elements relative range and range rate. These data must be available at the location of the controlling unit. It shall be capable of providing these measurements to the following nominal accuracies:

Range	Range Accuracy	Range Rate
10 to 50 feet	±6 in.	±0.1 ft/sec
50 ft to 30 n mi	±5 ft	±0.5 ft/sec
30 to 60 n mi	±100 ft	±1.0 ft/sec
60 n mi and over	±1 n mi	±10 ft/sec

(Rendezvous - 7)

7-6 The tug element must have a sequence timer or computer scheduled timing activation system that can automatically activate or wake up specified subsystems utilized in stationkeeping of two unmanned near-earth orbital elements. This is either automatically programmed at the end of the last previous operation or is set up in a ground contact to the active element. Stationkeeping (1)

7-7. The tug must have a computer memory capable of storing attitude reference data and predicted attitudes for all stationkeeping operations. The computer must be programmed and a look-up routine available that can perform a computation to determine the difference between actual and predicted attitudes and to calculate the attitude control maneuvers to correct the attitude within prescribed limits. Stationkeeping (3)

7-8. Communications capability shall be provided for crew members. Two-way voice communications must be maintained to crewmen at all times. Crew Transfer (16), Cargo Transfer (17), Orbital Assembly (10)

7-9. Audio and visual alarms shall be provided along crew and cargo transfer routes. Audio alarms could be tone and/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. Crew Transfer (20), Cargo Transfer (27)

7-10. A means shall be provided in unmanned tug for processing and storing operations commands and for transmitting verification signals for authentication and execution authority and operation-executed signals data.

Operations commands will be transmitted from a controlling tug for execution. Such received signals must be processed before they can be used for operation. Detached Element Operations (2).

7-11. A means shall be provided in the tug (ground or space) to command and control real-time data from the detached element. Detached Element Operations (5)

7-12. Monitoring and checkout of detached element condition, operations, and equipments by continuous or periodic interrogation shall be provided for determining element status, isolating faults, processing and displaying such data for evaluation and possible correction. Detached Element Operations (8)

7-13. A means shall be provided for inspection of the detached element by direct visual observation or by a television system. Detached Element Operations (11), Mating (3)

7-14. The tug shall be equipped with RF communications systems. The minimum characteristics of the system are given in the Table on page 3-51. The system shall, at a minimum, have the capabilities defined in the Table on page 3-52. Mating (40), Separation (8), Rendezvous (6), Stationkeeping (4), (6), (7), (8), (11), Detached Element Operations (1), (4), (9), (10), and Communications (1) through (11).

Communications/Data Management Characteristics

TUG

Operation with
EOS, Tug, RAM, Sat, MSS, CPS, RNS, OPD, Ground Station, TDRS

Frequency Band	Ku	S	VHF
Frequency Ret. Fw.	14.4 - 15.35 gHz 13.4 - 14.2 gHz	2200 - 2300 MHz 2025 - 2120 MHz	136 - 144 MHz 126 - 130 MHz
Data - Transmit	Not Used ↓		
Analog - voice		1 channel	1 channel
Analog - TV		Apollo type	--
Digital		50 kbps	10 kbps
Data - Receive			
Analog - voice		1 channel	1 channel
Analog - TV		--	--
Digital		10 kbps	1 kbps
Antenna type		Omni	Omni
Gain		0 db	0 db
Size		--	--
Receiver Noise Temp.		800°K	1200°K
Transmitter Power output		30 watts	25 watts
Tracking/Ranging		PRN code transponder	
Measure		X	--
Respond		X	--
Use both active SLR and passive optical reflectors for docking maneuvers.			

Use of Apollo type TV deletes need for TDRS Ku-band use - continuity of communications is supported by TDRS-VHF link.

Space Tug Capabilities

	Tug (Controlling)	EOS	Tug	RAM	MSS	Ground
1	Command Data Transmission to Digital, BER 1 x 10^{-6} Voice (0.3-3 kHz)	 4 kbps Yes	 → Yes	 → NA	 4 kbps Yes	 NA
2	Command Verification Digital from BER 1 x 10^{-6} Receive/verify	 4 kbps Yes →	 → →	 → →	 4 kbps Yes	 NA NA
3	Data Storage	NA				NA
4	Digital Data Transfer Receive from Transmit to	 2 kbps 4 kbps →	 10 kbps →	 5 kbps →	 10 kbps 4 kbps	 2 kbps 50 kbps
5	Analog Data Transfer Voice Channels Television Facsimile Other	 1 NA → NA → NA →	 1 → → →	 NA → → →	 1 → → →	 1 NA NA NA
6	Tracking/Ranging PRN range capability ± 1 n mi range ± 5 ft/sec range rate	 Respon	 Meas.	 →	 Meas.	 Respond
7	Computer Capability to Determine Ephemerides	No	Yes →	→	Yes	NA
8	Visual Inspection	Yes TV →	→	→	Yes, TV	NA
9	Analog Data Transmission to Voice Television Other	 1 NA → NA →	 1 → →	 NA → →	 1 NA →	 1 B&W 2.9 MHz NA

CREW AND HABITABILITY SUBSYSTEM FUNCTIONAL REQUIREMENTS

8-1. If the TUG is manned, a means shall be provided to perform visual tracking of the other element during the terminal phase at a separation of less than 5 miles. Rendezvous (10)

8-2. All IVA, EVA and hazardous shirtsleeve operations shall be conducted with a minimum of two crew members (buddy system). One crew member acting as a backup, monitors the operations of the active crew member providing a rescue capability. Crew Transfer (1), Orbital Assembly (9), Cargo Transfer (12)

8-3. The backup crew member during IVA and hazardous shirtsleeve operations shall be positioned to observe the other crew member at all times and, in the case of IVA activities, will be required to control the other crew member tether or umbilical to prevent entanglement.

8-4. Crew mobility aids and restraint devices shall be provided along all crew transfer routes and worksites in order to facilitate crew translation and stabilization in zero-g environment. Crew Transfer (3)

8-5. Crew mobility aids shall be capable of use by a 5 to 95 percentile crew member in either a shirtsleeve or pressurized suited mode of operation. Crew Transfer (4), Cargo Transfer (11)

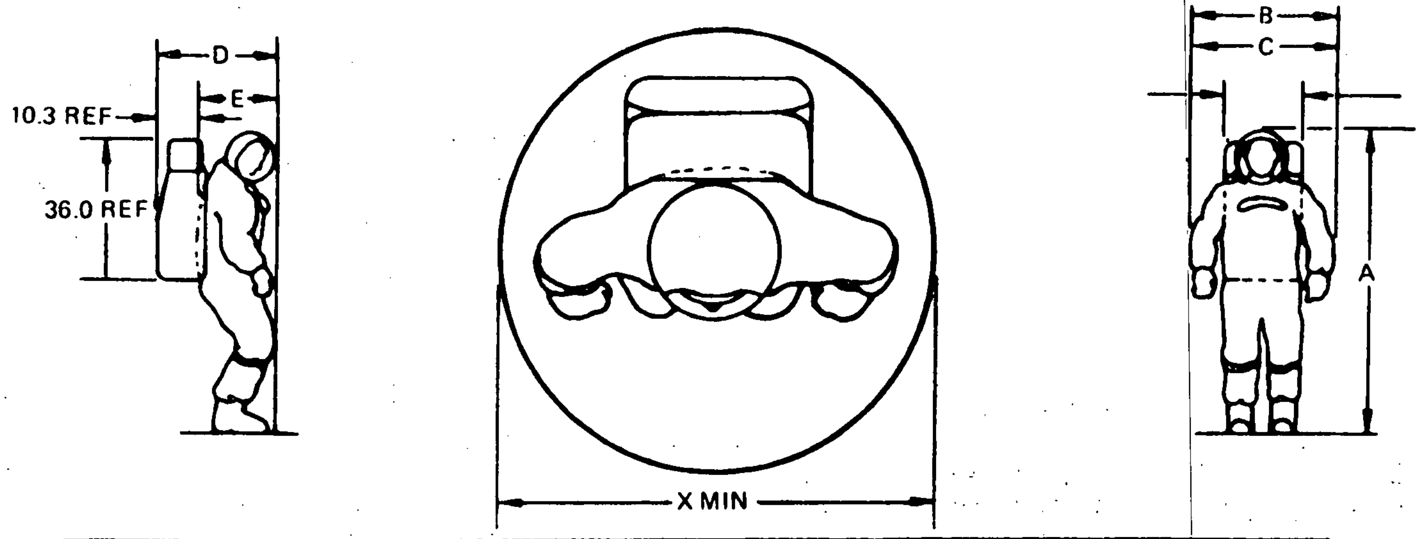
8-6. Crew restraint devices shall be capable of use by a 5 to 95 percentile crew member in either a shirtsleeve or pressurized suited mode of operation. Development of worksite crew restraint device requirements will be dependent upon the reach capability of the 5 to 95 percentile crew propulation while restrained. Figures on pages 3-54 and 3-55 define anthropometric data. Crew Transfer (6)

8-7. Crew restraint devices shall be easily operable, not restrictive of required crew motions, and possess a high degree of crew acceptability. Crew Transfer (7)

8-8. Crew restraint devices shall be designed to allow crew members to apply various combinations of loads at 1 g equivalent force values with or without a pressurized space suit. Crew Transfer (8), Cargo Transfer (16).

8-9. Cargo restraint devices shall be capable of single hand attachment operations by a crewman in a pressurized space suit. Cargo Transfer (4)

8-10. Crew restraint devices shall be provided along the cargo transfer path and at cargo transfer worksites to provide capability for crewman positioning and stabilization. Cargo Transfer (15)



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 3-12. Envelope Dimensions for a Suited Pressurized Male Crew Member

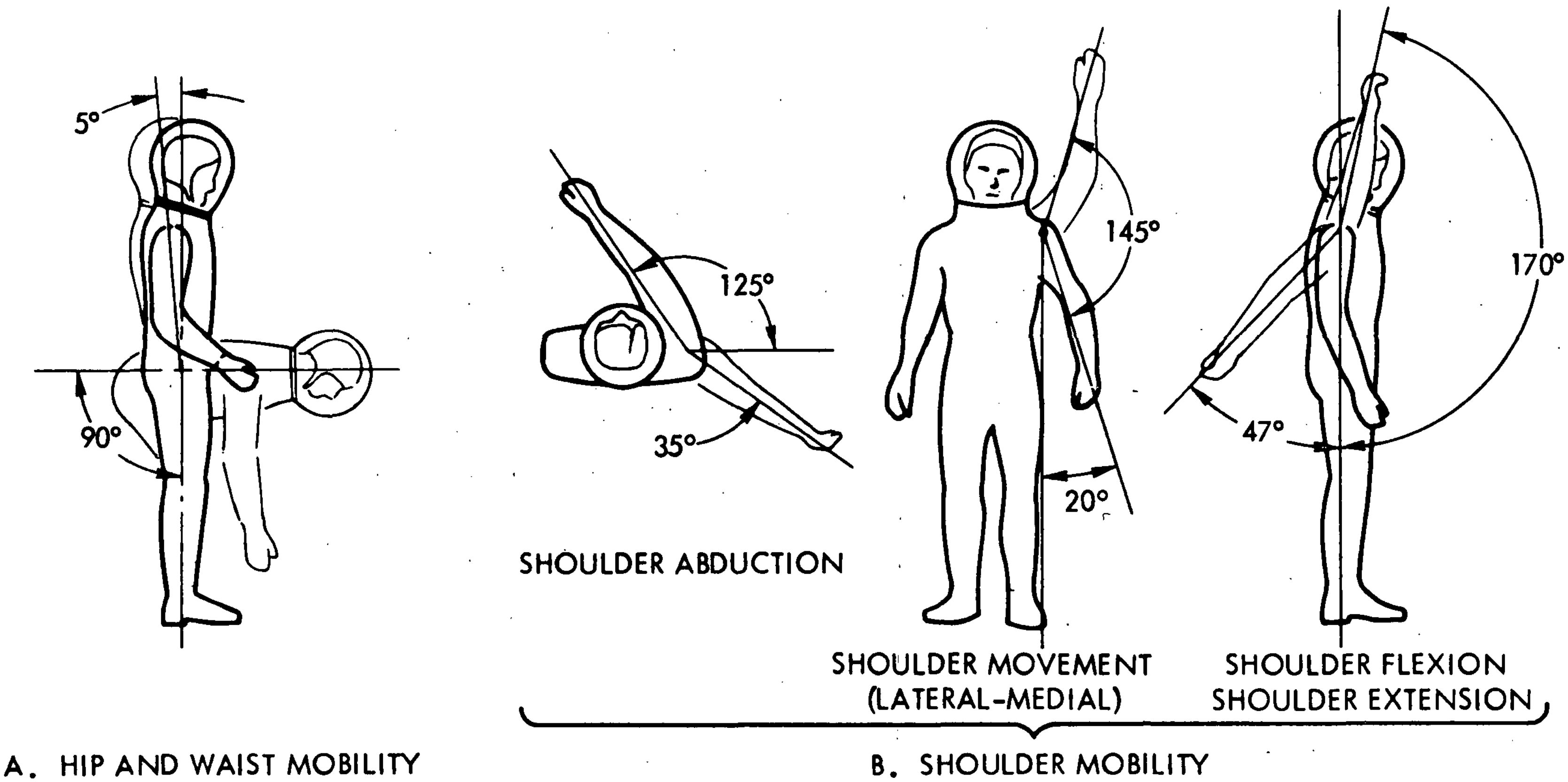


Figure 3-11. PGA Mobility

8-11. 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. Cargo Transfer (18)

SECTION 4. RESEARCH & APPLICATIONS MODULE (RAM)

RAM is a family of manned or man-tended payload carriers that provide flexible and economical accommodations, and are transportable to and from orbit by the Space Shuttle. RAM will evolve in capability from early austere versions operating with the Space Shuttle during short-duration sortie missions, to more advanced capabilities operating in this sortie mode, and will finally evolve to advanced labs operating attached to an orbiting Space Station; this evolution will include providing for man-tended observatories.

Figure 4-1 illustrates the basic RAM family elements furnished by the NASA for use in this study. Table 4-1 adds some of the major characteristics to these elements.

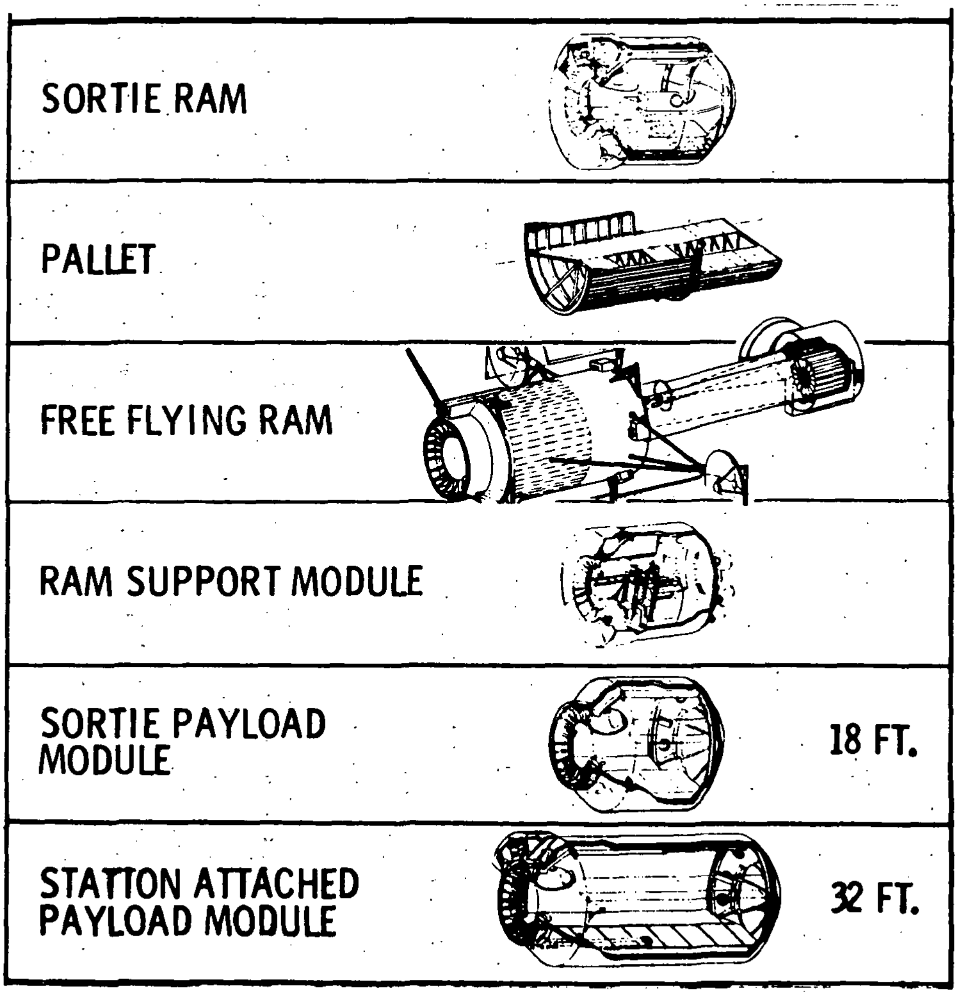
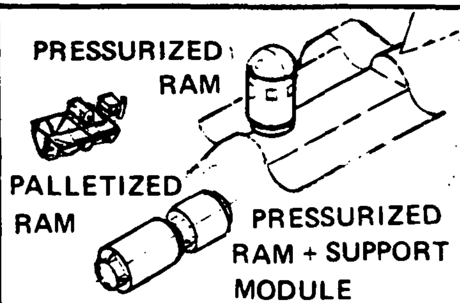
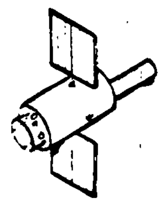
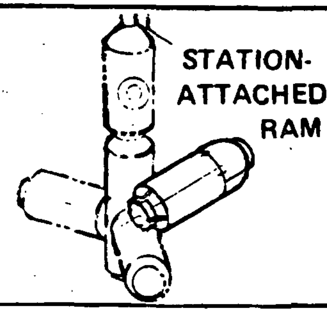


Figure 4-1. Research & Applications Module Model (RAM)

NOTE: The significant analyses results and recommendations contained in this section were not sensitive to the specific RAM model of Figure 4-1.

Table 4-1. RAM Characteristics

	SORTIE MISSION	MAN-TENDED OBSERVATORIES	ATTACHED TO STATION
RAM CONCEPTS		 FREE-FLYING RAM	
RAM PAYLOADS, DISCIPLINES & (NO. PAYLOADS)	● ASTRONOMY (8) ● PHYSICS (5) ● EARTH SURVEYS (6) ● COMMUNICATIONS/ NAVIGATION (3) ● MATERIALS SCIENCE (4) ● TECHNOLOGY *(8) ● LIFE SCIENCES (2)	ASTRONOMY ● HIGH-ENERGY STELLAR (1) ● X-RAY (1) ● ADVANCED STELLAR (1) ● ADVANCED SOLAR (1) ● TECHNOLOGY— PIGGYBACK *(2)	● PHYSICS (2) ● EARTH SURVEYS (2) ● COMMUNICATIONS/ NAVIGATION (2) ● MATERIALS SCIENCE (1) ● TECHNOLOGY *(3) ● LIFE SCIENCES (2)
MISSION CHARACTERISTICS	● LOW EARLY YEAR FUNDING ● EARLY SCIENTIFIC RETURN ● SHUTTLE-COMPATIBLE ● SHORT-DURATION MISSION ● GROUND DATA ANALYSIS	● EXTENDED MISSION TIME ● ENVIRONMENTAL SENSITIVITY ● UNMANNED OPERATION ● INFREQUENT SERVICING ON-ORBIT ● STATION OR SHUTTLE SUPPORTED ● EARTH RETURN FOR REFURBISHMENT	● EXTENDED MISSION ● MANNED ATTENDANCE ● STATION-COMPATIBLE ● STATION SUPPORTED

*INCLUDES TWO TECHNOLOGY PIGGYBACK PAYLOADS.

SUMMARY

This section of the basic element summaries is structured to provide the key operational/design approaches recommended for incorporation in the RAM model as a direct result of the interfaces between the RAM and associated vehicles. These interfaces were identified and analyzed using fourteen interfacing activities as the interface drivers. The 14 activities listed and defined in Figure 4-2 include every type of interaction pertinent to this study that can occur between the RAM and the study inventory of earth orbital space elements.

Volume II, Part 2	
MATING The attachment in earth orbit of any two elements (or modules), including the operations of final closure prior to contact **ORBITAL ASSEMBLY** The joining together of two or more major parts to form a particular configuration of a single operational element in earth orbit, or to facilitate transport to lunar orbit or high-energy earth orbit **SEPARATION** The physical uncoupling of two mated elements and the subsequent maneuvers required to provide adequate clearance between elements	**EOS PAYLOAD DEPLOYMENT** The removal of a payload from the orbiter cargo bay and readying it for operation or separation **EOS PAYLOAD RETRACTION** The insertion of a payload into the orbiter cargo bay subsequent to initial mating of the payload to the orbiter
Volume II, Part 3	
COMMUNICATIONS The transmission of sound, video, and digital/analog data via space links from element-to-element and from element-to-ground **RENDEZVOUS** The operations required to achieve close proximity of one element to another for purposes of stationkeeping and/or mating	**STATIONKEEPING** The maintaining of a predetermined (not necessarily fixed) relative position between two orbiting elements **DETACHED ELEMENT OPERATIONS** The operational support required by a free-flying element from another element and/or ground control
Volume II, Part 4	
CREW TRANSFER The transfer of personnel between two elements in orbit **CARGO TRANSFER** The transfer of solid and fluid cargo between two elements in orbit **PROPELLANT TRANSFER** The transfer of large quantities of liquid hydrogen and liquid oxygen between elements in orbit	**ATTACHED ELEMENT OPERATIONS** Support by one element to another attached element while the latter is operating or being serviced, checked out, or stored **ATTACHED ELEMENT TRANSPORT** Support by a major propulsive element to an attached payload (element or module) during transport from one orbit to another

Figure 4-2. Interfacing Activity Definition

Three major topics were used to report the RAM related results of the interfacing activity analyses. These major topics are:

- o Element Inventory, Mission Models and Interactions
- o Recommended Operational/Design Approaches and Design Influences
- o System and Subsystem Functional Requirements

ELEMENT INVENTORY, MISSION MODELS AND INTERACTIONS

This subsection discusses all of the mission models that are applicable to the RAM's and all of the elements which the RAM's interface with. Four categories of RAM are included in this study as follows: (1) EOS Attached RAM (EOS-ARMA), (2) EOS Detached RAM (EOS-DRAM), (3) MSS Attached RAM (MSS-ARAM), and (4) MSS Detached RAM (MSS-DRAM).

These four types of RAM's can be involved in nine of the eleven mission models. The EOS-ARAM and EOS-DRAM interface with the EOS only. However, the MSS-ARAM's and MSS-DRAM's interface with the various delivery vehicles used to transport the RAM's to either the Low Earth Orbital, Geosynchronous or Lunar Modular Space Stations.

RECOMMENDED OPERATIONAL/DESIGN APPROACHES AND DESIGN INFLUENCES

Nine major recommendations were derived from a detail analysis of the 14 interfacing activities. Table 4-2 summarized these recommendations and provides reference to the specific activity that either drove or supported the recommendation. The rationale for and design influence on the total element inventory resulting from these recommendations is contained in paragraphs subsequent to this summary.

Table 4-2. Major RAM Recommendation

Major Recommendations	Hdw & Oper'l Considerations	Interfacing Activities
1. Direct Automated Dock DRAMS to MSS, EOS, & TUG	·Common Mating Port ·100-400 ft-lb Atten. ·$\leq$0.4 ft/sec Closing Velocity ·Laser Reflectors	Mating
2. Jet Translation for Separation from MSS, EOS & TUG	·RAM Active ·RAM Passive	Separation
3. ARAMS Added to MSS Via EOS W/Manipulator - Direct Dock Backup	·Manip Attach Points ·Mating Ports at Both Ends	Orbital Assembly
4. Universal EOS/Payload Retention for All RAMS	·4 Point Coplaner Retention Concept (Except Pallets)	EOS P/L Deploy EOS P/L Retract Attached Elem Xport
5. Crew/Cargo Transfer to P/L in Cargo Bay & in Deployed Position - Shirtsleeve Prime Mode - IVA Backup Mode	·41-in. dia Clear Opening ·Mechanically Aided Transfer Device	EOS P/L Deploy EOS P/L Retract Attach Elem Ops Crew Transfer Cargo Transfer
6. Direct RAM-to-Element, Direct RAM-to-Ground, & RAM-to-TDRSS Comm Links	·S-Band & Omni ·VHF & Omni ·Ku-Band & Directional Antenna	Communications Detached Elem Ops
7. Ground, EOS, and MSS Control of Rendezvous and Stationkeeping	·Laser Reflectors ·S-Band Link ·Star Tracker & Att Reference	Rendezvous Stationkeeping Detached Elem Ops
8. Transfer of Small Quantity Fluids & Gasses from EOS & MSS via Manual Plumbed Interconnect	·Shirtsleeve ·Flex Lines & Quick Disconnects	Cargo Transfer
9. Attached RAMS have Access to Available EOS and Designated MSS Subsystem Capability	·Data Process & Storage ·Electrical Power ·Thermal & ECLSS ·Communication ·Att Stab & Pointing	Attached Elem Ops

SYSTEM AND SUBSYSTEM FUNCTIONAL REQUIREMENTS

This subsection identifies the pertinent quantitative and qualitative requirements that apply to the RAM during the operations associated with the 14 interfacing activities. These functional requirements are presented in quasi-spec format with reference to the specific activity(s) that generated the requirement.

Two distinct categories have been used to report the functional requirements as follows:

System Level - those functional requirements relating to the overall performance of the entire system, or by their nature they are involved in each subsystem (i.e., safety or general subsystem requirements). This section will also include requirements that form interfaces between subsystems.

Subsystem Level - those functional requirements that relate to one specific subsystem. Again as with the system level requirements, cross reference will be made to the appropriate interfacing activity that initially defined the requirement.

ELEMENT INVENTORY, MISSION MODELS AND INTERACTIONS

This subsection identifies all of the mission models that are applicable to the Research & Applications Modules, and all of the elements with which the RAM has an interface with for each of the 14 interfacing activities.

ELEMENT INVENTORY

Figure 4-3 shows a generic grouping the 25 study elements. The right hand column indicates the number of actual elements included in each of the categories.

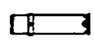
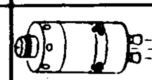
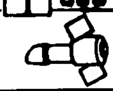
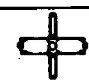
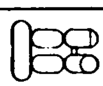
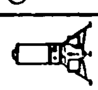
Earth orbital shuttle (EOS) - One element only, referred to throughout this report as EOS, orbiter and shuttle orbiter.		1
Interim tug - Various types of nonreusable nonreturnable, and nonreusable returnable kick stages such as Centaur, Agena, Titan Transtage, and Burner II.		2
Space tug - Reusable unmanned and manned ground-based tug, and unmanned and manned space-based tug.		2
Chemical propulsion stage (CPS) - The orbital insertion stage (mounted on the EOS booster at launch), the earth orbit-to-orbit shuttle, and the cislunar shuttle. The CPS can be modular or nonmodular, and single-stage or two-stage.		3
Reusable nuclear shuttle (RNS) - Both the earth orbit-to-orbit shuttle and the cislunar shuttle application. The RNS can be modular or nonmodular and is single-stage only.		1
Modular space station (MSS) - The low earth orbital station and the geosynchronous station.		2
Research and applications module (RAM) - Both attached and detached RAM's, supported by the EOS and by either of the two MSS's (see above).		4
Satellite - Satellites deliverable to orbit by the EOS and those requiring the EOS plus a third stage for delivery. Also included are satellites requiring retrieval and servicing.		3
Orbital propellant depot (OPD) - The low earth orbital propellant depot located in an orbit optimized to support the RNS or CPS and the space-based tug.		1
Earth orbital resupply module - Cargo and propellant modules for resupply of earth orbiting elements.		1
Orbiting lunar station (OLS) - Both the modular and nonmodular configurations (deliverable to lunar orbit by CPS or RNS).		1
Lunar surface base (LSB) - The modular base only (deliverable to lunar orbit by CPS or RNS).		1
Lunar landing tug (LLT) - Both the unmanned and manned tugs (deliverable to lunar orbit by CPS or RNS).		2
Lunar resupply module - Crew, cargo and propellant modules for delivery to lunar orbit by CPS or RNS.		1

Figure 4-3. Element Inventory

MISSION MODELS

In the Orbital Operations Study, a total of eleven generic missions have been generated which encompass all of the mission events, element-to-element interfaces (element pairs), and interfacing activities which can occur in earth orbit. Each of the eleven mission models (refer to Volume I) consists of a sequence of mission events, with an identification of related interfacing activities and interfacing elements for each event. Four categories of RAM are included in this study including EOS and MSS attached RAM (ARAM) and EOS and MSS detached RAM's (DRAMS). These four types of RAM's can be involved in nine of the eleven missions (see Table 4-3).

In MM-1, "EOS Emplacement Mission", both the MSS DRAM and the EOS DRAM can be emplaced in the desired orbit by the EOS orbiter. In the former case the DRAM is under the control of, and supported by, the MSS during the experiments operation period and for resupply/maintenance. In MM-2, "EOS Logistics/Retrieval Mission", the EOS orbiter can retrieve the EOS DRAM and the MSS DRAM from space for return to earth or for maintenance and subsequent emplacement in space. Also the MSS ARAM can be transported to or from the MSS by the EOS orbiter. In MM-3, "EOS Sortie Mission", the EOS orbiter delivers an EOS ARAM to orbit, remains attached to the RAM during the experiments operations period, then returns the RAM to earth.

In MM-4, "Space-Based Tug Retrieval/Emplacement Mission", a tug separates from its space base, retrieves a free-flying MSS DRAM, transports it to the MSS for servicing and resupply, then returns the DRAM to space. In MM-5, "Space-Based Tug Logistics Mission," the tug separates from its space base, picks up an MSS ARAM or an MSS DRAM from the EOS orbiter, and transports the RAM to the MSS. In another application the tug picks up an MSS ARAM or MSS DRAM (which are docked to the MSS) and transports it to the EOS orbiter for return to earth.

In MM-7, "Ground-Based Tug Emplacement/Sortie Mission", the tug can emplace the geosynchronous MSS DRAM in the desired orbit in which it receives support from the MSS. In MM-8, "Ground-Based Tug Logistics/Retrieval Mission", the tug can transport an MSS ARAM to or from the geosynchronous MSS, or can retrieve a free-flying MSS DRAM from a high energy orbit and deliver it to the EOS orbiter.

In MM-10, "Staged Geosynchronous Cislunar Shuttle Logistics Mission", and MM-11, "Non-Staged Geosynchronous Cislunar Shuttle Logistics Mission," the MSS ARAM or MSS DRAM can be transported to the geosynchronous MSS from the EOS orbiter, or returned to the orbiter from the MSS.

Table 4-3. Mission Model, Interfacing Activity, and Element Inter-relationships with RAM

Interfacing Element	Interfacing Activity														Mission Model										
MSS SUPPORTED RAMS	Mating 1	Orbital Assy 2	Separation 3	Cargo Transfer 4	Crew Transfer 5	Propel. Transfer 6	EOS Payload Deployment 7	EOS Payload Retr. & Stowage 8	Communications 9	Rendezvous 10	Stationkeeping 11	Attached Elem. Operations 12	Detached Elem. Operations 13	Attached Elem. Transport 14	EOS Emplacement 1	EOS Logis/Retriev. 2	EOS Sortie 3	SB Tug Retr/Emplace. 4	SB Tug Logistics 5	SB Tug Disposal 6	Grd-Based Tug Emplace/Sortie 7	Grd-Based Tug Logis/Retriev. 8	OIS Delivery 9	CLS Staged Logistics 10	CLS Nonstaged Logistics 11
ARAM TO EOS	✓	✓	✓				✓	✓						✓		✓			✓			✓		✓	✓
ARAM TO G.B. TUG	✓		✓						✓					✓							✓	✓			
ARAM TO S.B. TUG	✓	✓	✓						✓				-	✓		✓			✓					✓	✓
ARAM TO LO EO MSS	✓	✓	✓	✓	✓							✓				✓		✓	✓			✓			
ARAM TO GEO MSS	✓	✓	✓	✓	✓							✓				✓		✓	✓		✓	✓		✓	✓
ARAM TO EO CPS	✓	✓	✓						✓					✓		✓		✓	✓			✓		✓	✓
ARAM TO RNS	✓	✓	✓						✓					✓		✓		✓	✓			✓		✓	✓
DRAM TO EOS	✓	✓	✓				✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓		✓	✓		✓	✓
DRAM TO G.B. TUG	✓		✓						✓		✓	✓	✓	✓							✓	✓			
DRAM TO S.B. TUG	✓	✓	✓						✓	✓	✓	✓	✓	✓		✓		✓	✓					✓	✓
DRAM TO LO EO MSS	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓		✓	✓		✓	✓		✓	✓			
DRAM TO GEO MSS	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓			✓		✓	✓		✓	✓		✓	✓
DRAM TO EO CPS	✓	✓	✓						✓					✓		✓		✓	✓					✓	✓
DRAM TO RNS	✓	✓	✓						✓					✓		✓		✓	✓					✓	✓

ARAM = Attached RAM   DRAM = Detached RAM   G.B. = Ground Based   S.B. = Space Based

Space Division
North American Rockwell

Table 4-3. Mission Model, Interfacing Activity, and Element Inter-relationships with RAM (Cont.)

Interfacing Element	Interfacing Activity														Mission Model										
EOS Supported RAMS	Mating	Orbital Assy	Separation	Cargo Transfer	Crew Transfer	Propel. Transfer	EOS Payload Deployment	EOS Payload Retr. & Stowage	Communications	Rendezvous	Stationkeeping	Attached Elem. Operations	Detached Elem. Operations	Attached Elem. Transport	EOS Emplacement	EOS Logis/Retriev.	EOS Sortie	SB Tug Retr/Emplace.	SB Tug Logistics	SB Tug Disposal	Grd-Based Tug Emplace/Sortie	Grd-Based Tug Logis/Retriev.	OIS Delivery	CLS Staged Logistics	CLS Nonstaged Logistics
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11
ARAM to EOS				✓	✓		✓	✓	✓			✓		✓			✓								
DRAM to EOS	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓									

ARAM = attached RAM DRAM = detached RAM

ELEMENT INTERACTIONS

The methodical in-depth approach used in the generation of the mission models (see Section 1.0 of Volume I) made possible the identification of all potential element-to-element interfaces (i.e., element pairs) and all interfacing activities that can occur between elements in earth orbit. A summary of the total list of orbital elements considered in this study was presented in Figure 4-3. Those elements with which the RAM elements may interface with and those interfacing activities which may occur between RAM's and these other elements are also identified in Table 4-3.

The EOS detached RAM (DRAM's) will be emplaced in orbit by the orbiter, and will be retrieved and resupplied by the orbiter. Therefore, the EOS orbiter supported RAM (both attached and detached) will interface with the orbiter only. The MSS supported RAM (attached and detached) will obviously interface with both of the MSS's (low earth orbital and geosynchronous). In addition, they will interface with their transport vehicles which include the manned CPS, RNS, Space-Based Tug, and Ground-Based Tug.

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RECOMMENDED OPERATIONAL/DESIGN APPROACHES AND DESIGN INFLUENCES

Several major operational/design approaches for the RAM were synthesized from the detail analyses conducted for each of the 14 separate interfacing activities. These major recommendations are illustrated by Figure 4-4. The nine recommendations highlighted on the figure are amplified in subsequent paragraphs.

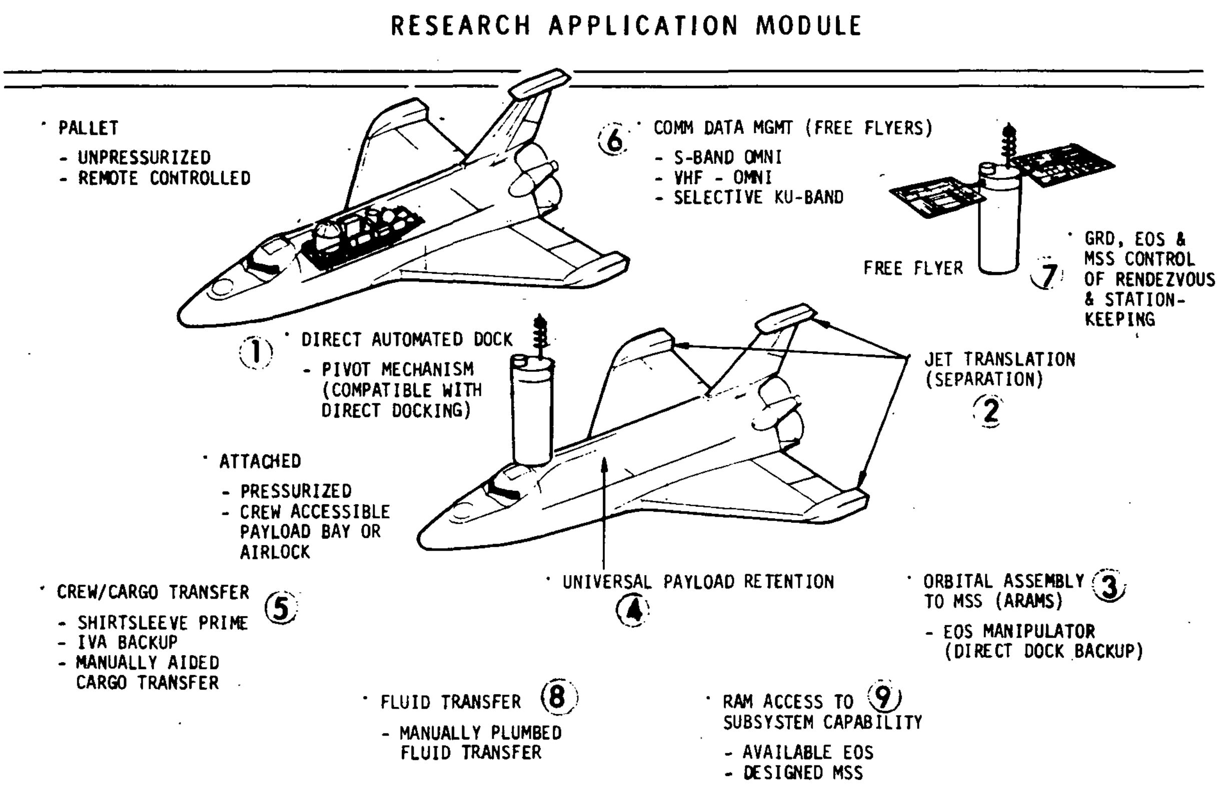

Figure 4-4. Major RAM Recommendations

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DIRECT AUTOMATED DOCK (1)

An automated direct docking approach is recommended for the mating of a detached RAM to the EOS, MSS or TUG.

Selection Considerations

The Mating and Orbital Assembly interfacing activities each considered two generic approaches to mating:

(A) Direct Dock (automatic and manual)

(B) Manipulator Berth (manual only)

Ten separate comparison factors were considered:

- Technology
- Checkout and Maintenance
- Safety
- Reliability
- Commonality
- Relative Cost
- Operational/Design Complexity
- Subsystem Interfaces
- Near Term Bias
- Far Term Bias

An overall evaluation of these comparison factors tends to favor (A) Direct Dock over (B) Manipulator for DRAM matings. Also an automated direct dock approach must be developed for the mating of unmanned elements, therefore the automated approach is recommended for commonality across all element pairs.

(1) Refer to Table 4-2 and Figure 4-4

RAM Design/Operational Influences

An automated direct dock approach with a manual backup mode requires the following be incorporated as part of the basic RAM design:

- Common Mating Port. Active attenuation in the 100-400 ft-lb range with closing velocity held to $\leq$ 0.4 ft/sec.

Design/Operational Influences on Interfacing Elements

The RAM can be either the active or passive vehicle during automated direct dockings. The elements that mate with the RAM are required to have a scanning laser radar and passive laser reflectors.

JET TRANSLATION SEPARATION (2)

The preferred mode of RAM separation from mated elements is via mass expulsion of RCS engines. Dependent upon operational considerations the RAM may be either active or passive during the separation.

Selection Considerations

Two generic approaches for separation were considered in the Separation interfacing activity:

(A) Jet translation (manual or automatic modes)

(B) Manipulator extension (manual or automatic modes)

Nine comparison factors were considered in making a selection. These factors are as follows:

- Technology
- Checkout & Maintenance
- Plume Impingment
- Safety
- Reliability
- Relative Cost
- Commonality
- Near Term Bias
- Far Term Bias

An evaluation of the factors showed that both approaches are adequate in either manual or automatic modes. However both approaches offer significant advantages.

(A) Jet translation is significantly lower in cost because at least one of the two mated elements will be equipped with a translation capability.

(B) Manipulator extension appears to offer a more safe operation in that the elements can be physically separated some distance prior to independent operations.

Jet translation is the recommended approach for all separation operations as it requires little or no additional hardware than is already included in the elements; it has been demonstrated to be safe; and it can be utilized for all element pairs in the study inventory.

(2) Refer to Table 4-2 and Figure 4-4

RAM Design/Operational Influences

The jet translation separation approach does not impose any additional hardware to the RAM model used during this study. However, a reliable means must be provided to assure that any stored energy that can impart a noticeable thrust to one of the separating elements has been released prior to the jet translate maneuver. Examples of this stored energy are:

- compressed docking attenuation struts
- crew/cargo transfer tunnel pressurization
- spring type capture latches

Design/Operational Influences on Interfacing Elements

RAMS will at times be exposed to jet plume contaminations prior to mating, while attached to the EOS/TUG and during the separation maneuver. The preferred operational option is to have the RAM perform the translation with the EOS/TUG engines inhibited.

The only identified critical alignment separation is for the MSS where a RAM to be separated is adjacent to a station module. A laser radar guidance concept is recommended for this operation.

ATTACHED RAMS ADDED TO MODULAR SPACE STATION (3)

The selected concept for adding ARAM to the MSS is to utilize both the EOS with its manipulator and direct dock as a backup.

Selection Considerations

The Orbital Assembly Interfacing Activity considered (a) direct dock and (b) manipulator berth for the attachment of RAM to the modular space station. The primary constraints considered in the comparison of the two approaches are:

Direct Dock	Manipulator Berth
o Alignment tolerance	o Reach criteria
o Appendage clearance	o Module size
	o Berthing port location
	o End effector location

An evaluation of these factors showed that both approaches are adequate and no strong operational preference was established for either approach.

An interactivity commonality analysis between the manipulator and the direct dock modes showed the following advantages for manipulator:

- commonality with EOS deployment and MSS orbit assembly - manipulator preference

- more positive control of modules in close proximity and when near appendages

- operation flexibility - can minimize design complexity and/or EVA with its external maintenance capability and with the handling of experiment exposure packages, lens covers, hatch covers, antennas, etc.

To insure mission continuation a backup mode of direct dock was selected. This made use of the existing module spacing that was defined by the MSS orbital assembly interfacing activity.

(3) Refer to Table 4-2 and Figure 4-4

Design/Operational Influences

ARAM Influences

Since the selection for ARAM additions to the MSS is a manipulator concept the following is the basic design influence - all ARAM will have to have manipulator end effector receptacles. However, since direct dock has been selected all ARAM will have to be designed with mating ports at both ends of the modules.

Influences on Interfacing Elements

The two elements that interface with the ARAM's are the MSS and the EOS. The impact on both of these elements, of having the ARAM's capable of both direct dock and manipulator placement is essentially a greater degree of flexibility and operational capability. Since the requirements for module (mating port) spacing are basically driven by the direct dock mode; use of a manipulator, with its inherent tighter tolerance capability, simplifies this operation. Replacement of multiple ARAM modules on a single mission is more easily accommodated by use of a manipulator.

UNIVERSAL EOS/RAM RETENTION (4)

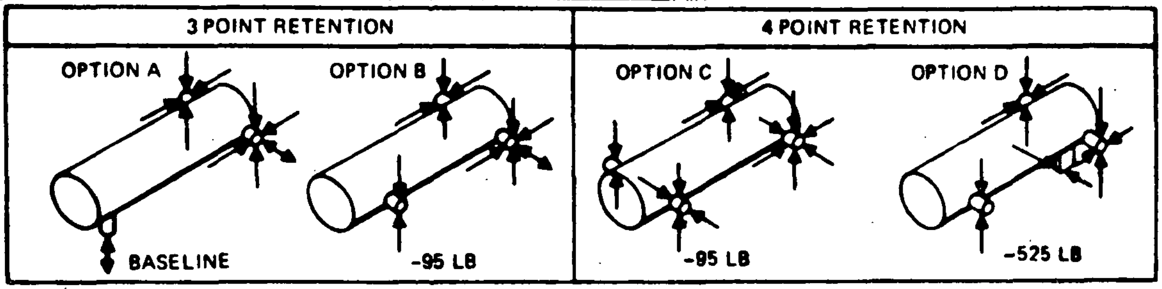
The selected payload retention concept for RAM modules is the universal EOS/Payload retention concept. It is a four point co-planar concept (see sketch). RAM pallets will utilize only the side mounted retention points in the cargo bay.

Selection Considerations

The EOS payload deployment and retraction/stowage interfacing activities each considered two approaches to payload retention:

1) 3 point concepts (two options A & B)

2) 4 point concepts (two options C & D)



Trade study A-5 (Appendix A) determined that of the three and four point concepts, option D offered the largest savings to the orbiter (525 lbs). The study also showed that 4 point concepts impact payloads less than 3 point concepts. The other part of the retention concept is the number of retention locations that the mechanisms can be attached to. The baseline concept had five fixed points in which the retention assembly could be attached. The weight penalty of additional locations is only 6 lbs per location.

If the retention points were located on 4-ft centers the additional weight penalty would be 60-lbs (10 locations above baseline at 6 lbs ea.). The hinge locations for the cargo bay doors appears to be the limiting factor in determining the optimum for the spacing. Taking this into consideration a 4-foot spacing appears to be a reasonable selection.

RAM pallets would also utilize the trunnion locations but would use 4 points (2 fore and 2 aft) to secure the pallet. The impact on the pallet design would be the same as that for the RAM modules. The only location constraint on the forward trunnion would be located at a distance, that was a multiple of four feet from the aft trunnions.

(4) Refer to Table 4-2 and Figure 4-4

RAM Design/Operational Influences

The selected RAM/EOS payload retention concept has a minimum impact on the RAM. It uses 3 trunnion fittings and a heel (passive) slot fitting. The dual aft trunnions react horizontal and vertical loads. In the same plane at the bottom of the bay it employs a passive mechanism (slot) heel fitting that reacts side loads. The fourth retention point is forward and it reacts vertical loads.

Design Influences Interfacing Element

The only other element that would be affected by RAM retention concepts is the EOS orbiter. Since the selected concept for RAM is that it adopts the universal EOS payload retention concept (4 pt co-planer) the interface problems for the EOS are eliminated.

RAM CREW/CARGO TRANSFER (5)

This study identified the necessity to transfer crew and cargo to and from RAM. A shirtsleeve entry is the preferred mode; however IVA provisions are also recommended as a backup mode.

Selection Considerations

The Crew Transfer and Cargo Transfer interfacing activities each considered three generic methods for crew/cargo transfer as follows:

Method	Approaches	
	Crew Transfer	Cargo Transfer
EVA	1) No	1a) Manual unaided
IVA	2) Yes	2a) Manual unaided
Shirtsleeve	3) Yes	3a) Manual unaided 3b) Manual aided 3c) Automated

Shirtsleeve crew transfer (approach 3) was selected due to the high degree of crew movement between the RAM and EOS or MSS. The ease of crew movement offered by the shirtsleeve transfer is the deciding factor.

Manually aided cargo transfer in a shirtsleeve environment (approach 3b) was selected for the transfer of cargo items between RAM's, or from MSS to RAM. EOS-supported RAM's do not require significant cargo transfer, and would be manually unaided.

The IVA method (approach 2 and 2a) is recommended as a backup for the shirtsleeve mode of crew and cargo transfer for cases where RAM is unpressurizable.

EVA crew and/or cargo transfer was not selected as all interfacing elements can be accommodated by either shirtsleeve or IVA transfer.

(5) Refer to Table 4-2 and Figure 4-4

Design/Operational Influences

The selection of shirtsleeve and IVA crew/cargo transfer between the RAM and its interfacing elements creates the following design influences:

- Flexible tunnel on EOS - required for payload entry with the pivot mechanism in both the stowed and deployed positions
- Airlock on EOS and MSS - required for IVA

  Note: The airlock can be either part of the basic orbiter design or a kit installation
- 41 in. diameter clear opening - although large cargo items are not carried in the orbiter crew compartment; the 41 in. diameter hatch is derived from commonality of RAM to MSS
- Establish, monitor, and maintain a habitable environment for shirtsleeve activities
- Pressure suits and related provisions for use with IVA airlock

COMMUNICATION LINKS (6)

Operation in three radio frequency bands, S-band, VHF, and Ku-band is recommended for RAM communication to ground or to other space elements. Equipment compatible with both the communication and ranging signals of the NASA ground network is recommended. Ku-band is needed to support a high (up to 35 Mbps) data rate link to ground via the TDRS. VHF can be used for low data rate and voice communication to ground via TDRS to provide greater than 90 percent orbital contact continuity.

When necessary, VHF can be used as a back-up link to other elements. Both S-band and VHF RAM terminals can adequately support the link criteria with omni-directional antennas. A high-gain, 45 dB, directional antenna is needed to support the link from RAM to TDRS or RAM to MSS with sufficient link margin.

Selection Considerations

Communications and Detached Element Operations each considered three alternate approaches:

a. Element-to-element
b. Element-to-ground direct
c. Element-to-ground via TDRS

All these approaches are required to fulfill the operations of RAM missions. High data rates (≃ 35Mbps), B&W TV (2.9 mHz) data transfer, the large quantities of daily data generation and the desire for near-continuous communication with ground necessitates the use of the TDRS, Ku-band links. Direct to ground links at S-band support tracking and ranging operations as well as provide a second ground link for data communications. S-band is also used for other element communications and tracking/ranging links. VHF can be used as a back-up voice and low data rate link as well as support TDRS order wire service.

Equipment at these frequency bands provides compatibility with cooperative terminals without necessitating any technology breakthroughs or any changes to existing or presently planned NASA space/ground networks.

(6) Refer to Table 4-2 and Table 4-4

MSS Design/Operational Influence

Implementation of all three approaches requires that the RAM provide the following to meet the approach requirements:

	Antenna System	Receiver System	Transmitter System
S-band equipment	Omni-directional	800°K system Noise Temp.	30 watts RF Power output
Data capability	--	10 Kbps PRN range	1 Mbps T.A.-PRN range
VHF equipment	Omni-directional	1200°K system Noise Temp.	25 watts RF power output
Data capability	--	1 Kbps 1 voice channel	10 Kbps 1 voice channel
Ku-band equipment	5' parabolic steerable antenna	1200°K system Noise temp.	25 watts RF power output
Data capability	--	10 Kbps PRN range	Up to 35 Mbps 2.9 Mhz B&W TV T.A. PRN range

Design/Operation Influences on Interfacing Elements

RAM interfaces with Ground (direct or via TDRS) and/or MSS to transfer large quantities of digital data and or TV signals. Ku-band is used for this purpose in operation with TDRS. MSS can use the Ku-band link for the higher data rates and TV and, therefore, must provide Ku-band capability. Interfaces with EOS and TUG are limited to operations consistent with rendezvous, stationkeeping and orbital emplacement or logistics missions. These activities require a cooperative terminal on S-band on these elements for Telemetry, Tracking or Command (TT&C) functions. MSS would support TT&C in a similar manner. VHF can be used as a back-up link for these terminals.

AUTONOMOUS CONTROL FOR RENDEZVOUS AND STATIONKEEPING (7)

It is recommended that any unmanned RAM Rendezvous and Stationkeeping operations be controlled by either Ground or by another Space Element.

The RAM, however, must act as an active target element but not a control element, when it is performing these operations with the MSS.

Selection Considerations

Rendezvous, Stationkeeping and Detached Element Operations interfacing activities supported by the Communications activity considered three basic alternate approaches for control, as follows:

1. Autonomous or independent
2. Ground control
3. Space control

The RAM will be involved in each of the alternate approaches during its range of missions. It will be a target element for an MSS or EOS when the autonomous mode is used at separation distances of 50 n miles and less. At greater distances, when necessary to LOS, ground or autonomous control can be used.

With an unmanned TUG, these operations will be controlled by either ground or a third manned space control element. At close distances, control will be performed by ground but one vehicle must have range, range-rate measuring equipment and be capable of relaying this information to ground.

Safety and successful completion of the operation dictate the need for control by manned element-either space or ground.

(7) Refer to Table 4-2 and Figure 4-4

Design/Operational Influence

Operation in the three control modes requires that the MSS and its interfacing element provides the following to meet the control requirements:

		RAM	Interfacing Element TUG, EOS, MSS, CPS, RNS
1.	For separation distances >50 n miles S-band PRN Ranging equipment	Respond	Measure
2.	For separation distances <50 n miles Scanning laser Radar	Passive Optical Reflectors	Active SLR to Measure
3.	Communication link at S-band or VHF to provide RAM to target command operation and to provide target to RAM vehicle status as well as command verification.	S-band or VHF Transmitter and Receiver with Omni directional antenna	S-band or VHF Transmitter and Receiver with Omni directional antenna
4.	A TV camera for inspection purposes.	Not Applicable	Under EOS, TUG, MSS control
5.	An attitude reference with an accuracy of $\pm$ 0.5 degree	Yes	Yes
6.	An attitude control capable of $\pm$ 0.5 degree stabilization	Yes	Yes
7.	Delta-V maneuver capability	Yes	For orbital makeup only.
8.	Onboard computation capability	Yes for total mission operation	For attitude determination and control only

TRANSFER OF FLUIDS TO RAM (8)

RAM require interconnecting fluid lines to the MSS and EOS, both for routine subsystem support, and for periodic DRAM servicing. The interface should consist of fixed plumbing at adjacent locations which are manually interconnected.

Selection Considerations

Fluid transfer (other than that which is transferred in bulk packages) considered three approaches: 1) Manual Temporary, 2) Manual Plumbed, and 3) Automatic Plumbed.

The recommended Manual-Plumbed concept consists of rigid, permanently-affixed plumbing, which is brought to a terminus close to the element interface. Final connection is done manually by short, flexible, semi-rigid, or rigid attachments. The concept has the highest reliability and damage protection, allows fixed purging and venting provisions, and permits hazardous fluid lines to be installed completely outside the pressure shell.

Manual Temporary approach (No. 1), which consists essentially of stringing hoses across the interface, is the simplest design, and might be satisfactory for infrequent use, but it has significant disadvantages. It encroaches on the crew access path and is subject to damage or entanglement, especially with non-rigid pressure lines. Also it is not susceptible to venting and purging provisions especially for accidental breaks in the connected line. This could be prohibitive even for safe liquids, but especially for hazardous liquids or gases.

For some element interfaces, e.g., unmanned payloads where crew access is not feasible, the Automatic-Plumbed method may be required, and is recommended in addition to the Manual-Plumbed concept for such special cases. While making connections automatically during mating is feasible, it has the disadvantages of requiring precision indexing and greater potential for damaged connectors.

(8) Refer to Table 4-2 and Figure 4-4

Design/Operational Influences

- Manual Plumbed

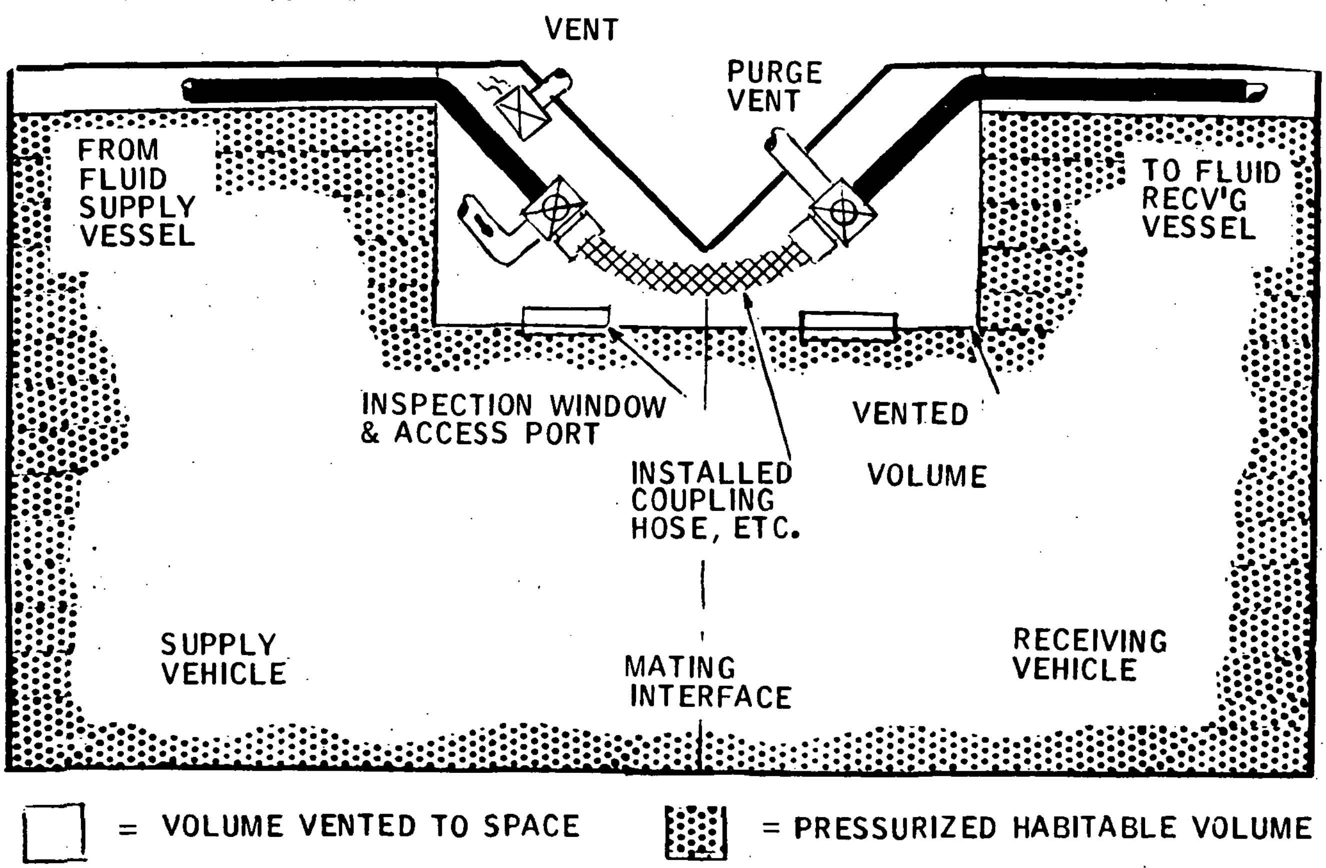
  1) Common, indexed docking interface--RAM-to-EOS, RAM-to-MSS, and RAM-to-RAM

  2) Crew workspace at the shared interface volume--48-inch diameter (minimum) adjacent to the line(s) requiring connecting, (3) EOS and MSS must have provisions to accommodate a range of payloads even where there is not complete correlation in the fluids required by each payload. The figure, below, illustrates typical fluid line installation.

- Automatic Plumbed

  1) Requires commonality of fluid interfaces.

  2) Requires precision indexing of interconnects.



Manual Plumbed Fluid Connection

ATTACHED ELEMENT SUBSYSTEM SUPPORT (RAM) (9)

This study recommends that the RAM utilize EOS "available" subsystem capability and the "designated" MSS subsystem capability.

NOTE: "Available" means that quantity of capability inherently required for normal EOS mission sizing that is not fully utilized on any specific flight. "Designated" means that quantity specifically provided a part of the basic design to support a multi-disciplinary experiment and applications program.

Selection Considerations

The Attached Element Operations interfacing activity considered three generic approaches for attached element support from the EOS:

1) Payload Dependent on EOS/MSS
2) Payload Independent of EOS/MSS
3) Payload Dependent on added modules or kits

The following matrix represents the selected approach for the major subsystem functions:

Function		1) Dependent	2) Independ.	3) Modular Dependent
Tracking and voice		✓	-	-
Data	MSS	✓	-	-
	EOS	1 Mbps	10-50 Mbps	1-10 Mbps
Electrical power	MSS	✓	-	
	EOS	500 W avg and 20 kw-hr max.	500 W avg and 20 kw-hr max.	
Attitude stability	MSS	0.25 deg and 0.05 deg/sec	-	0.25 deg and 0.05 deg/sec
	EOS	0.5 deg and 0.05 deg/sec	-	0.5 deg and 0.05 deg/sec
Envir. control	MSS	Basic atmosphere and utilities	Emergency & circulation	Contamination and waste
	EOS		✓	
Thermal control	MSS	✓	-	-
	EOS	-	✓	-
Habitability	MSS	✓	-	-
	EOS	Pre- and post-orbit	-	On-orbit hygiene and food prep.

(9) Refer to Table 4-2 and Figure 4-4

RAM FUNCTIONAL REQUIREMENTS

The vehicle functional requirements for the Research and Applications Module--RAM (both attached and detached) were developed from the functional requirements defined for each of the 14 interfacing activities. This subsection will contain the requirements that relate principally to the RAM and are necessary for performing the interfacing activities. Along with the functional requirement there will be a cross-reference mode to the interfacing activity that established the requirement. There are eight categories of functional requirements. The initial category contains the system level (i.e., those that apply to more than one subsystem or relate to the performance of the entire system as a whole) functional requirements. The following seven categories contain the functional requirements by subsystem, again with references to the appropriate interfacing activity where the requirement was established.

A separate numerical designator has been established for each of the eight functional requirement categories as follows:

Category	Designator
RAM System	1-X
Structures/Mechanical Subsystem	2-X
Environmental Control Subsystem	3-X
Electrical Power Subsystem	4-X
Guidance and Control Subsystem	5-X
Propulsion Subsystem	6-X
Communication/Data Management Subsystem	7-X
Crew/Habitability Subsystem	8-X

SYSTEM FUNCTIONAL REQUIREMENTS

1-1. Alignment aids shall provide relative positional information from RAM to mating elements. The information provided shall be centerline miss distance and angular misalignment.

Accuracy shall be as follows:

automatic systems, such as laser radar: +/- 1 degree

direct visual systems: knowledge to identify when the vehicles are off aligned with the mating port centerlines greater than 3 degrees

(Mating 5)

1-2. Residual attitude misalignments remaining after capture shall be corrected by the active vehicle prior to rigidizing. (Mating 16)

1-3. The mating interfaces shall be drawn together by the active vehicle mating system to remove residual attenuation stroke and seat the interfaces. The rate at which the vehicles are drawn together must be controlled to within the structural capability of the docking ports. (Mating 17)

1-4. Propulsive venting (other than attitude control systems) shall be inhibited or controlled during the mating and separation operations. During mated operations venting must still be controlled, particularly venting of condensable gases to minimize exterior contamination of susceptible elements. However, if venting is necessary, it should be performed on an intermittent least-interference basis. (Mating 19, Separation 12, Attached Element Operations 9)

1-5. Throughout mated operations, the mated RAM shall be capable of being separated upon command. This requirement naturally applies only after the interface between the elements has been properly isolated/sealed for safe separation or before the interface hatches have been opened. (Mating 25) (See Separation 14)

a. Once separation occurs, one or both of the elements shall maneuver to a safe distance prior to resuming operations. A minimum safe distance can be determined by computing a passive vehicle worst trajectory assuming jet "stuck-on" failure giving both translation and rotation. A minimum time to a safe distance during jettision shall be established by "hardover" rotational control system failure of either vehicle. (Separation 4)

b. The separation system shall be capable of being inhibited after mating operations are secure and before the interface hatches are opened.

1-6. Throughout a docking or separation maneuver the control systems of both vehicles shall be monitored for indications of control failures such as reaction jet "stuck-on" and "stuck-off". (Mating 26, Separation 5)

1-7. Prior to activation of fluid interfaces, seal integrity should be verified. Deviation is not permitted where liquids or hazardous gases are involved. For non-hazardous gases, the lines shall be activated individually with the interface integrity verified prior to activation of the next line. (Mating 29, Orbital Assembly 16)

1-8. Interface assemblies that contain plugs, receptacles, and couplings shall be equipped with compatible guides such that alignment will be achieved prior to engagement of the connectors. Individual connectors and fluid couplings shall be provided with independent mechanical guides such that alignment is achieved prior to engagement of connector pins or fluid coupling interface seals. (Mating 30, Orbital Assembly 23)

1-9. Extension and connection of automatic utility interface connectors and couplings shall be delayed until after the mating rigidizing mechanism has engaged and locked up. (Mating 31, Orbital Assembly 17)

1-10. Manual interface connections shall be located, designed, and mounted such that a worker can mate the connectors in a pressurized IVA suit. (Mating 32, Cargo Transfer 34)

1-11. Manual interconnects shall be located to permit visual inspection of the connection. Where possible provision shall be made to permit inspection of automatic couplings. (Mating 33, Orbital Assembly 22)

1-12. Electrical cables and fluid lines that traverse crew and cargo passages shall be suitably enclosed or otherwise protected to minimize hazards to the crew and provide protection for the hardware. (Mating 34, Orbital Assembly 24)

1-13. For a jet translation separation where alignment is critical and alignment aids are utilized, the alignment aids must be active and aligned before separating. (Separation 3)

1-14. The separation technique shall be such that no damage will occur to the mating ports such that succeeding matings and separations cannot occur. The mating ports shall be left in a condition ready for a subsequent mate, unless remote control configuring of the mating port is available (e.g., the rigidizing latches shall be unlocked and recycled, the draw-down system shall extend the attenuators to the unstraped position, and the capture latches unlocked and recycled). (Separation 13)

1-15. A credible accident to, or a credible failure of an interface function or adjacent function shall not cause the loss of redundantly provided functions or compound the accident or failure by creating additional hazards (explosion, fire). In this sense, the following criteria apply. (Mating 37, Orbital Assembly 28, Cargo Transfer 31 and 32)

a. Hazardous fluid lines shall be barriered or physically separated from power wires and each other (O_2 lines shall be considered hazardous in interface areas).

b. Redundant fluid lines shall be separated a minimum of 45 degrees.

c. Redundant connectors shall be separated a minimum of 45 degrees.

1-16. The interface between mated elements must be designed to be closed and sealed without performing a prolonged demating of interface connectors. (Mating 39, Attached Element Operations 18)

1-17. The RAM, 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. (Attached Element Operations 13)

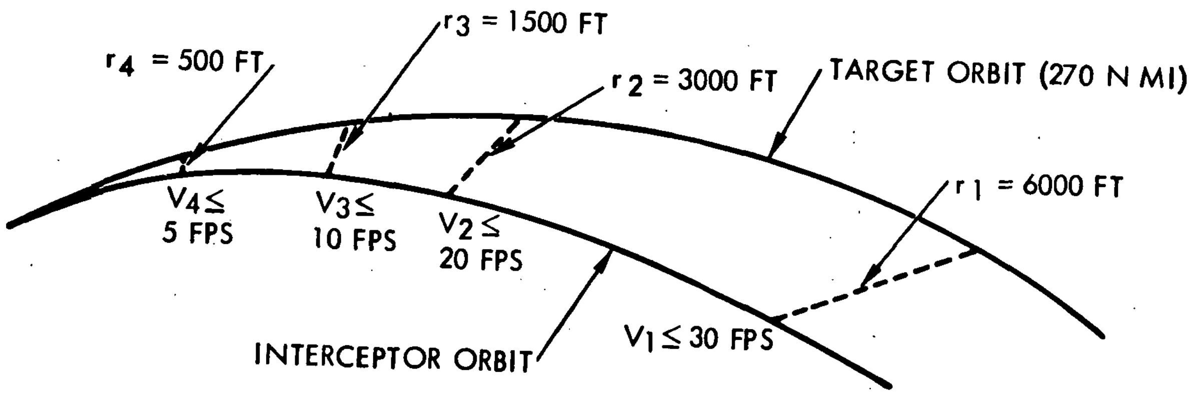
1-18. Hazardous fluid interconnects that are to be disconnected shall be purged with a non-hazardous (inert) gas and shall be pressure vented prior to separation. (Separation 18, Attached Element Operations 25)

1-19. Prior to initiation of the separation routine those subsystems that will be utilized during the separation activity shall be verified. Where backup systems are available, these shall also be statused. (Separation 19)

1-20. When hatches between elements are closed such that separation can occur, the hatch seal integrity shall be verified. (Separation 20)

1-21. During terminal rendezvous a braking gate similar to that shown below, where the relative velocity (V_r) varies with the relative distance between elements must be satisfied. (Rendezvous 11)

Braking Gate Criteria



NOTE: BRAKING GATE ΔV'S APPLIED ALONG LINE OF SIGHT

1-22. Accessible surfaces shall be capable of being touched by a crewman in shirtsleeve or spacesuit. Surface materials shall be selected to ensure that high and low temperatures and conductivity are not limiting factors in crew or cargo transfer. (Crew Transfer 5, Cargo Transfer 14)

1-23. All equipment installations within crew mobility areas shall be capable for use for push-off. Installations be capable of withstanding multi-directional application of crewman impact loads. (Crew Transfer 9, Cargo Transfer 20)

1-24. Equipment susceptible to damage or that is hazardous to crew and cargo transfer operations shall be separated from crew mobility areas and color-coded or placarded. (Crew Transfer 10, Cargo Transfer 21)

1-25. All hatches between elements shall be capable of operation from either side of the hatch, including a capability for pressure equalization across the hatch. Included is the capability for pressure monitoring and leak rate checks. This shall include any docking interface volume. (Crew Transfer 12, Cargo Transfer 22, Attached Element Operations 21, Orbital Assembly 40)

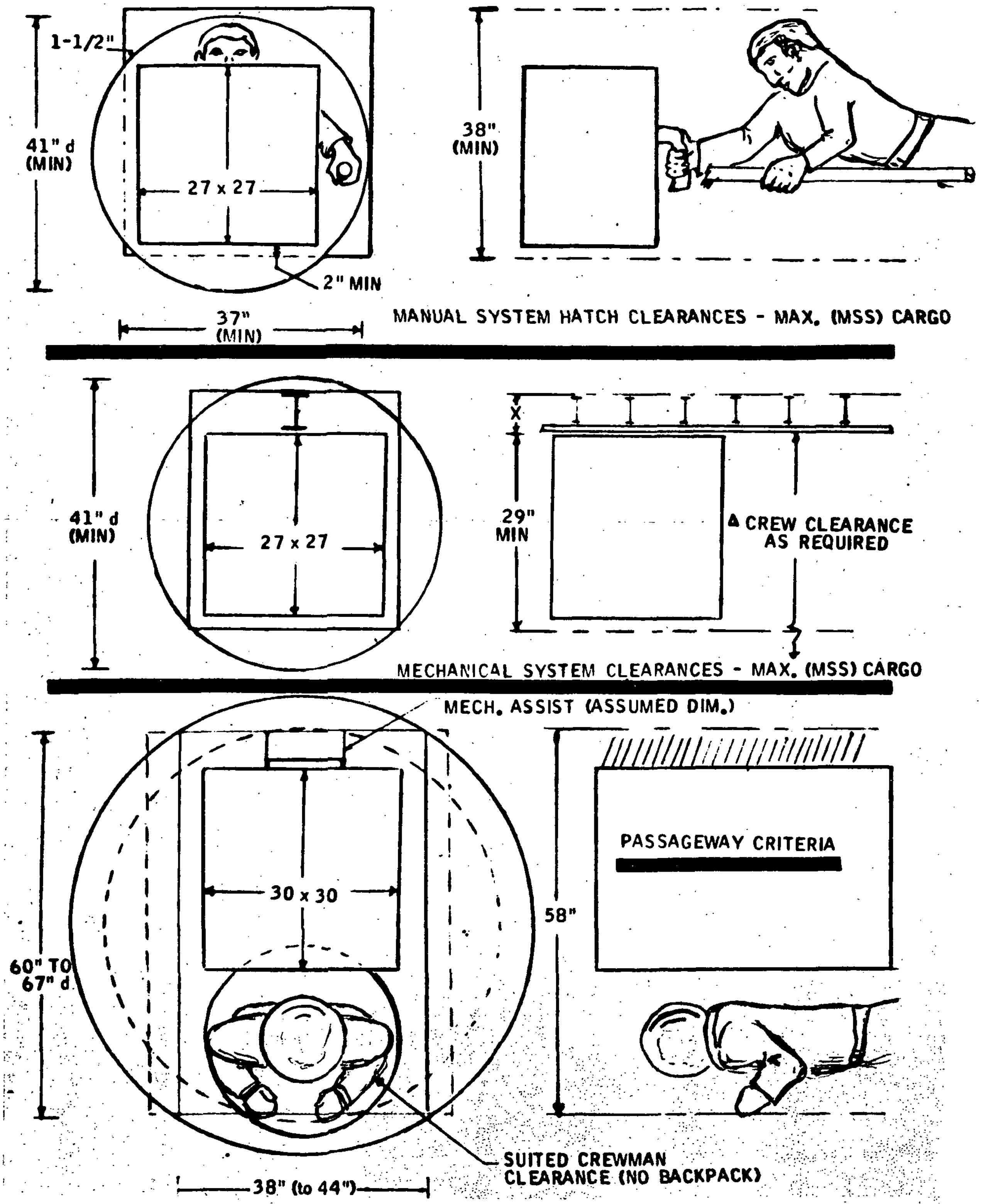
1-26. Acceptable noise levels shall be maintained during crew and cargo transfer operations to prevent discomfort to crew members and interference with verbal communications at normal voice levels. (Crew Transfer 14, Cargo Transfer 24)

1-27. Passageways/aisles shall be capable of accommodating crew and cargo transfer operational requirements. Page 4-38 illustrates primary passageway criteria. (Crew Transfer 18, Cargo Transfer 25, Attached Element Operations 30)

1-28. Atmospheric contamination levels shall be monitored within habitable areas for 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 per the following table. (Crew Transfer 19, Cargo Transfer 26, Attached Element Operations 16)

Atmospheric Criteria

Humidity	Water vapor partial press: 8-12 mm Hg
Temperature	65 to 85 degrees F
Air velocity	15 (min) to 100 (max) feet per minute. 40 feet per minute nominal
Oxygen	P_p 3.1 psi
Odor	Controlled
Carbon Dioxide	<7.6 mmHg
Microbiological, bacterio-contaminants	Controlled
Radiation level	Safe level



Cargo Transfer Sizing

1-29. The capability shall be provided to ensure that passageways/hatchways to a normally uninhabited element are free of obstructions so that crew can enter safely and cargo movement will not be inhibited. This may include direct visual inspection through a view window or remotely monitored sensors or closed circuit television. (Crew Transfer 21, Cargo Transfer 28)

1-30. The weight (mass) of cargo/resupply items requiring manual handling will be limited by crew maneuvering capabilities. Cargo transfer approaches, except 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 the table below. For two men, a 250-pound mass is considered the upper limit. (Cargo Transfer 1)

Crew Cargo Mass Handling Limits (190-lb Crewman)

g level	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	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	51	55	58	59	60

1-31. 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. (Cargo Transfer 2)

1-32. Individual cargo items within a general container shall be packaged to prevent movement or damage during transfer. (Cargo Transfer 6)

1-33. Containers that enclose pressure vessels shall be connected to vents prior to and after transfer. (Cargo Transfer 7)

1-34. All fluid lines shall be secured to the requirements of the fluids being transferred. (Cargo Transfer 30)

1-35. A method shall be provided whereby fluid interfaces can be verified to be free of residuals that may contaminate the surrounding environment prior to disconnect. (Cargo Transfer 33)

1-36. Leak detection sensors shall be provided when transferring any contaminable fluid. Vent systems are required to protect against contamination for plumbed transfer. (Cargo Transfer 35)

1-37. RAM shall augment attitude pointing, orientation maneuvering, attitude hold deadband (limit cycle), and attitude rate as provided by attaching element, to meet experiment needs. (Attached Element Operations 7)

STRUCTURES/MECHANICAL SUBSYSTEM FUNCTIONAL REQUIREMENTS

2-1. Protection of eyes and video visual system from reflected or high intensity light damage shall be provided. (Mating 2)

2-2. Mating port mechanisms shall be designed to the following criteria: (Mating 12)

a. The design shall be applicable to direct docking and manipulator berthing operations. The concept may be of a design that will perform one type of mating, but with an adapter added can perform the other type.

b. The design shall be inherently dynamically stable when fully engaged to an associated mating port.

c. The design shall provide redundant features where active mechanisms are involved.

d. Both active and passive mating systems shall incorporate in their design the means to automatically reduce angular misalignment and lateral miss distance between the mating interfaces to permit initial capture on first structural connection (i.e., the capture mechanisms shall be automatically triggered and self-locking). The duration of time between triggering and capture latch engagement shall be minimized to prevent the latch from missing if an element rebounds out of the mechanism.

e. A method of monitoring the status of capture mechanism (latch position) shall be provided.

f. The capture mechanism shall be capable of quick release and recycle to its initial state at any phase of the capture operation.

g. The mating port shall be capable of successfully capturing and hard docking to an opposing mating port with a miss distance and misalignment tolerance as follows:

Miss distance: ± 6 inches min.
Misalignment: ± 3 degrees min.
(Pitch, yaw, roll)

h. Mating port design shall be capable of accommodating the full complex of study vehicles identified. Vehicle masses range between 500 slugs and 4000 slugs.

2-3. RAM's shall be designed with a common androgynous mating port system or with a passive concept that mates with the androgynous concept. (Mating 13)

2-4 The mating interfaces shall be structurally connected either automatically or manually to provide the required intervehicular stiffness for combined vehicle maneuvering. The engaged and locked rigidizing latches shall be preloaded such that the fundamental bending/torsional mode of the mated pairs is determined by the primary structures of the mated pairs; i.e., latch spring stiffness shall not affect vehicle control systems that depend on structural modes. (Mating 20)

2-5. Mechanical radial position and roll indexing shall be provided at the mated interface to prevent interface slippage and damage to pressure seals during combined vehicle maneuvering. (Mating 21)

2-6. The capability to inspect, maintain, and manually recycle both capture and rigidizing latches in a shirtsleeve environment shall be provided. (Mating 23)

2-7. The tunnel leak rate between the mated elements shall be no greater than the leak rate of the hatch seal of the individual elements. (Mating 36)

2-8. Separation velocities and angular rates caused by the extension of shock attenuation system or other energy storage system shall be controlled by delaying release until the extension dynamics cease. (Separation 2)

2-9. A window or other viewing method shall be provided through each pressure hatch that is capable of being closed for either normal or emergency operations. This permits crew observation of IVA operations and viewing prior to ingress whenever hatches are closed. (Attached Element Operations 15, Crew Transfer 13)

2-10. 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. (Cargo Transfer 3)

2-11. 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 area required for crew transfer. (Cargo Transfer 8)

2-12. 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. (Cargo Transfer 9)

2-13. 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. (Cargo Transfer 10)

2-14. Impact velocities and alignment of automatic interconnections shall be controlled to prevent damaging electrical connectors and fluid couplings. (Orbital Assembly 18)

2-15. Rigidizing techniques shall be designed such that during the application of the rigidization, the module structural fabrication cannot be overstressed. (Orbital Assembly 39)

ENVIRONMENTAL CONTROL LIFE SUPPORT SUBSYSTEM FUNCTIONAL REQUIREMENTS

3-1. Pressure equalization capability and leak rate verification transducers shall be provided on each side of each docking interface hatch requiring shirtsleeve environment for manned mated operations. (Mating 26)

3-2. Prior to separation, the pressurized tunnel between the elements must be pumped down or vented to space. The pressure remaining in the tunnel shall be low enough such that when separation occurs no noticeable delta velocity, due to the remaining pressure, will be imparted to the separating elements. (Separation 9, Attached Element Operations 22)

3-3 A RAM attached to an EOS shall provide its own environmental control system capability. (Attached Element Operations 29)

ELECTRICAL POWER SUBSYSTEM FUNCTIONAL REQUIREMENTS

4-1. All electrical and signal interfaces shall be deadfaced prior to being connected or disconnected. (Mating 27, Separation 16, Orbital Assembly 14)

4-2. Prior to activating electrical interface circuits or closing deadface switches, proper mate of the interface connectors shall be verified. (Mating 28, Orbital Assembly 15)

4-3. When electrical or fluid interfaces are to be mated between elements, a ground connection between the element structures shall be established to provide a consistent measured low impedance bond between the elements rather than rely on the mating interface for structural ground. (Mating 38, Orbital Assembly 29)

4-4. For mating operations, DRAM shall provide self-illumination. The lighting shall provide the capability to identify the orientation of the DRAM at a minimum range of 1000 feet. Colored lighting or light patterns should be used to aid in visual acquisition and proper geometric orientation between the two vehicles. The lights should present a narrow beam output, be spectrally tailored to the most sensitive visual threshold, and probably utilize a flash (strobe) mode.

Lighting shall artificially illuminate the mating ports to the extent that they can be inspected utilizing closed circuit television or optical aids at ranges of 20 feet to 100 feet or direct visual at a range of less than 20 feet.

Passive mating aids that require direct viewing (targets) shall be artificially illuminated. Illumination criteria is as follows:

The aids shall stand out and not be obscured by other lighting on the vehicle (colored lighting is acceptable).

The illumination does not blur characteristics of the aid (cross hairs).

Active vehicle lighting shall not cause reflections on the aids that will obscure characteristics.

The aids can be utilized at distances up to 100 feet.

(Mating 1)

4-5. Electrical power in support of the attached RAM , pallet experiment and detached RAM may be limited to the following: (Attached Element Operations 1)

	Min.	Max.	
Peak power (watts)	100	7,000	
Average power (watts)	100	4,500	
Energy (kw-hr)	1	110	(7-day sortie)
	1	476	(30-day sortie)

4-6. Illumination of the separating element(s) is required by the ARAM for separation where man is involved or when remote television coverage is required for unmanned elements. Illumination shall be such that appendages of associated elements are visible and element attitude and stabilization can be ascertained. The illumination can be provided independently by each element or one of the elements can illuminate the opposing element utilizing floodlights. Floodlight usage shall be designed such that it does not blind alignment sensors or opposing pilots. (Separation 15)

4-7. Adequate lighting shall be provided along all personnel crew transfer routes. General illumination criteria for shirtsleeve operations are presented below. (Crew Transfer 11, Cargo Transfer 5, Orbital Assembly 8)

Tasks	Description	Illumination (ft-c)		
		Max.	Desirable Range	Min.
General	General lighting requirements 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

GUIDANCE AND CONTROL SUBSYSTEM FUNCTIONAL REQUIREMENTS

5-1. For inspection routines, the RAM shall maintain an attitude hold of ± 5 degrees and a rate deadband no greater than 0.5 degree/second. (± 1.0 degree and 0.05 degree/second for manipulator capture.) Standoff distance between the elements for the inspection will depend on the configuration of the elements, the inspection aids available, and the inspection detail required. (Mating 7 and 8)

5-2. Prior to separation, one element will be maintaining attitude hold control of the mated pair. At separation, the RAM will have attitude control capability. (Separation 1)

For a jet translation separation, the RAM will be only holding attitude.

5-3. Prior to final separation, the attitude reference systems of the RAM will be aligned. (Separation 11)

5-4. RAM must contain an attitude reference system, either horizon sensor, or star tracker capable of determining the element attitude in relation to the element coordinates and orbital or earth coordinates.

For these requirements the attitude reference system shall be capable of measuring attitude to an accuracy of ± 0.5 degree. (Rendezvous 4)

5-5. RAM must contain an attitude reference system capable of determing the element attitude in relation to the element coordinates and orbital or earth coordinates. Knowledge of element attitude is necessary for the pointing of on-board sensors, antennas, and for orientation to perform delta-V orbital makeup maneuvers. (Stationkeeping 2)

5-6. RAM must have attitude control enabling implementation of a change in attitude. (Stationkeeping 5)

PROPULSION SUBSYSTEM FUNCTIONAL REQUIREMENTS

6-1. Prior to contact between the mating interfaces, the relative closing rate (axial velocity) must be reduced to a velocity that is compatible with both vehicles structure and mating port energy absorption capabilities. (Mating 14)

The range of closing velocities for the RAM are as follows:

Longitudinal velocity -
with attenuation, 0.3 fps to 0.4 fps
without attenuation, 0.05 fps to 0.12 fps

Lateral velocity -
with attenuation, 0.16 fps to 0.4 fps
without attenuation, 0.05 fps to 0.12 fps

Angular velocity -
0.1 d/s to 0.3 d/s

6-2. Translation jets utilized for separation shall be selected and propellants utilized so as to minimize the effects of exhaust plume impingement on sensitive areas of interfacing elements. This applies where more than one set of jets can be selected. (Separation 6)

6-3. Detached RAM must have propulsive systems capable of performing delta velocity maneuvers in accordance with the computed requirements for orbital makeup. (Stationkeeping 10)

COMMUNICATIONS/DATA MANAGEMENT SUBSYSTEM FUNCTIONAL REQUIREMENTS

7-1. Electronic acquisition for automated docking maneuver control shall have remote backup for manual override of the docking operation. If the manual override is to continue the docking rather than abort the functions, visual capability must be provided through a video system to the remote control site. (Mating 10)

7-2. After mating, one of the vehicle control systems shall be inhibited to permit combined vehicle maneuvering and prevent inadvertent control system activity resulting in plume impingement damage. (Mating 24)

7-3. Sensing shall be provided to ascertain positive capture has occurred at the mating port or for positive separation prior to initiating a jet separation or mechanical extension by a manipulator. (Separation 7, Mating 12, Attached Element Operations 5, Orbital Assembly 19)

A measurement system must be available that is capable of determining rendezvous elements relative range and range rate. These data must be available at the location of the controlling unit. It shall be capable of providing these measurements to the following nominal accuracies:

Range	Range Accuracy	Range Rate
10 to 50 feet	±6 in.	±0.1 ft/sec
50 ft to 30 n mi	±5 ft	±0.5 ft/sec
30 to 60 n mi	±100 ft	±1.0 ft/sec
60 n mi and over	±1 n mi	±10 ft/sec

(Rendezvous - 7)

7-5. 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. (Attached Element Operations 4)

7-6. 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. (Attached Element Operations 24)

7-7. There shall be a means of monitoring the RAM subsystem parameters from the supporting vehicle. (Attached Element Operations 27)

7-8. Communications capability shall be provided for crew members. Two-way voice communications must be maintained to IVA crewmen at all times. (Crew Transfer 16, Cargo Transfer 17, Orbital Assembly 10)

7-9. Audio and visual alarms shall be provided along crew and cargo transfer routes. Audio alarms could be tone and/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. (Crew Transfer 20, Cargo Transfer 27)

7-10. A means shall be provided in the detached RAM for processing and storing operations commands and for transmitting verification signals for authentication and execution authority and operation-executed signals/data.

7-11. Data processing, storage, and display provisions shall be available in the ARAM for handling dumped or real-time data transferred from the detached element and/or for evaluation and utilization of such data. (Detached Element Operations 6)

7-12. A means shall be provided in the detached RAM for onboard collection, recording, and storage of data, and for dumping or real-time transfer. (Detached Element Operations 7)

7-13. Monitoring and checkout of detached element condition, operations, and equipments by continuous or periodic interrogations shall be provided for determining element status, isolating faults, processing and displaying such data for evaluation and possible correction. (Detached Element Operations 8)

7-14. ARAM shall have the means for inspection of the detached element by direct visual observation or by a television system. (Detached Element Operations 11, Mating 3)

7-15. The RAM shall be equipped with RF communications systems. The minimum characteristics of the system are given on page 4-51. The system shall at a minimum, have the capabilities defined in the table on pages 4-52 and 4-53.
(Mating 40, Separation 8, Rendezvous 6, Stationkeeping 4, 6, 7, 8, 11, Detached Element Operations 1 and 4, and Communications 1 through 11)

Communication/Data Management
Characteristics

RAM

Operation With
RAM, EOS, MSS, Tug, Ground Station, TDRS

Frequency Band	Ku	S	VHF
Frequency Ret.	14.4 - 15.35 GHz	2200 - 2300 MHz	136 - 144 MHz
Fw.	13.4 - 14.2 GHz	2025 - 2120 MHz	126 - 130 MHz
Data - Transmit			
Analog - voice	--	--	--
Analog - TV	B&W - 2.9 MHz		--
Digital	35 Mbps	1 Mbps	10 kbps
Data - Receive			
Analog - voice	--	--	--
Analog - TV	--	--	--
Digital	10 kbps	10 bkps	1 kbps
Antenna Type	Parabolic	Omni	Omni
Gain	45 db	0 db	0 db
Size	5-foot		
Receiver Noise Temperature	1200 K	800 K	1200 K
Transmitter			
Power output	25 watts	30 watts	25 watts
Tracking/Ranging			
Measure	X	X	--
Respond	X	X	--
Passive optical reflectors for SLR for rendezvous and docking			

ARAM Capabilities

ARAM	MSS	EOS	DRAM	GROUND	SAT
1 Command Data Transmission to Digital, BER $1x10^{-6}$ Voice	NA	NA	10 kbps NA	NA NA	2 kbps
2 Command Verification Digital from BER $1x10^{-6}$ Receive/verify	NA	10 kbps Yes	NA NA	NA NA	2 kbps Yes
3 Data Storage Digital storage per day Later dump per day Film or tape delivery	NA	NA NA NA	$94x10^9$ (max) 30 Mbps for 1 hour 15 reels per day (to ground)	NA NA NA	NA NA NA
4 Digital Data Transfer Receive from Transmit to	10 kbps 35 Mbps	NA 5 kbps	10 kbps 10 kbps	10 kbps 35 Mbps	50 kbps 2 kbps
5 Analog Data Transfer From Voice (4 kHz) Channels Television Facsimile	1 NA NA	1 NA NA	NA NA NA	1 NA NA	NA NA NA
6 Tracking/Ranging PRN range capability ± 1000 ft/range ± 1 ft/sec range rate	NA	NA	NA	NA	Measure
7 Computer Capability to Determine Ephemerides	NA	NA	NA	NA	NA
8 Visual Inspection	NA	Yes,TV	Yes,TV	NA	Yes,TV
9 Analog Data Transmission to Voice (4 kHz) Channels Television Other	1 2.9 MHz TV NA	1 NA NA	NA NA NA	1 2.9 MHz B&W NA	NA NA NA

DRAM Element Pair Requirements Matrix

	DRAM	EOS/ARAM	MSS	TUG	GROUND
1	Command Data Transmission to Digital, BER 1×10^{-6} Voice (4 kHz)	NA →	→	→	NA
2	Command Verification Digital from BER 1×10^{-6} Receive/verify	NA →	→	→	NA
3	Data Storage				
	Digital storage per day	NA →	→	NA	94×10^9
	Later dump per day	NA →	→	NA	30 Mbps/for 1 hour
	Film or tape delivery	NA		NA	15 reels/day
4	Digital Data Transfer				
	Receive from	2 kbps	10 kbps	4 kbps	10 kbps
	Transmit to	5 kbps	50 kbps	4 kbps	35 Mbps
5	Analog Data Transfer Receive from				
	Voice (4 kHz) Channels	NA →	→	→	NA
	Television	NA →	→	→	NA
	Facsimile	NA →	→	→	NA
	Other	NA →	→	→	NA
6	Analog Data Transmission to				
	Voice (4 kHz)	NA →	→	→	NA
	Television	NA	B&W, 2.9 MHz	NA	B&W, 2.9 MHz
	Other	NA →	→	NA	7 MHz
7	Tracking/Ranging PRN range capability ±1000 ft/range ±1 ft/sec range rate	respond	measure respond	respond	respond
8	Computer Capability to Determine Ephemerides	NA →	→	→	NA
9	Visual Inspection	NA →	→	→	NA

CREW AND HABITABILITY SUBSYSTEM FUNCTIONAL REQUIREMENTS

8-1. If the logistics element is manned, a means shall be provided to perform visual tracking of the other element during the terminal phase at a separation of less than 5 miles. (Rendezvous 10)

8-2. All IVA, EVA, and hazardous shirtsleeve operations shall be conducted with a minimum of two crew members (buddy system). (Crew Transfer 1, Orbital Assembly 9)

8-3 The buddy crew members during IVA and hazardous shirtsleeve operations shall be positioned to observe the other crew member at all times and, in the case of IVA/EVA activities, will be required to control the active crew member tether and/or umbilical to prevent entanglement. A third crewman shall be available for voice communications and for C&W monitoring. (Crew Transfer 2)

8-4. Crew mobility aids and restraint devices shall be provided along all crew transfer routes and worksites in order to facilitate crew translation and stabilization in zero g environment. (Crew Transfer 3)

8-5. Crew mobility aids shall be capable of use by a 5 to 95 percentile crew member in either a shirtsleeve or pressurized 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 grasping the hand hold/hand rail. A circular cross section is applicable for nontorque applying forces while an elliptical cross section is required for application of torque forces. (Crew Transfer 4, Cargo Transfer 11)

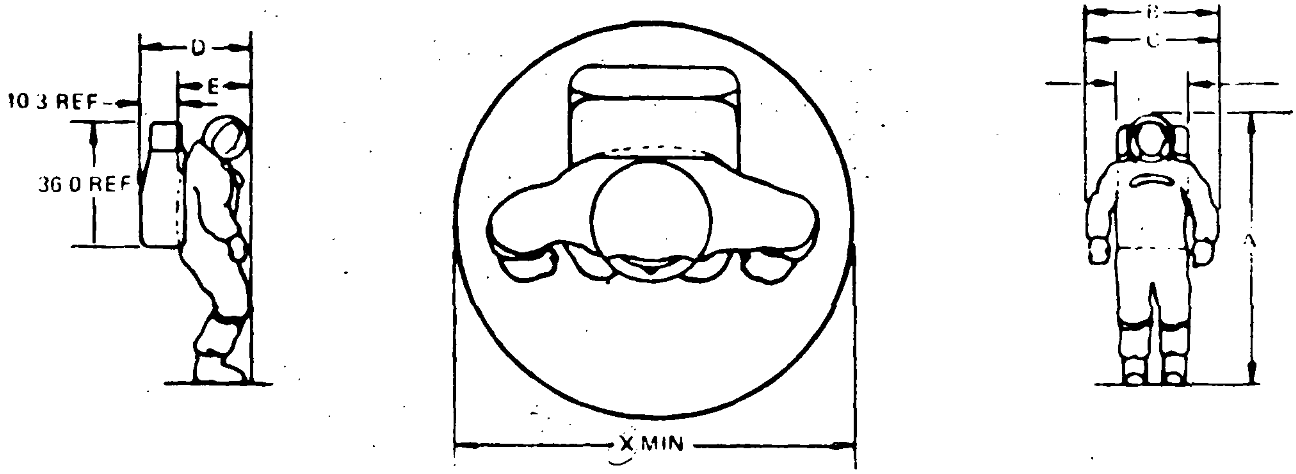
8-6. Crew restraint devices shall be capable of use by a 5 to 95 percentile crew member in either a shirtsleeve or pressurized suited mode of operation. Development of worksite crew restraint device requirements will be dependent upon the reach capability of the 5 to 95 percentile crew population while restrained by lower torso restraints. Figures on page 4-55 define anthropometric data. (Crew Transfer 6)

8-7. Crew restraint devices shall be easily operable, not restrictive of required crew motions, and possess a high degree of crew acceptability. (Crew Transfer 7)

8-8. Crew restraint devices shall be designed to allow crew members to apply various combinations of loads at 1 g equivalent force values, with or without a pressurized space suit. (Crew Transfer 8, Cargo Transfer 16)

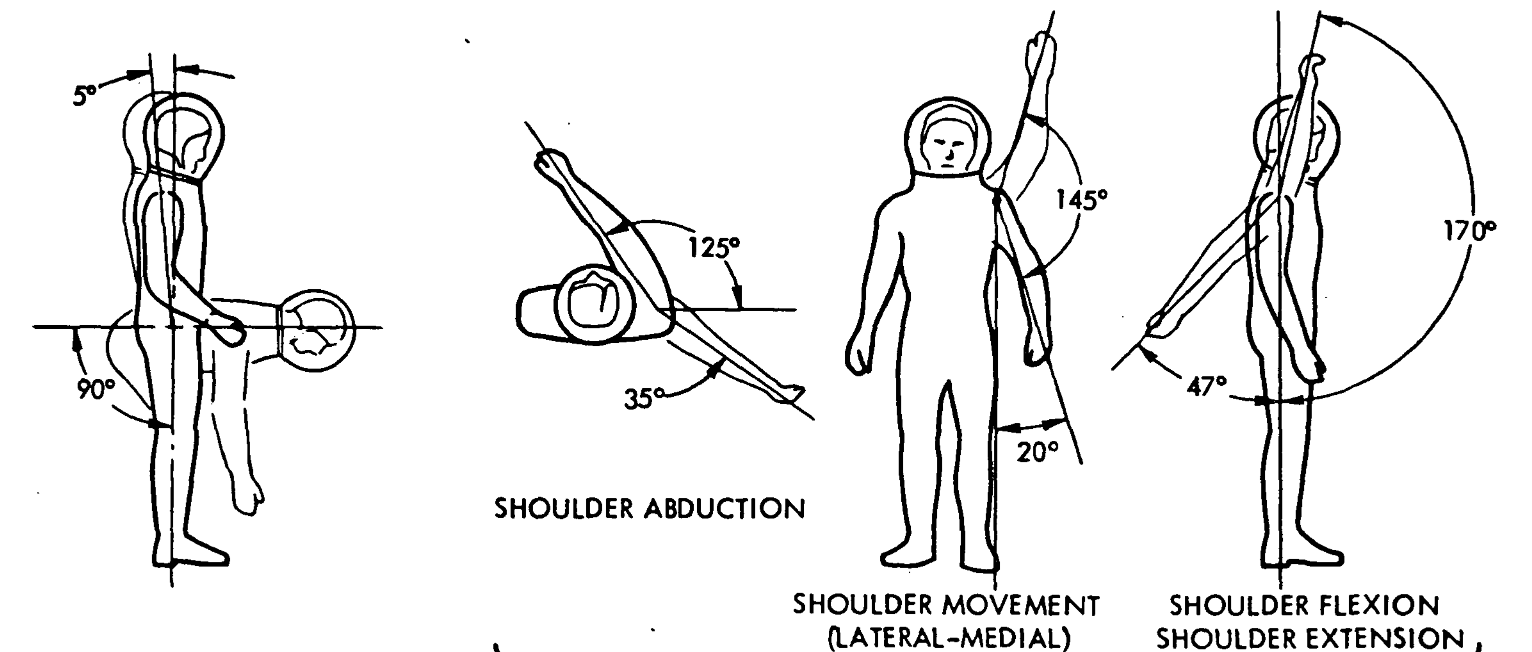
8-9. Cargo restraint devices shall be capable of single hand attachment operations by a crew man in a pressurized space suit. (Cargo Transfer 4)

8-10. Crew restraint devices shall be provided along the cargo transfer path and at cargo transfer worksites to provide capability for crewman positioning and stabilization. (Cargo Transfer 15)



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



A. HIP AND WAIST MOBILITY

B. SHOULDER MOBILITY

8-11. 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 surrouding structure. (Cargo Transfer 18)

8-12. RAM operations shall exclude mandatory use of the orbiter pilot and copilot. (Attached Element Operations 11)

SECTION 5. MODULAR SPACE STATION (MSS)

The assembly of a space station in earth orbit is planned to begin in the early 1980's. The space station will extend the capability of the sortie module to operate continuously and autonomously in space for long periods of time. The size and capability of the space station will be flexible in that it can be placed in operation, then extended or modified to satisfy changing requirements. Its modules will be launched into earth orbit and provided periodic logistics support by the EOS.

Since it will be a relatively permanent as well as flexible laboratory, the space station will make it possible to conduct diverse experiments in space. These experiments further broaden the scope of science and applications information available, observe the physical and psychological behavior of varied groups of individuals and the performance of their support equipment over extended periods of time, and develop experience in the operation of systems requiring long operating lifetimes in space. The space station will thus complement the short duration sortie missions through its capability to extend almost indefinitely the periods of observation in space.

The EOS-launched space station configuration described in Figure 5-1 and Table 5-1 can be readily adapted to other applications. For example, with minor modifications, the modules can be applied to a geosynchronous space station or an orbiting lunar station. With more extensive modifications, the modules could be assembled into a lunar surface base. By adding modules of similar design, the initial six-man station can be extended to a 12-man capability.

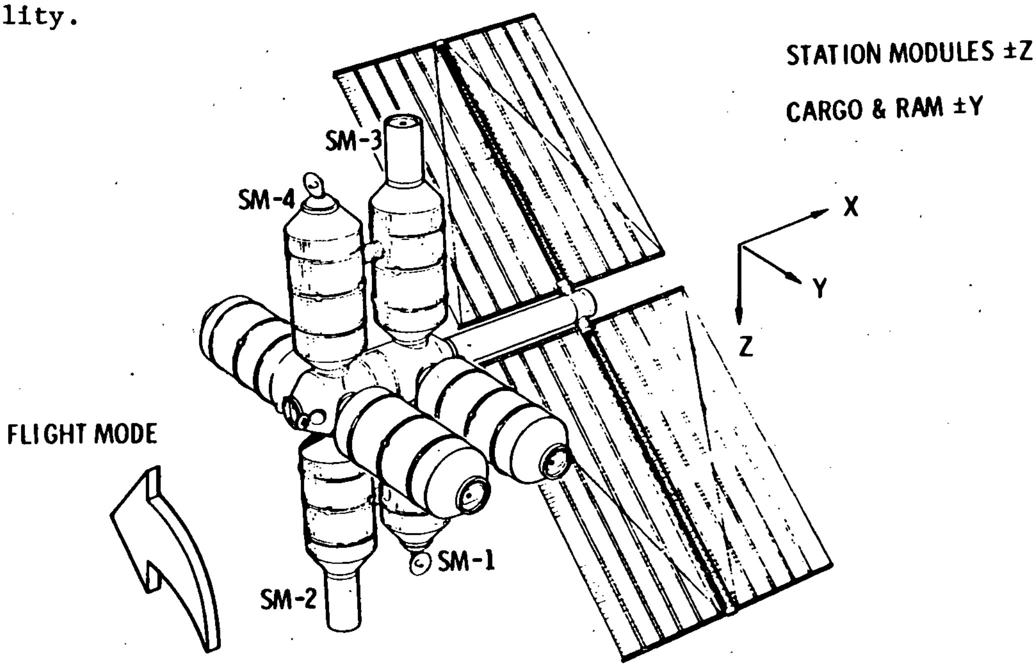
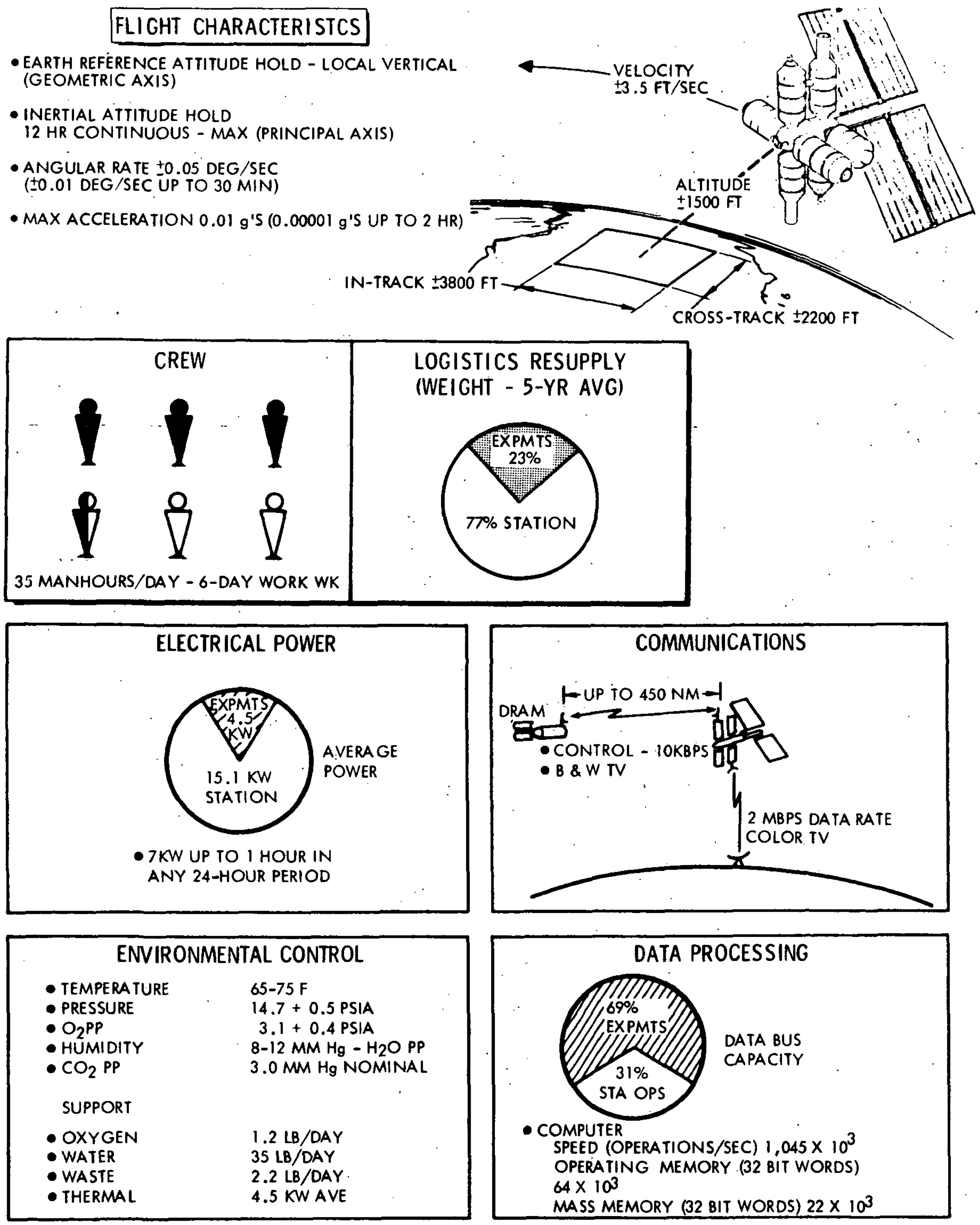


Figure 5-1. Modular Space Station Model (MSS)
(6-Man Initial Level)

Table 5-1 highlights the salient characteristics of a 6-man initial MSS. These characteristics are in terms of the MSS ability to support the conduct of a multi-disciplinary experiment and applications program.

Table 5-1. Modular Space Station Model Characteristics



SUMMARY

This section of the basic element summaries is structured to provide the key operational/design approaches recommended for incorporation in the MSS model as a direct result of the interfaces between the MSS and associated vehicles. These interfaces were identified and analyzed using fourteen interfacing activities as the interface drivers. The 14 activities listed and defined in Figure 5-2 include every type of interaction pertinent to this study that can occur between the MSS and the study inventory of earth orbital space elements.

Volume II, Part 2	
MATING The attachment in earth orbit of any two elements (or modules), including the operations of final closure prior to contact **ORBITAL ASSEMBLY** The joining together of two or more major parts to form a particular configuration of a single operational element in earth orbit, or to facilitate transport to lunar orbit or high-energy earth orbit **SEPARATION** The physical uncoupling of two mated elements and the subsequent maneuvers required to provide adequate clearance between elements	**EOS PAYLOAD DEPLOYMENT** The removal of a payload from the orbiter cargo bay and readying it for operation or separation **EOS PAYLOAD RETRACTION** The insertion of a payload into the orbiter cargo bay subsequent to initial mating of the payload to the orbiter
Volume II, Part 3	
COMMUNICATIONS The transmission of sound, video, and digital/analog data via space links from element-to-element and from element-to-ground **RENDEZVOUS** The operations required to achieve close proximity of one element to another for purposes of stationkeeping and/or mating	**STATIONKEEPING** The maintaining of a predetermined (not necessarily fixed) relative position between two orbiting elements **DETACHED ELEMENT OPERATIONS** The operational support required by a free-flying element from another element and/or ground control
Volume II, Part 4	
CREW TRANSFER The transfer of personnel between two elements in orbit **CARGO TRANSFER** The transfer of solid and fluid cargo between two elements in orbit **PROPELLANT TRANSFER** The transfer of large quantities of liquid hydrogen and liquid oxygen between elements in orbit	**ATTACHED ELEMENT OPERATIONS** Support by one element to another attached element while the latter is operating or being serviced, checked out, or stored **ATTACHED ELEMENT TRANSPORT** Support by a major propulsive element to an attached payload (element or module) during transport from one orbit to another

Figure 5-2. Interfacing Activity Definition

Three major topics were used to report the EOS related results of the interfacing activity analyses. These major topics are:

- o Element Inventory, Mission Models and Interactions
- o Recommended Operational/Design Approaches and Design Influences
- o System and Subsystem Functional Requirements

ELEMENT INVENTORY, MISSION MODELS AND INTERACTIONS

This subsection discusses all of the mission models that are applicable to the MSS and all of the study elements with which the MSS interfaces with.

Both a geosynchronous and a low earth orbital MSS have been included in this study. These two space stations combined are involved in 9 of the 11 missions generic mission models identified and developed in the Mission Analyses Volume (Vol. I). Twenty-five elements were identified for potential interactions.

The low earth orbital MSS interfaces with the following elements: (1) EOS, (2) Space-Based Tug, (3) Attached RAM, (4) Detached RAM, and (5) Earth Orbital Resupply Modules.

The geosynchronous MSS has the same interfaces with the addition of the CPS and the RNS which are potential delivery vehicles.

RECOMMENDED OPERATIONS/DESIGN APPROACHES AND DESIGN INFLUENCES

Nine major recommendations were derived from a detail analysis of the 14 interfacing activities. Table 5-2 summarized these recommendations and provides reference to the specific activity that either drove or supported the recommendation. The rationale for and design influence on the total element inventory resulting from these recommendations is contained in paragraphs subsequent to this summary.

Table 5.2. Major MSS Recommendation

Major Recommendations	Hdw & Oper'l Considerations	Interfacing Activities
1. Direct Automated Dock of all DRAMS & TUGS. Manipulator Berth of EOS, Cargo Mod, & ARAMS	•Common Mating Port •100-400 ft-lb Atten •≤0.4 ft/sec Closing Velocity •Laser Reflectors •TV & Backup Aids	Mating
2. Jet Translation Separation by Mated Elements	•MSS Active •MSS Passive	Separation
3. Orbital Assembly by EOS W/ Manipulator - Direct Dock Backup	•Manip Attach Points •Mating Ports at both Ends of all Modules	Orbital Assembly
4. Universal EOS/Payload Retention for all MSS Modules	•4 Point Coplaner Retention Concept	EOS P/L Deploy EOS P/L Retract Attached Elem Xport
5. Crew/Cargo Transfer Between all MSS Modules and to Attached RAMS	•41-in. dia Clear Opening •Mechanically Aided Transfer Device	Crew Transfer Cargo Transfer Attached Elem Ops
6. Direct MSS-to-Element, Direct MSS-to-Ground, and MSS-to-TDRS Comm Links	•S-Band & Omni •VHF & Omni •Ku-Band & Directional Antenna	Communications Detached Elem Ops
7. Complete Autonomous Control for Rendezvous & Station-keeping of RAMS & Space TUG - Ground Control of EOS to within ~50 n mi for Normal Missions	•Horizon Scanners & IMU •Star Trackers •Scanning Laser Radar •VHF & S-Band Omni Antennas •TV (for Inspection)	Rendezvous Stationkeeping Detached Elem Ops Communications
8. Transfer of Small Quantity Fluids & Gasses from Cargo Module via Manually Plumbed Connections	•Shirtsleeve •Flex Lines & Quick Disconnects	Cargo Transfer
9. Attached RAMS have Access to Designated MSS Subsystem Capability	•Data Process & Storage •Electrical Power •Thermal & ECLSS •Comm (S, VHF & Ku Band) •Att Stab & Pointing	Attached Elem Ops

SYSTEM AND SUBSYSTEM FUNCTIONAL REQUIREMENTS

This subsection identifies the pertinent quantitative and qualitative requirements that apply to the MSS during the operations associated with the 14 interfacing activities. These functional requirements are presented in quasi-spec format with reference to the specific activity(s) that generated the requirement.

Two distinct categories have been used to report the functional requirements as follows:

System Level - those functional requirements relating to the overall performance of the entire system, or by their nature they are involved in each subsystem (i.e., safety or general subsystem requirements). This section will also include requirements that form interfaces between subsystems.

Subsystem Level - those functional requirements that relate to one specific subsystem. Again as with the system level requirements, cross reference will be made to the appropriate interfacing activity that initially defined the requirement.

ELEMENT INVENTORY, MISSION MODELS AND INTERACTIONS

This subsection identifies all of the mission models that are applicable to the Modular Space Station, and all of the elements with which the MSS has an interface with for each of the 14 interfacing activities.

ELEMENT INVENTORY

Figure 5-3 shows a generic grouping the 25 study elements. The right hand column indicates the number of actual elements included in each of the categories.

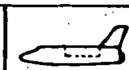
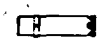
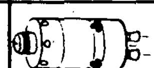
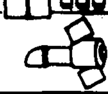
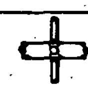
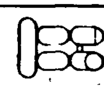
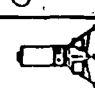
Earth orbital shuttle (EOS) - One element only, referred to throughout this report as EOS, orbiter and shuttle orbiter.		1
Interim tug - Various types of nonreusable nonreturnable, and nonreusable returnable kick stages such as Centaur, Agena, Titan Transtage, and Burner II.		2
Space tug - Reusable unmanned and manned ground-based tug, and unmanned and manned space-based tug.		2
Chemical propulsion stage (CPS) - The orbital insertion stage (mounted on the EOS booster at launch), the earth orbit-to-orbit shuttle, and the cislunar shuttle. The CPS can be modular or nonmodular, and single-stage or two-stage.		3
Reusable nuclear shuttle (RNS) - Both the earth orbit-to-orbit shuttle and the cislunar shuttle application. The RNS can be modular or nonmodular and is single-stage only.		1
Modular space station (MSS) - The low earth orbital station and the geosynchronous station.		2
Research and applications module (RAM) - Both attached and detached RAM's, supported by the EOS and by either of the two MSS's (see above).		4
Satellite - Satellites deliverable to orbit by the EOS and those requiring the EOS plus a third stage for delivery. Also included are satellites requiring retrieval and servicing.		3
Orbital propellant depot (OPD) - The low earth orbital propellant depot located in an orbit optimized to support the RNS or CPS and the space-based tug.		1
Earth orbital resupply module - Cargo and propellant modules for resupply of earth orbiting elements.		1
Orbiting lunar station (OLS) - Both the modular and nonmodular configurations (deliverable to lunar orbit by CPS or RNS).		1
Lunar surface base (LSB) - The modular base only (deliverable to lunar orbit by CPS or RNS).		1
Lunar landing tug (LLT) - Both the unmanned and manned tugs (deliverable to lunar orbit by CPS or RNS).		2
Lunar resupply module - Crew, cargo and propellant modules for delivery to lunar orbit by CPS or RNS.		1

Figure 5-3. Element Inventory

MISSION MODELS

In the Orbital Operations Study, a total of eleven mission models have been generated which encompass all of the mission events, element-to-element interfaces (element pairs) and interfacing activities which can occur in earth orbit. Each of the eleven mission models (refer to Volume I) consists of a sequence of mission events, with an identification of related interfacing activities and interfacing elements for each event. Both a geosynchronous and a low earth orbital MSS have been included in this study. These two MSS's can be involved in nine of the eleven missions (see Table 5-3).

In MM-1, "EOS Emplacement Mission," the EOS can emplace the initial module of the MSS in low earth orbit. If this is a geosynchronous MSS module, the MSS might be assembled in low earth orbit prior to delivery to the high energy orbit. In MM-2, "EOS Logistics/Retrieval Mission", the EOS can deliver an MSS module to low earth orbit and mate it to previously delivered modules of the MSS.

In MM-4, "Space-Based Tug Retrieval/Emplacement Mission", the tug separates from its space base and transports the initial MSS module from the EOS orbiter to the desired orbit for the low earth orbital MSS or the geosynchronous MSS. In another application of this mission the tug (based at either of the two MSS's) separates from the MSS, retrieves a free-flying element for servicing at the MSS, then returns the element to space. In MM-5, "Space-Based Tug Logistics Mission", the tug separates from its space based (which may be an MSS), transports a payload from the EOS orbiter to another major element (which may be an MSS), and then returns to its original space base (which again may be an MSS). This mission, as with most of the mission models, is generic and has multiple applications. The payload being transported may be an MSS module for either of the two MSS's. In MM-6, "Space-Based Tug Disposal Mission", the tug can separate from its space base (which may be a low earth orbital MSS) and dispose of a large free-flying element by phasing it in an earth intersecting orbit. This, of course, requires a tug retrograde burn, separation from the large element and a subsequent posigrade burn.

In MM-7, "Ground-Based Tug Emplacement/Sortie Mission", the tug can transport the initial module of a geosynchronous MSS from the EOS orbiter to the high energy orbit. In MM-8, "Ground-Based Tug Logistics/Retrieval Mission", the tug can deliver a payload from the orbiter to geosynchronous MSS.

In MM-10, "Staged Geosynchronous/Cislunar Shuttle Logistics Mission", and MM-11, "Non-Staged Geosynchronous/Cislunar Shuttle Logistics Mission", the geosynchronous shuttle (CPS or tug for MM-10 and CPS or RNS for MM-11) can deliver a payload (which may be one or more MSS modules) to the MSS in geosynchronous orbit.

Table 5-3. Mission Model, Interfacing Activity, and Element Inter-relationships with the MSS

Interfacing Element	Interfacing Activity														Mission Model										
LOW E.O. MSS TO	Mating	Orbital Assy	Separation	Cargo Transfer	Crew Transfer	Propel. Transfer	EOS Payload Deployment	EOS Payload Retr. & Stowage	Communications	Rendezvous	Stationkeeping	Attached Elem. Operations	Detached Elem. Operations	Attached Elem. Transport	EOS Emplacement	EOS Logis/Retriev.	EOS Sortie	SB Tug Retr/Emplace.	SB Tug Logistics	SB Tug Disposal	Grd-Based Tug Emplace/Sortie	Grd-Based Tug Logis/Retriev.	OIS Delivery	CLS Staged Logistics	CLS Nonstaged Logistics
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11
EOS	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓					✓	✓
TUG	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓		✓		✓	✓	✓					
MSS ARAM	✓	✓	✓	✓	✓							✓				✓		✓	✓			✓			
MSS DRAM	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓		✓	✓		✓	✓		✓	✓			
EO RESUP MOD	✓	✓	✓	✓	✓							✓				✓		✓	✓			✓			
MSS	✓	✓	✓	✓	✓										✓	✓		✓	✓	✓		✓			

Table 5-3. Mission Model, Interfacing Activity, and Element Inter-relationships with the MSS (Cont.)

Interfacing Element	Interfacing Activity														Mission Model										
GEOSYNCH. MSS TO	1 Mating	2 Orbital Assy	3 Separation	4 Cargo Transfer	5 Crew Transfer	6 Propel. Transfer	7 EOS Payload Deployment	8 EOS Payload Retr. & Stowage	9 Communications	10 Rendezvous	11 Stationkeeping	12 Attached Elem. Operations	13 Detached Elem. Operations	14 Attached Elem. Transport	1 EOS Emplacement	2 EOS Logis/Retriev.	3 EOS Sortie	4 SB Tug Retr/Emplace.	5 SB Tug Logistics	6 SB Tug Disposal	7 Grd-Based Tug Emplace/Sortie	8 Grd-Based Tug Logis/Retriev.	9 OIS Delivery	10 CLS Staged Logistics	11 CLS Nonstaged Logistics
EOS	✓	✓	✓	✓	✓		✓	✓	✓					✓	✓	✓		✓	✓		✓	✓		✓	✓
G.B. TUG	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓							✓	✓			
S.B. TUG	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓				✓	✓	✓					✓
MSS ARAM	✓	✓	✓	✓	✓							✓				✓		✓	✓		✓	✓		✓	✓
MSS DRAM	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓			✓		✓	✓		✓	✓		✓	✓
EO RESUP. MOD.	✓	✓	✓	✓	✓							✓				✓		✓	✓			✓		✓	✓
GEO MSS	✓	✓	✓	✓	✓										✓	✓		✓	✓		✓	✓		✓	✓
EO CPS	✓	✓	✓						✓	✓	✓	✓	✓	✓		✓		✓	✓			✓	✓	✓	✓
RNS	✓	✓	✓						✓	✓	✓	✓	✓	✓		✓		✓	✓			✓		✓	✓

ELEMENT INTERACTIONS

The methodical in-depth approach used in the generation of the mission models (see Section 1.0 of Volume I) made possible the identification of all potential element-to-element interfaces (i.e., element pairs) and all interfacing activities that can occur between elements in earth orbit. A summary of the total list of orbital elements considered in this study was presented in Figure 5-3. Those elements with which the two MSS's may interface with and those interfacing activities which may occur between the MSS's and these other elements are also identified in Table 5-3.

The low earth orbital MSS interfaces with the propulsive vehicles that are in the transport mission chain for initial delivery of the MSS (module by module) to orbit and for resupply of the MSS, i.e., the EOS orbiter and the space-based tug. The MSS interfaces with the attached RAM which is docked to it for extended periods of time. The MSS also interfaces with the detached RAM which it supports and controls through RF links while separated from it, and by maintenance and resupply while attached to it. In addition, the low earth orbital MSS interfaces with the resupply modules which are docked to it, and of course with other MSS modules during the initial assembly stage.

The geosynchronous MSS interfaces with the same orbital elements as does the low earth orbital MSS. In addition, the geosynchronous MSS interfaces with the ground-based tug, the earth orbital (orbit-to-orbit) CPS and the RNS. When the MSS is manned, after being initially assembled, it is considered probable that these propulsive vehicles will also be manned when they physically interface with the MSS.

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RECOMMENDED OPERATIONAL/DESIGN APPROACHES AND DESIGN INFLUENCES

Several major operational/design approaches for the MSS were synthesized from the detail analyses conducted for each of the 14 separate interfacing activities. These major recommendations are illustrated by Figure 5-4. The nine recommendations highlighted on the figure are amplified in subsequent paragraphs.

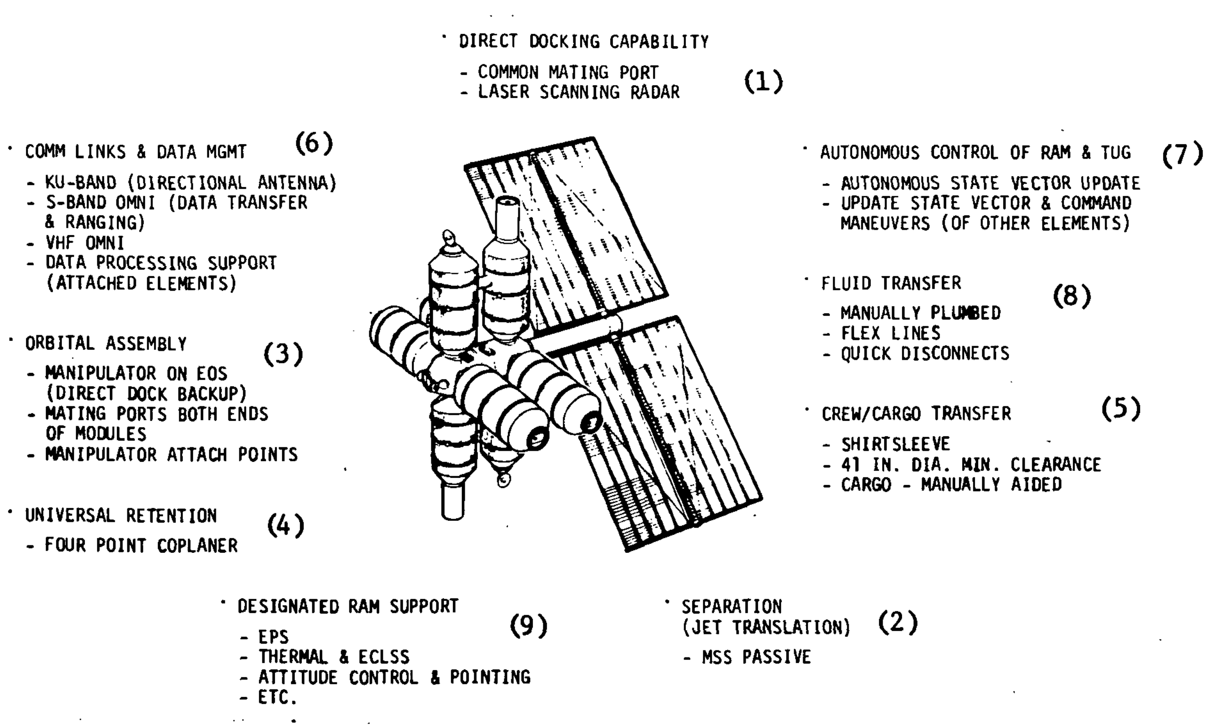

Figure 5-4. Major EOS Recommendations

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DIRECT AUTOMATED DOCK (1)

An automated direct dock approach is recommended for the mating of a tug or detached RAM to the MSS. In addition, the preferred approach for EOS matings is using the manipulator for EOS/MSS berthing and subsequent cargo module exchange or RAM attachment.

Selection Considerations

The Mating interfacing activity considered two generic approaches to mating:

A. Direct Dock (automatic and manual)
B. Manipulator Berth (manual only)

Then separate comparison factors were considered:

- Technology
- Checkout and Maintenance
- Safety
- Reliability
- Commonality
- Relative Cost
- Operational/Design Complexity
- Subsystem Interfaces
- Near-Term Bias
- Far-Term Bias

An overall evaluation of these comparison factors tends to favor (A) Direct Dock over (B) Manipulator for tug and RAM matings to the MSS. Also, an automated direct dock approach must be developed for the mating of unmanned elements; therefore, the automated approach is recommended for commonality across all element pairs.

A manipulator was recommended for the EOS (refer to Section 2.0) to accommodate small satellites matings and the handling of multiple payloads on the same mission. Trade Study A5 (Appendix A) showed synergistic benefits to the MSS that would result from the use of the manipulator for orbital assembly and the attachment/removal of cargo modules and attached RAMs.

(1) Refer to Table 5-2 and Figure 5-4

Design/Operational Influences

An automated direct dock approach for tug/DRAM and a manipulator berth for EOS requires the following be incorporated as part of the basic MSS design:

- Common Mating Port. Active attenuation in the 100 to 400-pound range with closing velocity held to $\leq$ 0.4 ft/sec.
- Scanning Laser Radar Transceiver. Provides range, range rate and angular misalignments.
- Passive Laser Reflectors
- Visual Alignment Target. Required for backup mode EOS manual direct dock.
- TV Camera. Required for visual inspection and backup to direct visual.
- Manipulator Attachments

JET TRANSLATION SEPARATION (2)

The preferred mode for elements separating from the MSS is via mass expulsion of RCS engines. The MSS will be passive during the separation.

Selection Considerations

Two generic approaches for separation were considered in the Separation interfacing activity:

A. Jet translation (manual or automatic modes)

B. Manipulator extension (manual or automatic modes)

Nine comparison factors were considered in making a selection. These factors are as follows:

- Technology
- Checkout & Maintenance
- Plume Impingement
- Safety
- Reliability
- Relative Cost
- Commonality
- Near Term Bias
- Far Term Bias

An evaluation of the factors showed that both approaches are adequate in either manual or automatic modes. However both approaches offer significant advantages.

A. Jet translation is significantly lower in cost because at least one of the two mated elements will be equipped with a translation capability.

B. Manipulator extension appears to offer a more safe operation in that the elements can be physically separated some distances prior to independent operations.

Jet translation is the recommended approach for all separation operations as it requires little or no additional hardware than is already included in the elements; it has been deomonstrated to be safe; and it can be utilized for all element pairs in the study inventory.

(2) Refer to Table 5-2 and Figure 5-4

MSS Design/Operational Influences

The jet translation separation approach does not impose any additional hardware to the MSS model used during this study. However, a reliable means must be provided to assure that any stored energy that can impart a noticeable thrust to one of the separating elements has been released prior to the jet translation maneuver. Examples of this stored energy are:

- compressed docking attenuation struts
- crew/cargo transfer tunnel pressurization
- spring type capture latches

The only identified critical alignment separation is for the MSS where a RAM to be separated is adjacent to a station module. A laser radar guidance concept is recommended for this operation.

Design/Operational Influences on Interfacing Elements

All elements that mate with the MSS shall have a translation capability to accomplish the separation maneuver.

MSS ORBITAL ASSEMBLY (3)

The recommended approach for the orbital assembly of the Modular Space Station (MSS) is to utilize the EOS with its manipulator. In addition, the direct dock approach is recommended as a backup method.

Selection Considerations

The Orbital Assembly interfacing activity considered 1) direct dock and 2) manipulator berth for the attachment of station mdoules during assembly. The primary constraints considered in the comparison of the two approaches are:

Direct Dock	Manipulator Berth
o Alignment tolerance	o Reach criteria
o Appendage clearance	o Module size
	o Berthing port location
	o End Effector location

An evaluation of these factors showed that both approaches are adequate and no strong operational preference was established for either approach.

An interactivity commonality analysis between the manipulator and the direct dock modes showed the following advantage for the manipulator.

- more positive control of module in close proximity and when near appendages
- allows selection of berthing ports on both ends of module or on a singular end as benefits the configuration and not the mating operations
- attaching antenna and airlock packages will be simplified
- the operational flexibility of the manipulator can be utilized to lessen design complexity and/or reduce the requirements for specialized airlocks (i.e., RCS engine pods, G&C sexton/telescope).

The use of the direct dock mode as a back-up was selected to insure mission continuation in the event of either manipulator failure of development delays.

(3) Refer to Table 5-2 and Figure 5-4

MSS Design Operational Influences

The selection of both the manipulator and the direct dock mode (for backup) have the following design/operational influences on the MSS:

- berthing ports at both ends of all modules
- manipulator attachment points on all modules
- attenuation device added to core module berthing ports
- ≈ 5 ft spacing between adjacent modules

Influences on Interfacing Elements

The orbital assembly of the MSS will only be accomplished by the EOS. Since the direct dock and manipulator berth capability were also selected for EOS payload Deployment and Retraction/Stowage, the impact of using these same capabilities for Orbital Assembly are minimized. The only significant additional EOS interface requirement is in the area of crew training software needed to control the manipulator during these operations.

UNIVERSAL EOS/MSS MODULE RETENTION (4)

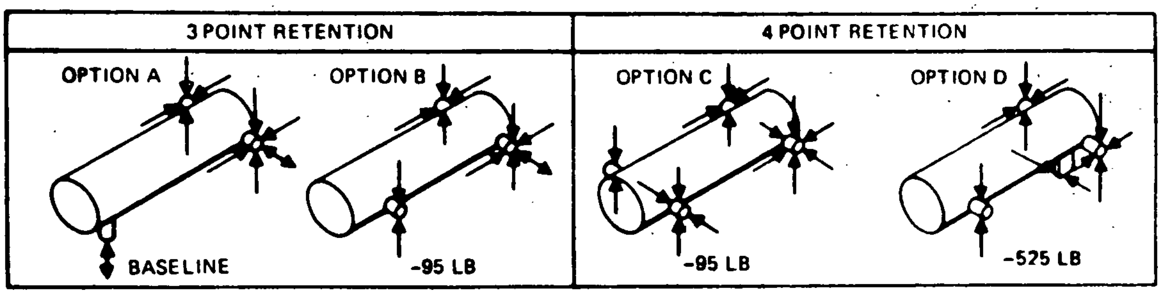
The recommended approach for retention of the Modular Space Station (MSS) modules is the EOS universal 4 point (co-planar) retention concept.

Selection Considerations

The EOS payload Deployment and Retraction/Stowage interfacing activities each considered two approaches to MSS module retention:

1) 3 point concept (options A & B)

2) 4 point concept (options C & D)



The selection of a retention concept for the MSS modules was documented in trade study A-5 (Appendix A). The concept is integrated approach that minimizes the impact to both the orbiter and the payload. The selected (optimum D) 4 point co-planar concept is 525 lbs lighter than the 3 point baseline. The baseline concept that was considered for the MSS modules was option C. Adapting to the four point co-planar system represented an approximate 300 lb weight increase. The selected concept of having locations on 4 foot centers for the retention mechanisms elements 150 lbs of the weight penalty. The weight of individual locations is 6 lbs per location (three retention fittings per location). Therefore if a spacing of 4 ft O.C. is adopted the maximum additional weight would be [15-5 (baseline) locations X 6 lbs per location] 60 lbs. The net effect of these selections is:

Orbiter	lbs	MSS	lbs
4 pt co-planar	- 525	4 pt co-planar	+ 300
Additional retention	+ 60	Additional retention	- 150
locations (10)	- 465	locations	+ 150

(4) Refer to Table 5-2 and Figure 5-4

MSS Design/Operation Influences

MSS Module Influence - The selected retention concept for MSS modules is shown in the sketch above (option D). It is a concept that utilizes dual aft trunnions that react horizontal and vertical loads. In the same vertical plane at the bottom of the module (with respect to the cargo bay) it has a passive mechanism (keel) that fits into a slot in the orbiter. This bottom keel reacts side loads only. This concept allows the shuttle to compensate for module thermal deflections (from long on-orbit stay times). The fourth retention trunnion is forward and near the orbiter moldline. It takes out vertical loads.

Influences on Interfacing Elements

The only other element that would be affected by the MSS retention concepts is the EOS orbiter. Since the selected concept for the MSS modules was to adopt the universal EOS payload retention concept (4 point co-planar) the interface problems are minimized.

CREW/CARGO TRANSFER TO MSS (5)

This study identified the necessity to enter payloads from the MSS docking interface. A shirtsleeve entry is the preferred mode, however IVA provisions are also recommended as a backup mode.

Selection Considerations

The Crew Transfer and Cargo Transfer interfacing activities each considered three generic methods for crew/cargo transfer as follows:

Method	Approaches	
	Crew Transfer	Cargo Transfer
EVA	1) No	1a) Manual unaided
IVA	2) Yes	2a) Manual unaided
Shirtsleeve	3) Yes	3a) Manual unaided 3b) Manual aided 3c) Automated

Shirtsleeve crew transfer (approach 3) was selected due to the high degree of crew movement between the MSS and its various RAM's. This selection is based on the ease of crew movement offered by the shirtsleeve transfer.

Manually aided cargo transfer in a shirtsleeve environment (approach 3) was selected for the transfer of cargo items between the MSS and the attached modules due to frequency and compatibility with the MSS system.

The IVA method (approach 2 and 2a) is recommended as a backup for the shirtsleeve mode of crew transfer and manually unaided cargo transfer.

This IVA backup will benefit some payloads that cannot accept the design penalties associated with a shirtsleeve environment. In addition, an airlock will provide an acceptable alternate mode to increase mission success for selected critical crew/cargo transfer operations.

EVA crew and/or cargo transfer was not selected as all interfacing elements can be accommodated by either shirtsleeve or IVA transfer.

(5) Refer to Table 5-2 and Figure 5-4

Design/Operational Influences

The selection of shirtsleeve and IVA crew/cargo transfer creates the following design influences:

- Airlock. Required for IVA
- 41-inch diameter clear opening. Large cargo items are required for MSS and should be common in attached modules
- Establish, monitor, and maintain a habitable environment for shirtsleeve activities
- Pressure suits and related provisions for use with IVA airlock

COMMUNICATION LINKS (6)

Operation in three radio frequency bands, S-band, VHF, and Ku-band is recommended for MSS communications to ground or to other space elements. Equipment compatible with both the communication and ranging signals of the NASA ground network is recommended. Ku-band is needed to support a high (up to 10 Mbps) data rate link to ground via the TDRS. VHF can be used for low data rate and voice communication to ground via TDRS to provide greater than 90 percent orbital contact continuity.

When necessary, VHF can be used as a back-up link to other elements. Both S-band and VHF MSS terminals can adequately support the link criteria with omni-directional antennas. A high-gain, 45 dB, directional antenna is needed to support the link from MSS to TDRS with sufficient link margin.

Selection Considerations

Communications and Detached Element Operations each considered three alternate approaches:

a. Element-to-element
b. Element-to-ground direct
c. Element-to-ground via TDRS

All these approaches are required to fulfill the operations of MSS missions. High data rates (> 2 Mbps), color TV (4.5 mHz) data transfer, the large quantities of daily data generation and the desire for near-continuous communication with ground necessitates the use of the TDRS, Ku-band links. Direct to ground links at S-band support tracking and ranging operations as well as provide a second ground link for data communications. S-band is also used for other element communications and tracking/ranging links. VHF can be used as a back-up voice and low data rate link as well as support TDRS order wire service.

Equipment at these frequency bands provides compatibility with cooperative terminals without necessitating any technology breakthroughs or any changes to existing or presently planned NASA space/ground networks.

(6) Refer to Table 5-2 and Table 5-4

MSS Design/Operational Influence

Implementation of all three approaches requires that the MSS provide the following to meet the approach requirements:

	Antenna System	Receiver System	Transmitter System
S-band equipment	Omni-directional	800°K system Noise Temp.	30 watts RF Power output
Data capability	--	500 Kbps 3 voice channel PRN range	1 Mbps 3 voice channel 500 MHz facsimile TA-PRN range
VHF equipment	Omni-directional	1200°K system Noise temp.	25 watts RF power output
Data capability	--	1 Kbps 1 voice channel	10 Kbps 1 voice channel
Ku-band equipment	5' parabolic steerable antenna	1200°K system Noise temp.	25 watts RF power output
Data capability	--	500 Kbps 3 voice channel 1 Hi-Fi audio channel PRN range	Up to 10 Mbps 3 voice channel 500 MHz facsimile 4.5 MHz color TV T.A PRN range

Design/Operation Influences on Interfacing Elements

The MSS can be either a controlling or controlled vehicle and must have the capability to transmit and receive TT&C signals to and from other elements and ground. All interfacing elements, i.e., EOS, Tug and RAM should have as a minimum, complementary S-band hardware. This would be similar to that described above. VHF capability is not a necessity on the interfacing elements, but if implemented it would provide an emergency backup link. Ku-band is necessary only on the RAM element for use in transforming high data rate digital signals or TV from RAM to MSS at distances up to 450 n miles.

AUTONOMOUS CONTROL FOR RENDEZVOUS AND STATIONKEEPING (7)

A fully autonomous Rendezvous and Stationkeeping capability is recommended for these MSS operations when MSS separation from its target vehicle is less than approximately 50 n miles.

The MSS should be capable of performing the control of target elements and all necessary communications, target tracking and ranging, and self-navigation to control the target vehicle for performance of the Rendezvous and Stationkeeping activities.

Selection Consideration

Rendezvous, Stationkeeping and Detached Element Operations interfacing activities supported by the Communications activity considered three basic alternate approaches for control, as follows:

1. Autonomous or independent
2. Ground control
3. Space control

Since the MSS is a manned vehicle with all necessary capability to control an active target vehicle at ranges up to line of sight, the autonomous control mode (No. 1) was considered the most efficient and effective alternate approach for successful mission accomplishment.

Emergency operations are available, if necessary, by utilizing ground/EOS communications links. The autonomous mode, however, provides EOS-to-element continuous contact during these maneuvers.

Ground control (No. 2), by direct link, would suffer from lack of contact continuity during orbital operations. Even TDRS could not guarantee 100 percent orbital coverage.

Space control (No. 3) from another vehicle could not in any case provide the accuracy of tracking and ranging necessary to assure safety and mission success at separation of ranges less than 50 nautical miles.

(7) Refer to Table 5-2 and Figure 5-4

Design/Operational Influence

As a control element or a target element, during Rendezvous and Stationkeeping operations, the MSS will provide the capability to perform these operations as a passive (non-maneuvering) vehicle with its interfacing elements as follows:

	MSS Control	Interfacing Elements TUG, RAM, EOS, CPS, RNS
1. For separation distances >50 n miles S-band PRN Ranging equipment	Measure	Transpond
2. For separation distances <50 n miles Scanning laser Radar	Active SLR to Measure	Passive Optical Reflectors
3. Communication link at S-band or VHF to provide MSS to target command operation and to provide target to MSS vehicle status as well as command verification.	S-band or VHF Transmitter and Receiver with Omni directional antenna	S-band or VHF Transmitter and Receiver with Omni directional antenna
4. A TV camera for inspection purposes.	Under EOS pilot control.	Not Applicable
5. An attitude reference with an accuracy of $\pm$ 0.5 degree	Yes	Yes
6. An attitude control capable of $\pm$ 0.5 degree stabilization	Yes	Yes
7. Delta-V maneuver capability	Yes	For orbital makeup only.
8. Onboard computation capability	Yes for total mission operation	For attitude determination and control only

TRANSFER OF FLUIDS FROM MSS (8)

RAM's require interconnecting fluid lines from the MSS, both for routine subsystem support, and for periodic DRAM servicing. The interface should consist of fixed plumbing at adjacent locations which are manually interconnected.

Selection Considerations

Fluid transfer (other than that which is transferred in bulk packages) considered three approaches: 1) Manual Temporary, 2) Manual Plumbed, and 3) Automatic Plumbed.

The recommended Manual-Plumbed concept consists of rigid, permanently-affixed plumbing, which is brought to a terminus close to the element interface. Final connection is done manually by short, flexible, semi-rigid, or rigid attachments. The concept has the highest reliability and damage protection, allows fixed purging and venting provisions, and permits hazardous fluid lines to be installed completely outside the pressure shell.

Manual Temporary (No. 1), which consists essentially of stringing hoses across the interface, is the simplest design, and might be satisfactory for infrequent use, but it has significant disadvantages. It encroaches on the crew access path and is subject to damage or entanglement, especially with non-rigid pressure lines. Also it is not susceptible to venting and purging provisions especially for accidental breaks in the connected line. This could be prohibitive even for safe liquids, but especially for hazardous liquids or gases.

For some element interfaces, e.g., unmanned payloads where crew access is not feasible, the Automatic-Plumbed method may be required, and is recommended in addition to the Manual-Plumbed concept for such special cases. While making connections automatically during mating is feasible, it has the disadvantages of requiring precision indexing and greater potential for damaged connectors.

(8) Refer to Table 5-2 and Figure 5-4

Design/Operational Influences

. Manual Plumbed

1) Common, indexed docking interface, RAM-to-MSS

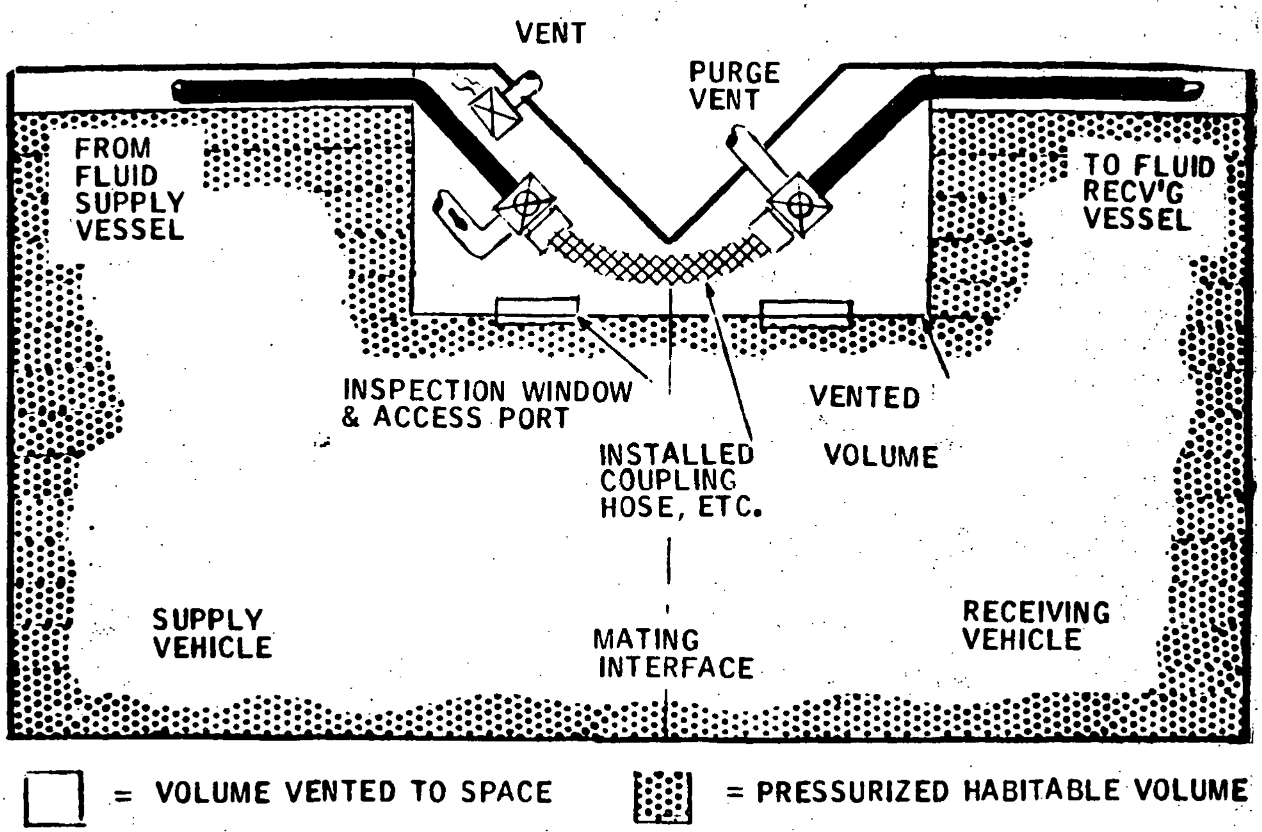
2) Crew workspace at the shared interface volume--48-inch diameter (minimum) adjacent to the line(s) requiring connecting

3) MSS must have provisions to accommodate a range of payloads even where there is not complete correlation in the fluids required by each payload. The figure below illustrates typical fluid line installation.

. Automatic Plumbed

1) Requires commonality of fluid interfaces

2) Requires precision indexing of interconnects



Manual Plumbed Fluid Connection

ATTACHED ELEMENT SUBSYSTEM SUPPORT (9)

This study recommends that the MSS provide interfaces to the RAMs to utilize the "designated" subsystem capability.

NOTE: "Designated" means that quantity of capability designed as utility support to an experiment program.

Selection Considerations

The Attached Element Operations interfacing activity considered three generic approaches for attached element support from the MSS:

1) Payload Dependent on MSS
2) Payload Independent of MSS
3) Payload Dependent on added modules or kits

The following matrix represents the selected approach for the major subsystem functions:

Function	1) Dependent	2) Independent	3) Modular Dependent
Tracking and voice	✓	-	-
Data	✓	-	-
Electrical power	✓	-	-
Attitude stability	≥0.25 deg and 0.05 deg/sec	-	<0.25 deg and 0.05 deg/sec
Environmental control	Basic atmosphere	Emergency and circulation	Contamination and waste
Thermal control	✓	-	-
Habitability	✓	-	-

(9) Refer to Table 5-2 and Figure 5-4

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MSS FUNCTIONAL REQUIREMENTS

The vehicle functional requirements for the Modular Space Station - MSS (both low earth orbital and geosynchronous) were developed from the functional requirements defined for each of the 14 interfacing activities. This subsection will contain the requirements that relate principally to the MSS and are necessary for performing the interfacing activities. Along with the functional requirement there will be a cross-reference made to the interfacing activity that established the requirement. There are eight categories of functional requirements. The initial category contains the system level (i.e., those that apply to more than one subsystem or relate to the performance of the entire system as a whole) functional requirements. The remaining seven categories contain the functional requirements by subsystem, again with references to the appropriate interfacing activity where the requirement was established.

A separate numerical designator has been established for each of the eight functional requirement categories as follows:

Category	Designator
EOS Orbiter System	1-X
Structures/Mechanical Subsystem	2-X
Environmental Control Subsystem	3-X
Electrical Power Subsystem	4-X
Guidance and Control Subsystem	5-X
Propulsion Subsystem	6-X
Communication/Data Management Subsystem	7-X
Crew/Habitability Subsystem	8-X

SYSTEM FUNCTIONAL REQUIREMENTS

1-1. Alignment aids shall provide relative positional information between the MSS and elements it will mate with. The information provided shall be centerline miss distance and angular misalignment to the following accuracy:

- automatic devices, such as laser radar: +/- 1 degree
- direct visual devices: knowledge to be able to identify when the vehicle mating port centerlines are misaligned by greater than 3 degrees (Mating 5)

1-2. Residual attitude misalignments remaining after capture shall be corrected by the MSS or associated mating vehicle prior to rigidizing. (Mating 16)

1-3. The mating interfaces shall be drawn together by the MSS mating concept to remove residual attenuation stroke and seat the interfaces. The rate at which the vehicles are drawn together must be controlled to within the structural capability of the docking ports. (Mating 17)

1-4. Once separation occurs, the MSS and/or the mated element shall maneuver to a safe distance prior to resuming independent operations. A minimum non-recontact separation distance shall be one and one-half times the combined length of the major axist of the MSS and the separating element. (Separation 4)

1-5. Throughout a docking or separation maneuver the control capability of both the MSS and the associated element shall be monitored for indications of control failures such as reaction jet "stuck-on" and "stuck-off" conditions. (Mating 26) (Separation 5)

1-6. Prior to the initiation of fluid transfer, seal integrity should be verified. This function is mandatory where hazardous liquids or gases are involved. (Mating 29) (Orbital Assembly 16)

1-7. Interface assemblies that contain plugs, receptacles, and couplings shall be equipped with compatible guides such that alignment will be achieved prior to engagement of the connectors. Individual connectors and fluid couplings shall be provided with independent mechanical guides such that alignment is achieved prior to engagement of connector pins or fluid coupling interface seals. (Mating 30) (Orbital Assembly 23)

1-8. Extension and connection of automatic utility interface connectors and couplings shall be delayed until after the mating rigidizing mechanism has engaged and locked up. (Mating 31)

1-9. Manual interface connections shall be located, designed, and mounted such that a worker can mate the connectors in a pressurized suit. (Mating 32) (Cargo Transfer 34)

1-10. Manual interconnects shall be located to permit visual inspection of the connection, where possible; provisions should be available to inspect automatic connections. (Mating 33) (Orbital Assembly 22)

1-11. Electrical cables and fluid lines that traverse crew and cargo passages shall be suitably enclosed or otherwise protected to minimize hazards to crew and provide protection for hardware. (Mating 34)

1-12. For a jet translation separation where alignment is critical and alignment aids are utilized, the alignment aids must be active and aligned before separating. (Separation 3)

1-13. Propulsive venting of MSS effluents shall be inhibited or controlled during the separation maneuver. The control of venting is not only necessary to prevent attitude control problems, but also should be avoided to prevent effluents from obscuring alignment aids. (Separation 12) (see Mating 19)

1-14. The separation technique shall be such that no damage will occur to prevent the mating ports from being used for succeeding matings and separations. The mating ports shall be left in a condition ready for a subsequent mate. (Separation 13) (see Mating 25.a)

1-15. A credible accident to, or a credible failure of an interface function or adjacent function shall not cause the loss of redundantly provided functions or compound the accident or failure by creating additional hazards (explosion, fire). In this sense, the following criteria apply:

a. Hazardous fluid lines shall be barriered or physically separated from power wires and each other (O_2 lines shall be considered hazardous in interfaces areas (DS-208).

b. Redundant fluid lines shall be separated a minimum of 45 degrees (DS-208).

c. Redundant connectors shall be separated a minimum of 45 degrees (DS-208). (Mating 37) (Orbital Assembly 8) (Cargo Transfer 31)

1-16. The interface between mated elements must be designed to be closed and sealed without performing a prolonged demating of interface connectors. (Mating 39) (Attached Element Ops 18)

1-17. A backup means for release and separation of mated elements in case of failure of the primary method shall be provided. If the backup scheme is a manual disengagement, the technique shall be designed for IVA or shirtsleeve operations rather than requiring EVA. (Separation 14) (Deployment 6) (Retraction and Stowage 7)

1-18. Prior to initiation of the separation routine those subsystems that will be utilized during the separation activity shall be verified. Where backup systems are available, these shall also be statused. (Separation 19)

1-19. Atmospheric contamination levels shall be monitored within habitable areas for 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.

1-20. The capability shall be provided to ensure that passageways/hatchways to a normally uninhabited element are free of obstructions so that crew can enter safely and cargo movement will not be inhibited. This may include direct visual inspection through a view window or remotely monitored sensors or closed circuit television. Crew Transfer (21), Cargo Transfer (28)

1-21. A method shall be provided whereby fluid interfaces can be verified to be free of residuals that may contaminate the surrounding environment prior to disconnect. Cargo Transfer (33)

1-22. Leak-detection sensors shall be provided when transferring any contaminable fluid. Vent systems are required to protect against contamination for plumbed transfer. Cargo Transfer (35)

STRUCTURES/MECHANICAL SUBSYSTEMS FUNCTIONAL REQUIREMENTS

2-1. MSS mating port mechanisms shall be designed to the following criteria:

a. The design shall be applicable to direct docking and manipulator berthing operations. The concept may be of a design that will perform one type of mating, but with an adapter added can perform the other type.

b. The design shall be inherently dynamically stable when fully engaged to an associated mating port.

c. The design shall provide redundant features where active mechanisms are involved.

d. The MSS mating concept shall incorporate in the design the means to automatically reduce angular misalignment and literal miss distance between the mating interfaces to permit initial capture on first structural connection (i.e., the capture mechanisms shall be automatically triggered and self locking).

e. A method of monitoring the status of capture mechanism (latch position) shall be provided.

f. The capture mechanism shall be capable of quick release and recycle to its initial state at any phase of the capture operation.

g. The mating port shall be capable of successfully capturing and hard docking to an opposing mating port with a miss distance and misalignment tolerance as follows:

Miss distance: $\pm$ 6 inches min.

Misalignment: $\pm$ 3 degrees min.
(pitch, yaw, roll)

h. Mating port design shall be capable of accommodating vehicle masses ranging from 500 slugs to 8000 slugs.

(Mating 12)

2-2. The mating interface shall be structurally connected either automatically or manually to provide the required intervehicular stiffness for combined vehicle maneuvering. The engaged and locked rigidizing latches shall be preloaded such that the fundamental bending/torsional mode of the mated pairs is determined by the primary structures of the mated; i.e., latch spring stiffness shall not affect vehicle control loops that depend on structural modes. (Mating 20)

2-3. Mechanical radial position and roll indexing shall be provided at the mated interface to prevent interface slippage and damage to pressure seals during combined vehicle maneuvering. (Mating 21)

2-4. The capability to inspect, maintain, and manually recycle both capture and rigidizing latches in a shirtsleeve environment shall be provided. (Mating 23)

2-5. The tunnel leak rate between the MSS and a mated element shall be no greater than the leak rate of the hatch seals of either element. (Mating 36)

2-6. Separation velocities and angular rates caused by the extension of shock attenuation or other energy storage shall be controlled by delaying release until the extension dynamics cease. (Separation 2)

2-7. A window shall be provided in each pressure hatch. This permits shirt-sleeve crew observation of IVA/EVA operations and viewing prior to ingress whenever hatches are closed. (Crew Transfer 13) (Cargo Transfer 28)

2-8. The opening of the docking/berthing port shall be large enough to accommodate the largest anticipated logistics item. For the MSS this would be a control moment gyro and require an opening of at least 41 inches. (Attached Element Operations 30)

2-9. Cargo transfer devices shall be capable of maintaining full control of cargo items at all times. For manual, unaided cargo transfer thethers and/or restraints will be required to affix the cargo item to the operator. Cargo Transfer (3)

ENVIRONMENTAL CONTROL SUBSYSTEM FUNCTIONAL REQUIREMENTS

3-1. Pressure equalization capability and leak rate verification transducers shall be provided on each side of each docking interface hatch of any MSS/vehicle combination requiring shirtsleeve environment for manned mated operations. (Mating 24)

3-2. Prior to separation the pressurized tunnel between the MSS and another element or module must be pumped down or vented to space. The pressure remaining in the tunnel shall be low enough such that when separation occurs no noticeable delta velocity, due to the remaining pressure, will be imparted to the separating elements. (Separation 9)

3-3. Prebreathing equipment shall be provided for use with the 3.7 psig suits to provide means for which crew can prebreathe oxygen for a sufficient length of time to accomplish denitrogenation. Use of the 8.0 psig suit may avoid any need for prebreathing equipment operations or time. The time involved for prebreathing for the 3.7 psig suit normally ranges from two to four hours. (Cargo Transfer (IVA/EVA only) 29)

3-4. The MSS shall provide a compatible shirtsleeve environment to an attached element.

ELECTRICAL POWER SUBSYSTEM FUNCTIONAL REQUIREMENTS

4-1. All electrical and signal interfaces shall be deadfaced on both sides of the interface prior to being connected or disconnected. (Mating 27) (Separation 16)

4-2. Prior to activating electrical interface circuits or closing deadface switches, proper mate of the interface connectors shall be verified. (Mating 28)

4-3. When electrical or fluid interfaces are to be mated between the MSS and an element, a ground connection between the structures shall be established to provide a consistent measured low impedance bond rather than rely on the mating interface for structural ground. (Mating 38) (Orbital Assembly 29)

4-4. The MSS shall supply electrical power in support of the attached RAM's, and detached RAM's and other elements attached to and being supported by an MSS. (Attached Element Operations 1)

4-5. Adequate lighting shall be provided along all personnel crew transfer routes. General illumination criteria for shirtsleeve operations are presented below.

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

(Cargo Transfer - 5, 11)

GUIDANCE AND CONTROL SUBSYSTEM FUNCTIONAL REQUIREMENTS

5-1. For docking the MSS must align its mating port with respect to the mating port of the other vehicle in both translation and rotation. (Mating 4)

Alignment shall be as follows:

Lateral miss distance - +/- 6 inches

Pitch/yaw/roll misalignment - +/- 3 degrees

During direct docking alignment and closure to docking contact, a narrow attitude deadband on the order of 0.2 degree shall be maintained by the MSS. (Mating 6)

5-2. Prior to separation, the MSS will maintain attitude hold control of the mated pair. At separation, both elements will have attitude control capability. (Separation 1)

For a jet translation separation, the MSS will be holding attitude. The other element will perform the translation maneuver holding a deadband attitude during the separation.

5-3. Prior to final separation, the attitude reference of the MSS and associated separating element will be aligned. (Separation 11)

5-4. The MSS must contain an attitude reference assembly, either horizon sensor, star tracker or capable of determining the element attitude in relation to the element coordinates and orbital or earth coordinates.

For these requirements the MSS attitude reference components shall be capable of measuring attitude to an accuracy of $\pm$0.5 degree. (Rendezvous 4)

5-5. Both the MSS and any DRAM it is supporting must contain an attitude reference assembly capable of determining the RAM attitude in relation to the MSS coordinates and orbital or earth coordinates. Knowledge of RAM attitude is necessary for the pointing of onboard sensors, antennas and for orientation to perform delta-V orbital makeup maneuvers. (Stationkeeping 2)

5-6. Both the MSS and DRAM's must have attitude control systems enabling implementation of a change in attitude. (Stationkeeping 5)

5-7. The MSS must have a computer system capable of computing state vectors and orbital parameters from range, range rate data or other data supplied from element onboard sensor systems. It shall also have the capability to compute delta velocity maneuvers from stored data for the make-up of orbital parameters. (Rendezvous 1) (Stationkeeping 9) (Detached Element Operations 10)

At the time of a state vector update, the one sigma uncertainty in element position and velocity shall not exceed the limits of the type presented below:

Element Position and Velocity Uncertainty

Component	Position	Velocity
Downrange	± 3 nautical mile	± 3 ft/sec
Crossrange	± 1 nautical mile	±10 ft/sec
Vertical	± 1 nautical mile	±20 ft/sec

During initial rendezvous operations when the controlling element is tracking a cooperative target, the one sigma uncertainties shall not exceed the limits of the type presented below:

Cooperative Target Tracking Uncertainty

Parameter	Uncertainty at 30 n mi
Range	± 100 feet
Range rate	± 1.0 ft/sec

5-8. The MSS control center must have the capability to calculate the relative positional state (position and velocity) of the rendezvous elements and then determine, based on a knowledge of the ephemerides of both elements, the maneuvers (vectorial velocity changes) which the active element must execute to effect rendezvous with the passive element. (Rendezvous 2)

PROPULSION SUBSYSTEM FUNCTIONAL REQUIREMENTS

6-1. Prior to contact between the mating interfaces, the relative closing rate (axial velocity) must be reduced to a velocity that is compatible with both the MSS and the mating vehicle's structure and mating port energy absorption capabilities. The range of relative closing velocities for the MSS and associated mating elements are:

Longitudinal velocity -

with attenuation, 0.3 fps
without attenuation, 0.05 fps

Lateral velocity -

with attenuation, 0.16 fps
without attenuation, 0.05 fps

Angular velocity - 0.1 d/s

(Mating 14)

6-2. The MSS must have attitude control capability enabling implementation of a change in attitude. It shall be capable of holding attitude within ± 0.5 degree of desired. (Rendezvous 5)

6-3. The MSS must have propulsive systems capable of performing delta velocity maneuvers in accordance with the computed requirements for orbital makeup. (Stationkeeping 10)

COMMUNICATIONS/DATA MANAGEMENT SUBSYSTEM FUNCTIONAL REQUIREMENTS

7-1. Range and range rate data shall be displayed during mating operations. This capability must also exist during other data transfer. (Mating 9) (See Rendezvous 8 and 9).

7-2. Electronic acquisition for automated docking maneuver control shall have remote backup for manual override of the docking operation. If the manual override is to continue the docking rather than abort the functions, visual capability must be provided through a video system to the remote control site. (Mating 10)

7-3. Sensing shall be provided to ascertain positive capture has occurred at the mating port. (Separation 7, Mating 12, Attached Element Operations 5, Orbital Assembly 19)

7-4 After mating, the control assemblies of the vehicle mated to the MSS shall be inhibited to permit combined vehicle maneuvering and prevent inadvertent control system activity resulting in plume impingement damage. (Mating 22)

7-5. Audio and visual alarms shall be provided along crew and cargo transfer routes. Audio alarms could be tone and/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. Crew Transfer (20), Cargo Transfer (27)

7-6. The following data parameters shall be provided to the ARAM by 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. (Attached Element Operations 3)

7-7. The MSS shall provide attitude pointing, orientation maneuvering, attitude hold deadband (limit cycle), and attitude rate capability to attached elements. (Attached Element Operations 7)

7-8. The MSS shall receive experiment data from the ARAM with subsequent recording and storage. (Attached Element Operations 14)

7-9. The MSS must have a sequence timer or computer scheduled timing activation device that can automatically activate or wake up specified subsystems utilized in stationkeeping of two unmanned near-earth orbital elements. This is either automatically programmed at the end of the last previous operation or is set up in a ground contact to the MSS. (Stationkeeping 1)

7-10. The MSS must have a computer memory capable of storing attitude reference data and predicted attitudes for all stationkeeping operations. The computer must be programmed and a look-up routine available that can perform a computation to determine the difference between actual and predicted attitudes and to calculate the attitude control maneuvers to correct the attitude within prescribed limits. (Stationkeeping 3)

7-11. The MSS must have an onboard autonomous navigation capability for determining its own state vectors and orbital parameters. A device composed of a star tracker and an earth horizon sensor satisfies this requirement. (Stationkeeping 13)

7-12. Communications capability shall be provided between transfer crew members. Two-way voice communications must be maintained to the IVA/EVA crewmen at all times. (Crew Transfer 16, Cargo Transfer 17, Orbital Assembly 10)

7-13. A means shall be provided in the MSS to command and control the collection, storage, and transfer of dumped or real-time data by the detached element. (Detached Element Operations 5)

7-14. Monitoring and checkout of detached element condition, operations and equipments by continuous or periodic interrogation shall be provided for determining element status, isolating faults, processing and displaying such data for evaluation and possible correction. (Detached Element Operations 8)

7-15. A means shall be provided for inspection of the detached element by direct visual observation or by a television system. (Detached Element Operations 11) (Mating 3)

7-16. The MSS shall be equipped with RF communications devices. The minimum characteristics are given in the following three matrices. It shall at a minimum have the capabilities defined in Table 5- . (Mating 10, Separation 8, Rendezvous 6, Stationkeeping 4, 6, 7, 8, 11, and Detached Element Operations 1 and 4)

EOS ELEMENT PAIR REQUIREMENTS MATRIX

	MSS	EOS	TUG	RAM	Ground
1	Command Data Transmission to Digital, BER $1x10^{-6}$ Voice (0.3-3 KHz)	 10 kbps Yes	 10 kbps Yes	 10 kbps NA	 NA NA
2	Command Verification Digital from BER $1x10^{-6}$ Receive/verify	 10 kbps Yes	 10 kbps Yes	 10 kbps Yes	 NA NA
3	Data Storage Digital from BER $1x10^{-6}$ Later dump per day Film or tape delivery	 10 kbps NA NA	 10 kbps NA NA	 $94x10^9$ (max) 30 Mbps for 1 hr 15 reels per day (to ground)	 NA NA NA
4	Digital Data Transfer Receive from Transmit to	 2 kbps 51.2 kbps	 4 kbps 10 kbps	 50 bkps 10 kbps	 500 kbps 2.0 Mbps
5	Analog Data Transfer from Voice (4 kHz) Channels Television Other	 1 NA NA	 1 NA NA	 NA B&W, 2.9 MHz NA	 3 NA 0.03 to 10 kHz Audio hi-fi
6	Tracking/Ranging PRN range capability 1 n mi/range ±5 ft/sec range rate	 measure respond	 measure respond	 measure --	 -- respond
7	Computer Capability to Determine Ephemerides	Yes	Yes	Yes	NA
8	Visual Inspection	Yes, TV	Yes, TV	Yes, TV	NA
9	Analog Data Transmission to Voice (4 kHz) Channels Television Other	 1 NA NA	 1 NA NA	 NA NA NA	 3 4.5 MHz color Facsimile 500 kHz

Element Characteristics Matrix

MSS

Operation with
EOS, Tug, RAM, Ground Station, TDRS

Frequency Band	Ku	S	VHF
Frequency band Ret. Fw.	14.4 - 15.35 GHz 13.4 - 14.2 GHz	2200 - 2300 MHz 2025 - 2120 MHz	136 - 144 MHz 126 - 130 MHz
Data - transmit	Note (1)	Note (1)	
Analog - voice Analog - TV Digital	3 channels Color, 4.5 Mhz 2.0 Mbps	3 channels -- 1 Mbps	1 channel -- 10 kbps
Data - receive	Note (2)	Note (2)	
Analog - voice Analog - TV Digital	3 channels -- 500 kbps	3 channels -- 500 kbps	1 channel -- 1 kbps
Antenna type Gain Size	Parabolic 45 db 5 ft dia.	Omni 0 db	Omni 0 db
Receiver Noise Figure	1200 K	800 K	1200 K
Transmitter Power output	25 watts	30 watts	25 watts
Tracking/Ranging Measure Respond	 -- X	 X X	 -- --

SLR active system and passive reflectors at docking ports

(1) Additional down data for facsimile - 0.5 MHz bandwidth

(2) Additional up channel for entertainment
Audio - 30 Hz - 10 kHz baseband

CREW AND HABITABILITY SUBSYSTEM FUNCTIONAL REQUIREMENTS

8-1. The MSS shall provide a means to perform visual tracking of the other element during the terminal phase at a separation of less than 5 miles. (Rendezvous 10)

8-2. All IVA, EVA and hazardous shirtsleeve operations shall be conducted with a minimum of two crew members (buddy system). One crew member, acting as a backup, monitors the operations of the active crew member providing a rescue capability. (Crew Transfer 1) (Orbital Assembly 9)

8-3. The backup crew member during IVA, EVA, and hazardous shirtsleeve operations shall be positioned at the point of egress. He will be required to observe the active crew member at all times and, in the case of IVA/EVA activities, will be required to control the active crew member tether and/or umbilical to prevent entanglement. A third crew member shall be available for voice communications and C&W monitoring. (Crew Transfer 2)

8-4. Crew mobility aids and restraint devices shall be provided along all crew transfer routes and worksites in order to facilitate crew translation and stabilization in zero-g environment. Crew Transfer (3)

8-5. Crew mobility aids shall be capable of use by a 5 to 95 percentile crew member in either a shirtsleeve or pressurized suited mode of operation. Crew Transfer (4), Cargo Transfer (11)

8-6. Crew restraint devices shall be capable of use by a 5 to 95 percentile crew member in either a shirtsleeve or pressurized suited mode of operation. Development of worksite crew restraint device requirements will be dependent upon the reach capability of the 5 to 95 percentile crew propulation while restrainted. Illustrations on pages 5-49 and 5-50 define anthropometric data. Crew Transfer (6)

8-7. Crew restraint devices shall be easily operable, not restrictive of required crew motions, and possess a high degree of crew acceptability. Crew Transfer (7)

8-8. Crew restraint devices shall be designed to allow crew members to apply various combinations of loads at 1 g equivalent force values with or without a pressurized space suit. Crew Transfer (8), Cargo Transfer (16).

8-9. Cargo restraint devices shall be capable of single hand attachment operations by a crewman in a pressurized space suit. Cargo Transfer (4)

8-10. Crew restraint devices shall be provided along the cargo transfer path and at cargo transfer worksites to provide capability for crewman positioning and stabilization. Cargo Transfer (15)

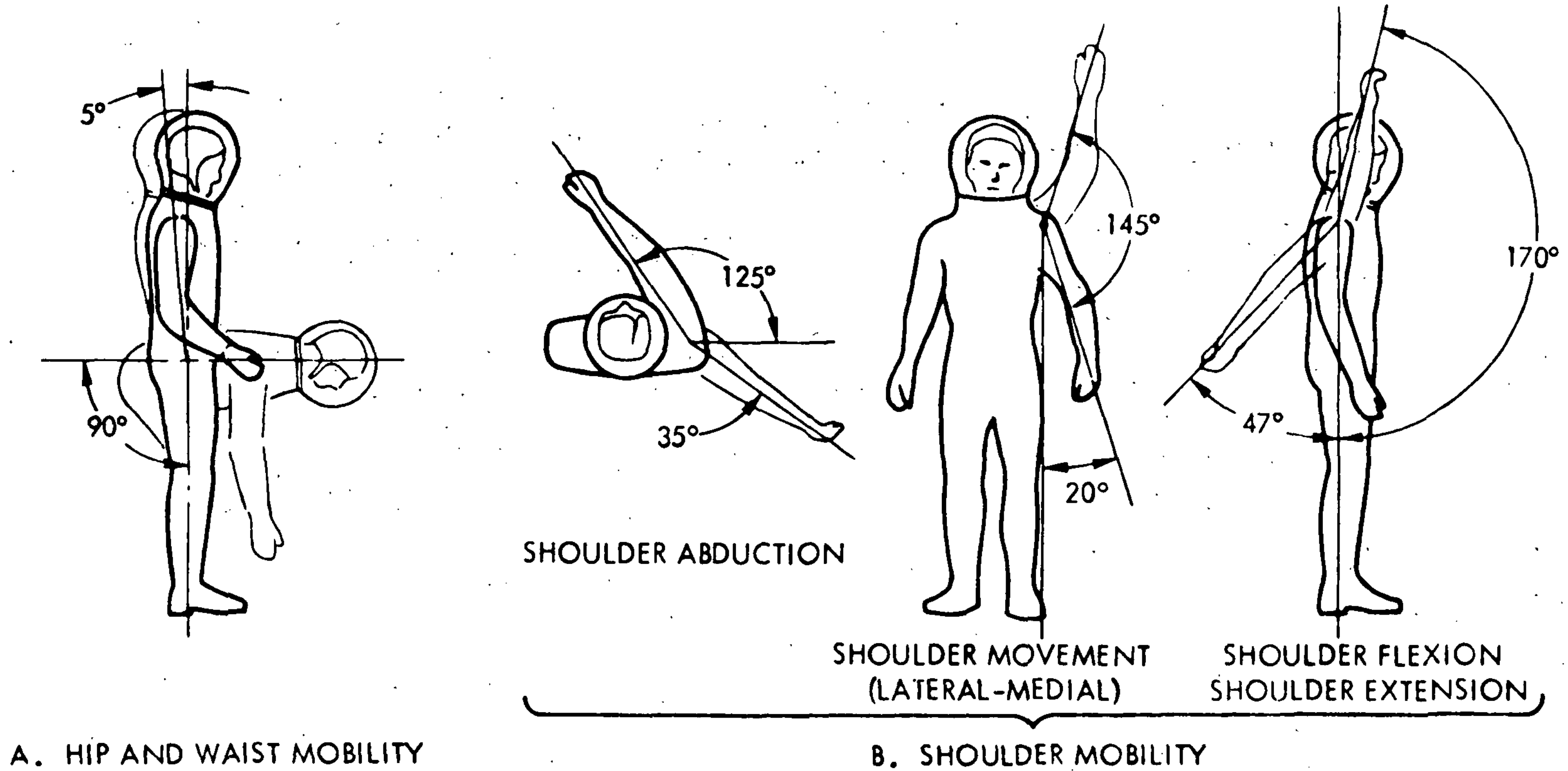
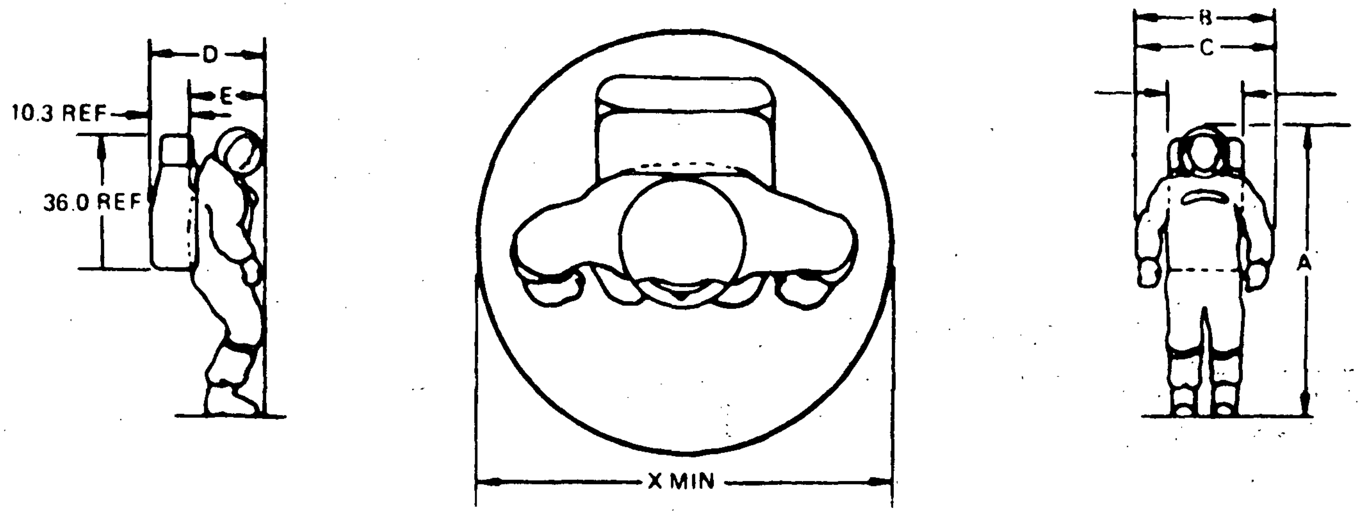


Figure 3-11. PGA Mobility



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 3-12. Envelope Dimensions for a Suited Pressurized Male Crew Member

8-11. 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. Cargo Transfer (18)

8-12. 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).

8-13. Manual interface connections shall be located, designed, and mounted such that a worker can mate the connectors in a pressurized IVA suit. Mating (32), Cargo Transfer (34)

8-14. Accessible surfaces shall be capable of being touched by a crewman in a shirtsleeve or spacesuit. Surface materials shall be selected to ensure that high and low temperatures and conductivity are not limiting factors in crew or cargo transfer. Crew Transfer (5), Cargo Transfer (14)

8-15. The weight (mass) of cargo/resupply items requiring manual handling will be limited by crewman maneuvering capabilities. All cargo transfer approaches, except 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 with 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 the table below. For two men, a 250-pound mass is considered the upper limit at zero-g. Cargo Transfer (1)

Cargo Mass Handling Limits (180-pound Crewman)

g level	0	.1	.2	.2	.4	.5	.6	.7	.8	.9	.10
% 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

8-16. 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. Cargo Transfer (2)

8-17. Individual cargo items within a general container shall be packaged to prevent movement or damage during transfer. Cargo Transfer (6)

8-18. Containers that enclose pressure vessels shall be connected to vents prior to and after transfer. Cargo Transfer (7)

8-19. All equipment installations within crew mobility areas shall be capable for use for push-off. Installations shall be capable of withstanding multi-directional application of crewman impact loads. Cargo Transfer (2)

8-20. Equipment susceptable to damage or that is hazardous to crew and cargo transfer operations shall be separated from mobility areas and color-coded or placarded. Crew Transfer (10), Cargo Transfer (21)

8-21. All hatches between elements shall be capable of operation from either side of the hatch, including a capability for pressure equalization across the hatch. Also included is the capability for pressure monitoring and leak rate checks. Crew Transfer (12), Cargo Transfer (22), Attached Element Operations (21), Orbital Assembly (40)

8-22. Acceptable noise levels shall be maintained during crew and cargo transfer operations to prevent discomfort to crew members and interference with verbal communications at normal voice levels. Crew Transfer (14), Cargo Transfer (24)

8-23. Passageways/aisles shall be capable of accommodating crew and cargo transfer operational requirements. Figure 3-9 presents primary passageway criteria. Cargo Transfer (18), Cargo Transfer (25), Attached Element Operations (30)

8-24. Cargo transfer device 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. Cargo Transfer (8)

8-25. Cargo transfer device shall not compromise emergency element interface undocking and pressure sealing capabilities. Provision for automatic or rapid disconnnetion of transfer system interfacing components will be required to maintain emergency capabilities. Cargo Transfer (9)

8-26. Automatic cargo transfer device 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. Cargo Transfer (10)