CONTRACT NAS9-12068
DRL LINE ITEM 7

MSC 04482
SD 72-SA-0007

ORBITAL OPERATIONS STUDY

APPENDIX B

OPERATIONAL PROCEDURES

FINAL REPORT

MAY 1972

APPROVED BY:

L. R. Hogan
Study Manager
ORBITAL OPERATIONS STUDY

Space Division
North American Rockwell

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ABSTRACT

THIS DOCUMENT IS APPENDIX B OF THE FINAL REPORT OF THE ORBITAL OPERATIONS STUDY. OPERATIONAL PROCEDURES ARE INCLUDED FOR EACH ALTERNATE APPROACH FOR EACH INTERFACING ACTIVITY. THE APPLICABILITY OF THE PROCEDURES TO INTERFACING ELEMENT PAIRS IS IDENTIFIED.

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

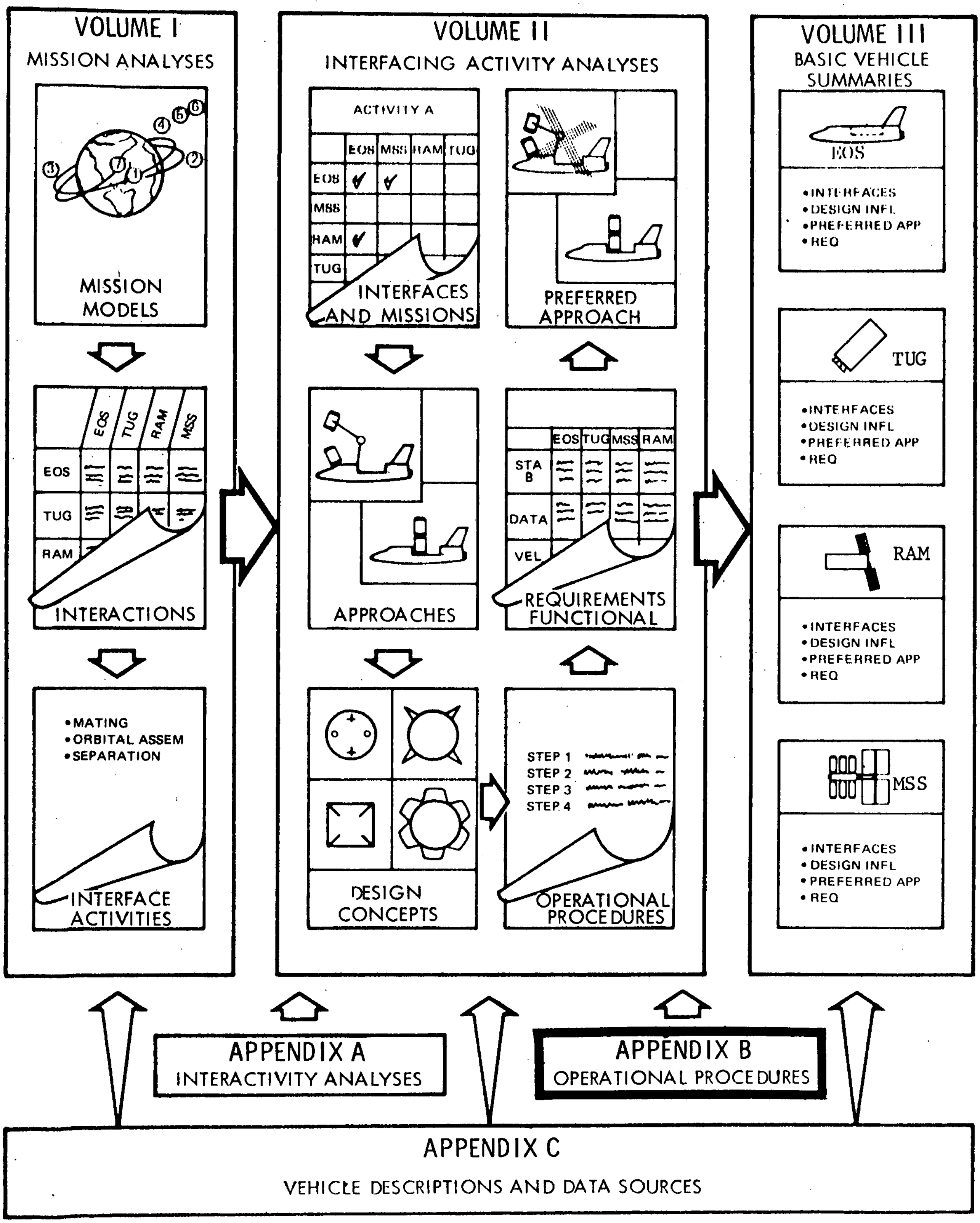
Volume III - BASIC VEHICLE SUMMARIES, contains a condensed summary of the study data pertaining to the following elements:

- 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

1.0 INTRODUCTION AND SUMMARY

Appendix B presents all of the operational procedures which have been developed in the Orbital Operation Study. Each operational procedure is a sequence of operations for performing an interfacing activity utilizing a particular alternate approach. The relationship between this appendix and Volume II is shown in Figure 1.0-1. As indicated, this appendix supports Volume II with detailed procedures for each of the 14 interfacing activities included in Volume II, and defined in Table 1.0-1.

A list of titles of a total of 38 operational procedures included herein appears on Table 1.0-2. A procedure has been developed for each unique alternate approach (see Volume II for discussion of approaches) for each interfacing activity. In a few cases it was deemed desirable to generate a single procedure applicable to two alternate approaches. An example of this is procedure No. 14-1 which applies equally to both internal and external attachment approaches.

The operational procedures are an end product in themselves. In addition, they have assisted greatly in the identification of functional requirements for the various interfacing activities and alternate approaches. These requirements are documented in Volume II and are cross-referenced herein in the procedures tables.

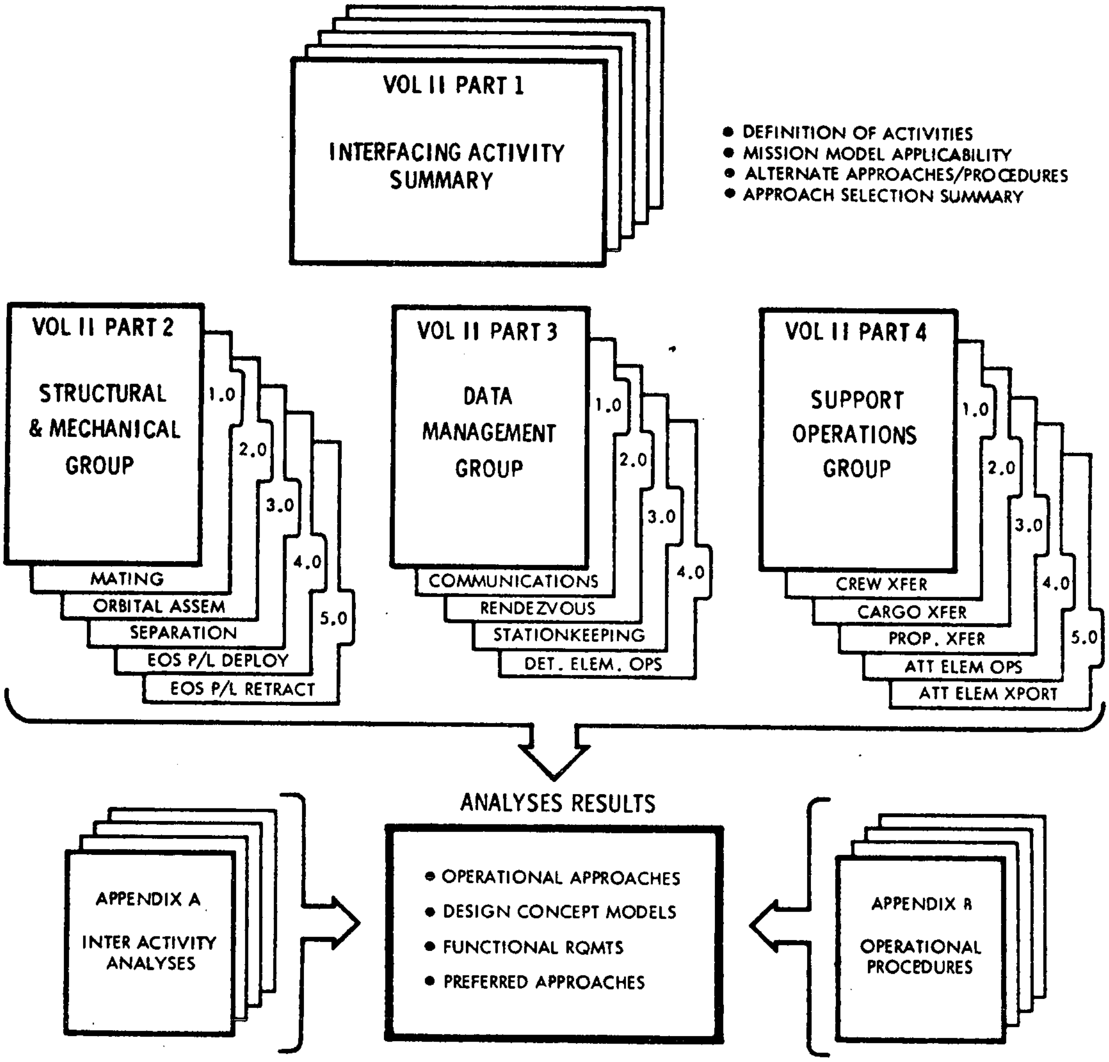

Figure 1.0-1. Relationship of Appendix B to Volume II

Table 1.0-1. Definition of Interfacing Activities

Activity Title	Activity Definition
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
Cargo Transfer	The transfer of solid and fluid cargo between two elements in orbit
Crew Transfer	The transfer of personnel between two elements in orbit
Propellant Transfer	The transfer of large quantities of liquid hydrogen and liquid oxygen between elements in orbit
EOS Payload Deployment	The removal of a payload from the orbiter cargo bay and readying it for operation or separation
EOS Payload Retraction and Stowage	The insertion of a payload into the orbiter cargo bay subsequent to initial mating of the payload to the orbiter
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
Attached Element Operations	Support by one element to another attached element while the latter is operating or being serviced, checked out, or stored
Detached Element Operations	The operational support required by a free-flying element from another element and/or ground control
Attached Element Transport	Support by a major propulsive element to an attached payload (element or module) during transport from one orbit to another

Table 1.0-2. List of Operational Procedures

Interfacing Activity	Procedure Number	Procedure Title
Mating	1-1	Direct Dock - Manned Element to Manned or Unmanned Element
	1-2	Manipulator - Manned Element to Manned or Unmanned Element
	1-3	Direct Automatic Dock - Unmanned Element to Unmanned Element
Orbital Assembly	2-1	Module to Unmanned Element - Shirtsleeve Assembly
	2-2	Module to Manned Element - IVA Assembly
	2-3	Module to Cislunar Shuttle - Automatic Assembly
Separation	3-1	Jet Translation - Manned Element from Manned or Unmanned Element
	3-2	Manipulator - Manned Element from Manned or Unmanned Element
	3-3	Jet Translation - Unmanned Element from Unmanned Element
Cargo Transfer	4-1	Manual Unaided - Shirtsleeve
	4-2	Manual Unaided - IVA
	4-3	Manual Unaided - EVA
	4-4	Manual Aided - Shirtsleeve
	4-5	Fluid (Plumbed) - Shirtsleeve
Crew Transfer	5-1	Shirtsleeve
	5-2	IVA
Propellant Transfer	6-1	Direct Fluid Transfer
	6-2	Direct Modular Transfer
EOS Payload Deployment	7-1	Manipulator
	7-2	Pivot Mechanism
EOS Payload Retraction and Stowage	8-1	Manipulator
	8-2	Pivot Mechanism
Communications	9-1	Element to Ground - Direct
	9-2	Element to Ground - via TDRS
	9-3	Element to Element
Rendezvous	10-1	Independent Approach, Passive Element in Control
	10-2	Independent Approach, Active Element in Control
	10-3	Ground Controlled or Space Controlled
Stationkeeping	11-1	Autonomous - Both Elements Unmanned
	11-2	Ground Controlled - Both Elements Unmanned
Attached Element Operations	12-1	RAM Operations
	12-2	Service and Checkout
	12-3	Quiescent Storage
Detached Element Operations	13-1	Ground Control - via MSFN
	13-2	Ground Control - via MSFN and Relay Orbiting Element
	13-3	Ground Control - via TDRS
	13-4	Space Control - Element to Element
Attached Element Transport	14-1	Internal or External Attachment

2.0 INTERFACING ACTIVITIES

This section presents the operational procedures developed for each of the 14 interfacing activities in the Orbital Operations Study. In addition, the applicability of each procedure to each element pair for each activity is identified and discussed.

The operational procedures and associated data are categorized and documented herein by interfacing activity. This categorization corresponds with the breakdown used in Volume II, which this appendix supports. The tables upon which the procedures are presented include the following information: the operations presented sequentially, the primary element that is performing each operation, and the rationale which explains the purpose or need for each operation.

For each interfacing activity a matrix is included that identifies the applicability of procedures to the potential interfacing element pairs. These matrices include 17 elements out of the total study inventory of 25 elements. A discussion of the reasons for reducing the number of elements for detailed study, and the rationale used in the element selection process, is presented in Section 4.0 of Volume I.

2.1. MATING

This section presents the operational procedures for mating, and includes one procedure for each alternate approach identified in Volume II of this report. Also presented and discussed is the applicability of these procedures to each element pair included in the in-depth analysis portion of the Orbital Operations Study.

2.1.1 OPERATIONAL PROCEDURES

The development of operational procedures for mating required that a number of considerations be evaluated in order that each of the possible element pairs in the study would be applicable to at least one of the developed procedures.

There were three possible manned or unmanned element relationships. Both of the mating elements could be manned, one of the elements could be manned and the other unmanned, or both elements could be unmanned.

There were also three methods of performing the mating operation. The operation could be performed using the direct dock method, it could be performed using a special extension-retraction device, or it could be performed with a manipulator attached to one of the elements. The extension-retraction device was eliminated from the procedural development in that it was a simplified manipulator (single degree-of-freedom) and would not provide the procedural depth of a manipulator concept.

A simple matrix, Table 2.1-1, was prepared and the combinations analyzed to determine what type procedures needed to be developed.

Table 2.1-1. Possible Procedural Development Array

	Manned to Manned	Manned to Unmanned	Unmanned to Unmanned
Direct dock	X	X	X
Manipulator berth	X	X	X

The use of a manipulator for performing unmanned-to-unmanned berthing operations did not appear to be a viable option. Most manipulator designs were developed around force feedback concepts or with man-in-the-loop to at least perform override functions. Also, those elements that appear to be candidates for built-in manipulators were elements that would probably be manned. Therefore, it was ground ruled that manipulator berth of unmanned elements-to-unmanned elements would not be investigated.

The direct docking concept is performed with one element essentially performing a passive role in that it will probably only hold attitude while the other element performs the maneuvers necessary to accomplish the dock. Because only one element will be performing the active operations, particularly at final docking phases, it was advantageous that the element should be the manned element of a manned-unmanned pair. Therefore, the procedure for a manned-to-manned or manned-to-unmanned direct docking would be so very similar that these two procedures could be combined.

Finally, when the preliminary procedures for manipulator berthing of manned-to-manned elements and manned-to-unmanned elements were developted it was found that they too were very similar and, like the direct docking, could also be combined.

Therefore, three procedures were developed: (1) direct docking - manned elements to manned elements and manned elements to unmanned elements, (2) direct docking - unmanned elements to unmanned elements, and (3) manipulator berth - manned elements to manned elements and manned elements to unmanned elements.

Before preparing any procedure it was necessary to select a pair of elements to use as a model. By doing this, the procedure would not become so generic that it could fail to uncover detail ambiguities of specific elements that may affect design concepts or be sensitive to particular design requirements. Since the EOS orbiter could be mated with the full array of study elements it was concluded that it be used in at least one of the procedures. The modular space station was the next element selected in that it presented the most stringent alignment problems with its variety of configurations during assembly, and because of its always-present interferring appendages that must be avoided during the mating operations. These two elements were utilized as the model for the manned direct docking concepts. Since the direct docking concept was to be evaluated against the manipulator berth concept it followed that the same elements should be utilized for the manipulator berth procedure as well, such that the procedural deltas would not be design oriented, but operationally oriented. For the unmanned element-to-unmanned element direct docking procedure, two candidate unmanned elements (space tug and detached research applications module) were selected. Table 2.1-2 shows the final operational procedures that were developed.

Table 2.1-2. Mating Procedures

	Manned to Manned	Manned to Unmanned	Unmanned to Manned
Direct dock	One procedure EOS orbiter to MSS		Space tug to DRAM
Manipulator berth	One procedure EOS orbiter to MSS		X

Procedural Comparison

The mating procedures include capture, attenuation of delta velocities or impact forces, structural alignment of the mated pair, and configuring of the interface between the elements for mated operations. The single manipulator procedure was extended to include the transfer of a module from an EOS orbiter cargo bay into a hard berth on the MSS so that these additional steps could be analyzed for any new requirements.

Figure 2.1-1 is a general comparison of a manipulator berth procedure with a direct docking procedure. The central balloons represent common procedures, whereas, the upper and lower balloons on the page represent procedural differences. The real difference between the procedures is that the manipulator procedure is a two-phase operation, involving a capture and transfer and mate, and the direct dock procedure performs capture at the mating port and effects the mate in essentially the same operation. The manipulator must null out the relative velocities between the vehicles after capture, whereas, with direct dock, impact energy is attenuated at capture.

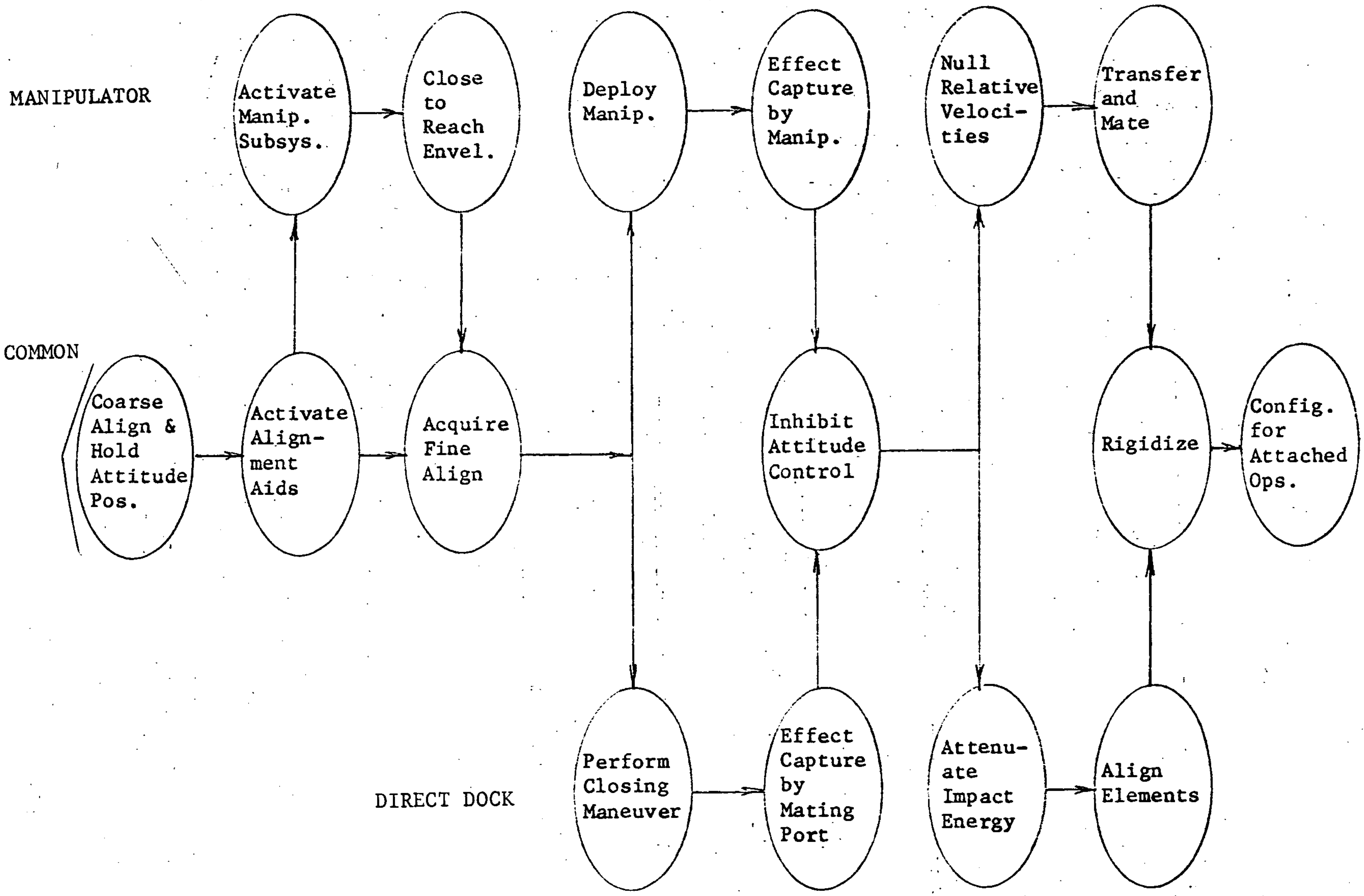

Figure 2.1-1. Comparison of Procedures

OPERATIONAL PROCEDURE NO. 1-1

Mating - Direct Dock, Manned Element to Manned Element or Manned Element to Unmanned Element

This procedure was developed utilizing an EOS orbiter and a modular space station (MSS) as the model.

Assumptions:

The EOS orbiter is equipped with control systems which are compatible with the structural design of the mated elements.

Initial Conditions:

The EOS orbiter has rendezvoused with the MSS. Running and orientation lights and communications between the elements have been activated and verified during the rendezvous activity. All independent preparations required by the elements to physically configure for the upcoming mate have been performed (i.e., adapters installed or ports extended, captive latches cocked, mating port environmental covers opened, TV cameras in place, viewing window covers opened, cargo bay doors opened, etc.).

Final Conditions:

The mated elements are ready for assembly activities or separation activities.

Description:

During the mating operation one element assumes the passive role, whereby, it will only maintain attitude hold while the other element actively performs the maneuvers to accomplish the dock. For this operation, the EOS orbiter will assume the "active" role and the MSS, the "passive."

Because the manned MSS can assist with the docking, when it is manned, by providing backup information, criteria are imposed on the EOS orbiter that may not be applicable for other dockings (i.e., orbiter illumination).

The direct docking procedure is made up of three primary operations: (1) precontact, (2) contact, and (3) post-contact).

Precontact operations include initiation of guidance aids, alignment, and the vehicle maneuvers to accomplish the closing operation. The contact operation includes physical contact of the docking interfaces, the initial capture of the vehicles, and the attenuation of the impact energy. Post-contact includes the mechanical alignment of the mated vehicles and the configuring of the interfaces for mated operations.

OPERATIONAL PROCEDURE NO. 1-1

TITLE: ONE ELEMENT MANNED (ASSUMING ACTIVE ROLE); OTHER ELEMENT MANNED OR UNMANNED (ASSUMING PASSIVE ROLE)

ELEMENT INTERFACES: EOS ORBITER (MANNED)/MSS (MANNED OR UNMANNED)

	Operation	Performed by:	Rationale
1	Illuminate passive element	Passive/ active	The passive element is illuminated to the extent that appendages can be viewed and avoided during closing operations. Emphasis will, however, be placed on the mating port to facilitate inspection of the mating interface. If backup docking capability exists in the passive element, the active vehicle will require illumination. Sun illumination is acceptable when it is available, but direct or specular glare emanating from sunlight may hinder rather than enhance visual accuity, requiring that the vehicle orient itself such that the operation is shadowed.
2	Active element commands passive element to acquire stable attitude (This step applies for unmanned passive element only)	Active	The unmanned passive element responds only to preprogrammed commands or commands transmitted from ground or another controlling element. For this procedure, the active element will be sole source of commands for the unmanned element.
3	Passive element acquires stable attitude	Passive	Prior to performing any alignment by the active vehicle, the passive vehicle must be in a relatively fixed attitude (wide deadband).

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OPERATIONAL PROCEDURE NO. 1-1

	Operation	Performed by:	Rationale
4	Inhibit venting systems	Active/ passive	Propulsive vent systems that can cause vehicle deviation during berthing (except attitude control jets) and venting systems that can contaminate the mating elements must be inhibited during mating and mated operations or, if required, the dump operations will be accomplished on a periodic basis utilizing times where least contamination will occur.
5	Inhibit independent tracking and maneuvering of large appendages	Active/ passive	The purpose of this step is to lock into a noninterference plane such items as solar arrays and gimballed antennas.
6	Maneuvers to inspect mating port	Active	The maneuver will bring the elements into a position where the inspection can be performed with the available aids on the active element (TV, direct viewing, telescope, etc.).
7	Inspect mating port	Active	The mating port is inspected to verify it is properly configured for mating operations and was not damaged during the last mate and separation operation.

OPERATIONAL PROCEDURE NO. 1-1

	Operation	Performed by:	Rationale
8	Acquire proper position to begin closure operation	Active	The selected position is one that provides clearance from interfacing passive element appendages and provides a path that requires minimum maneuvers to accomplish the mate.
9	Active vehicle commands passive vehicle to acquire attitude hold mode for final maneuvers (required for unmanned element only)	Active	This operation required only if the subsequent attitude hold mode did not provide sufficient attitude stability.
10	Passive element acquires narrow deadband attitude hold mode (attitude/rate stabilization)	Passive	Docking port capture tolerances and alignment aid utilization requires that the elements be in a relatively stable attitude during the docking operation.
11	Activate alignment/ranging aids and verify	Active/ passive	All aids (laser, TV cameras, targets, special lighting effects, etc.) that may be utilized to guide the active vehicle into dock must be activated. Verification includes the primary aids as well as the backup aids such that failure of a single aid will not create a hazard that could cause accidental collision.

OPERATIONAL PROCEDURE NO. 1-1

	Operation	Performed by:	Rationale
12	Elements verify they are ready for mate	Active/ passive	Verification includes statusing the primary systems as well as the backup systems. Backup systems are statused such that any time during the docking they are ready to be utilized. System verification shall include such things as docking port configuration, guidance, control properly configured, crew provisioned at their appointed stations, solar arrays oriented and locked to prevent impact loads from damaging them, loose equipment stowed, etc.
13	Align elements	Active	Element mating ports are aligned. Docking guidance (alignment) aids will be verified to be properly aligned between elements (i.e., laser transmitted/reflected beam is aligned within the reflector pattern).
14	Perform the closing maneuvers	Active	
15	Declerate closing translation to contact velocity	Active	This step occurs only if the preceding step is performed at a higher velocity.
16	Contact and continue thrusting until capture and verify	Active	Thrusting is maintained to prevent the elements from rebounding away from each other and not effecting capture or acquiring only a partial capture.

OPERATIONAL PROCEDURE NO. 1-1

Operation		Performed by:	Rationale
17	Inhibit ACS of one of the elements	-	This step should occur at capture verification. If both elements maintain an active ACS then the elements may tend to counteract the forces applied to damp the velocities (lateral/rotational) imparted by the docking as well as the waste propellants.
18	Attenuate impact forces	Active	This step occurs in parallel with the contact operation. The docking impact energy must be attenuated by the docking structure to prevent damage to the elements.
19	Damp angular and translational applied motions	-	The vehicle whose ACS was not inhibited (operational step 17) must damp the impact residual relative motion.
20	Rigidize interface and mechanically align elements	Active	Rigidization as applied to this step infers clampdown of the mating ports, the forced alignment of the elements and sealing the interface. The technique can be automatic or semi-automatic but must be capable of being rapidly disengaged in case of abort.

OPERATIONAL PROCEDURE NO. 1-1

	Operation	Performed by:	Rationale
21	Verify docking interface	Active/ passive	Prior to performing any extensive maneuvers or relaxing the docking vigilance, the latches are verified to be engaged and locked, and the mated elements mechanically aligned.
22	Assume mated operations flight mode	Active	Narrow deadband mode can be deactivated to conserve propellant.
23	Deactivate docking aids	Active/ passive	

The following operations configure the interface between the mated elements for shirtsleeve crew transfer. These operations are viable for either a transfer of personnel from a manned element into an unmanned element or for transfer of personnel between two manned elements. In both cases, the operations are performed by the crew of one of the elements only.

	Operation	Performed by:	Rationale
24	Activate controls and displays for entering tunnel area and verify habitability of mated element (See shirtsleeve crew transfer procedure for details)	Active	Those controls and displays required for tunnel pressurization and leak detection are activated. Communications are established between the tunnel area and the control center such that the control center is cognizant of the operations and can relay information to the mated manned element or visa versa or can pass information to the hatch opening crew on the status of the unmanned element. The necessary habitability criteria can be obtained utilizing RF link if it is still in existence. (Antenna patterns coincide)

OPERATIONAL PROCEDURE NO. 1-1

	Operation	Performed by:	Rationale
			However, if the RF link no longer exists then the required data must have been acquired prior to mating. If there is no RF link and the data were not available prior to mating, the extensiveness of the subsequent checkout operations must be expanded.
25	Pressurize tunnel between element hatches and equalize to active element pressure	Active	Prior to opening the hatch the pressure across the hatch must be equalized.
26	Verify tunnel leak rate		During and subsequent to the tunnel pressurization the tunnel seal integrity is verified.
27	Open hatch to tunnel and inspect mating interface	Active	The mating port interface is inspected for any damage that may have occurred during the mating operations and also to verify full engagement and lock of latches.
28	Pressurize unmanned element (This operation applies for an unmanned element only)	Active	If the unmanned element pressure has bled off during orbital operations, the element must be pressurized prior to entering.

OPERATIONAL PROCEDURE NO. 1-1

	Operation	Performed by:	Rationale
29	Isolate unmanned element and verify leak rate (This operation applies for an unmanned element only)	Active	Verifies that the leak rate of the unmanned element can be supported by the pressurization systems. The leak rate should be checked prior to fully pressurizing the element (preceding operation) such that gas can be salvaged rather than lost to space.
30	Verify the unmanned element atmosphere is compatible with the manned element atmosphere (This operation applies for an unmanned element only)	Active	Prior to entering the unmanned element, the atmosphere must be verified to be free of contaminants. It may be necessary to circulate the atmosphere to perform this task. Hardline interfaces can be mated at the unmanned hatch interface to provide command signals or monitor the atmosphere.
31	Equalize pressure between elements	Active	For an unmanned element, the pressure will be equalized to that of the manned element. For two manned elements, an interconnect valve between the hatches will be opened to equalize pressure.
32	Open hatch to other element	Active	Final hatch is opened and access between the elements can occur.
33	Connect and activate air circulation ducts	Active	If the environment is to be freely circulated between the elements, air circulation ducting will probably be required.

OPERATIONAL PROCEDURE NO. 1-1

	Operation	Performed by:	Rationale
34	Ingress element and perform initial inspection (This operation applies for unmanned element only)	Active	An initial inspection is performed to verify the general condition of the unmanned element prior to extensive mated operations.
35	Position tunnel crew restraint devices	Active	Crew restraint devices are positioned, adjusted or emplaced as required to perform the subsequent operations.
36	Install electrical interfaces	Active	Those electrical interfaces that are to be installed between the elements to support interoperations will be made.
37	Verify interface mate	Active/ passive	Prior to activating the interface, a connector mate verification is required.
38	Check out electrical interface	Active/ passive	
39	Connect plumbed interfaces and verify seal integrity	Active	Each interface seal is verified prior to passing fluids to prevent contamination of the area
40	Activate fluid interfaces as required	Active/ Passive	
	This concludes the direct docking procedure of a manned element to a maneed element or unmanned element.		

OPERATIONAL PROCEDURE NO. 1-2

Mating - Manipulator Affixed to Manned Element, Other Element can be Manned or Unmanned

This procedure was developed utilizing an EOS orbiter and a modular space station (MSS) as the model.

Assumptions

The EOS orbiter equipped with a manipulator does not transfer a module from the cargo bay directly into a mate with a stationkeeping element; rather it first berths that element to a port on the EOS orbiter, then performs the subsequent module transfer operation.

Initial Conditions

The EOS orbiter has rendezvoused with the MSS. Running and orientation lights and communications between the elements have been activated and verified during the rendezvous activity. All independent preparations required by the elements to physically configure for the upcoming mate have been performed (i.e., adapters installed or port extended, capture latches cocked, mating port environmental coveres opened, TV cameras in place, viewing window covers opened, cargo bay doors opened, etc.).

Final Conditions

The mated elements are ready for assembly activities or separation activities.

Description

This operation involves the delivery of a module by a manned transport element (EOS orbiter) to a manned or unmanned orbiting element (MSS). Throughout the procedure the EOS orbiter, which contains the manipulator, will be known as the active element and the MSS as the passive. The procedure is essentially a two-phase operation. The first phase involves the capture of the MSS and its subsequent berth to the EOS orbiter. The second phase is the transfer of the module from the orbiter cargo bay to a berth on the MSS. The first phase is applicable for any manned element with a manipulator that will be mating to a manned or unmanned element. Primary operations in the procedure are as follows:

1. Precapture operations - includes orienting elements, statusing systems, and performing closing operations

2. Capture operations - involves maneuvering of the manipulator to effect capture of the unmanned element, capture, and after capture nulling the relative velocities between the elements

3. Berth operations - transfer of the captured element from the point of capture into a hard mate on the active element

4. Post-berth operations - configures the berthing port for temporary mated operations and crew transfer

5. Transfer module to passive element - includes engaging the module in the cargo bay with the manipulator and maneuvering it from the bay into a hard berth on the passive element

6. Post berth operations - post berth operations for the module/ passive element interface involve orbital assembly operations

OPERATIONAL PROCEDURE NO. 1-2

TITLE: MATING - MANIPULATOR AFFIXED TO MANNED "ACTIVE" ELEMENT; OTHER ELEMENT "PASSIVE" AND CAN BE MANNED OR UNMANNED

ELEMENT INTERFACES: EOS ORBITER (WITH MANIPULATOR)/MSS

	Operation	Performed by:	Rationale
1	Illuminate passive element	Passive/ active	The passive element is illuminated to the extent that appendages can be viewed and avoided during closing and manipulator operations. Emphasis will, however, be placed on the manipulator end effector receptacle to assist with alignment and engagement. The berthing port is also illuminated to facilitate inspection of the mating interface. If backup manipulator alignment is performed by a manned passive element, illumination of the end effector and manipulator arm is necessary. Sun illumination is acceptable when it is available, but direct or specular glare emanating from sunlight may hinder rather than enhance visual accuity, requiring that the vehicle orient itself such that the operation is shadowed.
2	Active element commands passive element to acquire stable attitude (This step applies for unmanned passive element only)	Active	The unmanned passive element responds only to preprogrammed commands or commands transmitted from ground or another controlling element. For this procedure, the active element will be sole source of commands for the unmanned element.

OPERATIONAL PROCEDURE NO. 1-2

Operation		Performed by:	Rationale
3	Passive element acquires stable attitude	Passive	Prior to performing any alignment by the active vehicle, the passive vehicle must be in a relatively fixed attitude (wide deadband).
4	Inhibit venting systems	Active/ passive	Propulsive vent systems that can cause vehicle deviation during berthing (except attitude control jets) and venting systems that can contaminate the mating elements must be inhibited during mating and mated operations or, if required, the dump operations will be accomplished on a peridoic basis utilizing times where least contamination will occur.
5	Inhibit independent tracking and maneuvering of large appendages	Active/ passive	The purpose of this step is to lock into a noninterference plane such items as solar arrays and gimballed antennas.
6	Active element maneuvers into proper position to begin closure operation	Active	Selected position is one that provides most clearance from interferring passive element appendages and provides a path that requires minimum maneuvers by the active vehicle during the direct translation.
7	Activate manipulator	Active	Manipulator control must be activated and the arm released from the retention devices.

OPERATIONAL PROCEDURE NO. 1-2

	Operation	Performed by:	Rationale
8	Activate manipulator guidance aids/verify	Active/ passive	All aids (TV cameras, targets, special lighting effects, etc.) that may be utilized to guide the manipulator into position to effect capture are activated. Verification includes the primary aids as well as the backup aids such that when the capture operation begins, a failure of an aid will not create a hazard with manipulator control.
9	Translate active element to within manipulator reach envelope with respect to the passive element	Active	The active element must maneuver close enough to the active element to effect capture by the manipulator. The capture envelope includes the necessary stopping distance required to null out the relative velocities between the elements.
10	Active element commands unmanned element to assume a minimum deadband mode - attitude/rate stabilization (This operation applies for unmanned passive element only)	Active	
11	Elements acquire a minimum deadband flight mode - attitude/rate stabilization	Active/ passive	Manipulator control requires that the manipulator base and the target be stable such that precise positioning can be achieved.

OPERATIONAL PROCEDURE NO. 1-2

Operation		Performed by:	Rationale
12	Verify elements prepared for the capture operation	Active/ passive	Final evaluation of systems prior to initiating the capture operation (communications, attitude/rate stabilization, capture latches armed, etc.)
13	Deploy and extend manipulator to effect capture of passive element	Active	
14	Contact end effector receptacle and continue extending until capture and verify	Active	Extension is maintained to prevent the end effector from rebounding out of the receptacle prior to positive engagement
15	Inhibit captured element attitude control system	Passive	When the capture of the passive element has been verified, the captured element attitude control is inhibited to prevent it from counteracting manipulator maneuvers. The passive element rate stabilization may be required to prevent an uncontrolled oscillation of the manipulator/captured element during the subsequent operations that lead up to final berth.
16	Null the relative velocity differentials between the elements	Active	The manipulator must attenuate undesired motions of the passive element prior to transporting it to the berthing port.

OPERATIONAL PROCEDURE NO. 1-2

	Operation	Performed by:	Rationale
17	Verify positive capture	Active	The manipulator will apply forces to the captured element simulating the forces that will be applied during the transposition operation. The purpose of the operation is to verify that the manipulator has full control of the captured element and that the element will not escape during subsequent operations.
18	Deactivate capture aids	Active/ passive	TV cameras, targets, etc., utilized for the capture operation can be deactivated or utilized for another function.
19	Activate berthing aids	Active	Guidance aids utilized to perform the manipulator berthing operation will be activated and verified.
20	Acquire flight mode (TBD) for subsequent operations	Active	The selected flight mode for subsequent operations has not been determined. An attitude hold mode may cause erratic movement of the manipulator arm with a mass attached at the end when the attitude control system torques the vehicle. With free drift, changing sun angles may hinder visual acuity and controller (if it is not fully automatic) concentration.

OPERATIONAL PROCEDURE NO. 1-2

	Operation	Performed by:	Rationale
21	Maneuver captured element to berthing port and orient for final translation	Active	This step aligns the ports and provides the capability for the active element to inspect the passive element berthing port.
22	Inspect berthing port	Active	The berthing port is inspected to verify it is properly configured for berthing operations and was not damaged during the last mate and separation operation.
23	Close at berthing contact velocity and effect mate	Active	The manipulator maneuvers the passive element into position and translates it directly into a hard berth
24	Rigidize interface	Active/ passive	Rigidization as applied to this step infers clamp down of the mating ports such that mated maneuvers can occur and the interface seal seated.
25	Deactivate berthing aids	Active/ passive	The berthing operation has been completed. Subsequent steps configure the interface for mated operations.

The following operations configure the interface between the mated elements for shirtsleeve crew transfer. These operations are viable for either a transfer of personnel from a manned element into an unmanned element or for transfer of personnel between two manned elements. In both cases, the operations are performed by the crew of one of the elements only.

OPERATIONAL PROCEDURE NO. 1-2

	Operation	Performed by:	Rationale
26	Activate controls and displays for entering tunnel area and verify habitability of mated element (See shirtsleeve crew transfer procedure for details)	Active	Those controls and displays required for tunnel pressurization and leak detection are activated. Communications are established between the tunnel area and the control center such that the control center is cognizant of the operations and can relay information to the mated manned element or visa versa or can pass information to the hatch opening crew on the status of the unmanned element. The necessary habitability criteria can be obtained utilizing the RF link if it is still in existence (antenna patterns coincide). However, if the RF link no longer exists, then the required data must have been acquired prior to mating. If there is no RF link and the data were not available prior to mating, the extensiveness of the subsequent checkout operations must be expanded.
27	Pressurize tunnel between element hatches and equalize to active element pressure	Active	Prior to opening the hatch, the pressure across the hatch must be equalized
28	Verify tunnel leak rate		During and subsequent to the tunnel pressurization, the tunnel seal integrity is verified.

OPERATIONAL PROCEDURE NO. 1-2

	Operation	Performed by:	Rationale
29	Open hatch to tunnel and inspect mating interface	Active	The mating port interface is inspected for any damage that may have occurred during the mating operations and also to verify full engagement and lock of latches.
30	Pressurize unmanned element (This operation applies for unmanned passive element only)	Active	If the unmanned element pressure has bled off during orbital operations, the element must be pressurized prior to entering.
31	Isolate unmanned element and verify leak rate (This operation applies for unmanned passive element only)	Active	Verifies that the leak rate of the unmanned element can be supported by the pressurization systems. The leak rate should be checked prior to fully pressurizing the element (preceding operation) such that gas can be salvaged rather than lost to space.
32	Verify the unmanned element atmosphere is compatible with the manned element atmosphere (This operation applies for unmanned passive element only)	Active	Prior to entering the unmanned element, the atmosphere must be verified to be free of contaminants. It may be necessary to circulate the atmosphere to perform this task. Hardline interfaces can be mated at the unmanned hatch interface to provide command signals or monitor the atmosphere.

OPERATIONAL PROCEDURE NO. 1-2

	Operation	Performed by:	Rationale
33	Equalize pressure between elements	Active	For an unmanned element, the pressure will be equalized to that of the manned element. For two manned elements, interconnect valve between the hatches will be opened to equalize pressure.
34	Open hatch to other element	Active	Final hatch is opened and access between the elements can occur.
35	Connect and activate air circulation ducts	Active	If the environment is to be freely circulated between the elements, air circulation ducting will probably be required.
36	Ingress element and perform initial inspection (This operation applies for unmanned passive element only)	Active	An initial inspection is performed to verify the general condition of the unmanned element prior to extensive mated operations.
37	Disconnect manipulator from passive element and stow	Active	Manipulator can be disconnected from berthed element and stowed or utilized for another operation.
38	Position tunnel crew restraint devices	Active	Crew restraint devices are positioned, adjusted or emplaced as required to perform the subsequent operations.
39	Install electrical interfaces	Active	Those electrical interfaces that are to be installed between the elements to support interoperations will be made.

OPERATIONAL PROCEDURE NO. 1-2

	Operation	Performed by:	Rationale
40	Verify interface mate	Active/ passive	Prior to activating the interface, a connector mate verification is required
41	Check out electrical interfaces	Active/ passive	
42	Connect plumbed interfaces and verify seal integrity	Active	Each interface seal is verified prior to passing fluids to prevent contamination of the area.
43	Activate fluid interface as required	Active/ passive	

This concludes the mating operation of a manned or unmanned element to a manned element with a manipulator. Subsequent steps transfer a module from the cargo bay of an EOS and berth it to an applicable port on the MSS.

	Operation	Performed by:	Rationale
44	Crewman traverses to unmanned element berthing port where the next module is to be mated (This operation applies to the unmanned passive element only)	Active	Utilize crew and cargo transfer procedure.
45	Configure passive element for berth of the module	Passive	The assembly crew removes berthing port covers and activates alignment aids (lighting/targets). If a berthing port window is available, a CCTV camera will be installed or a crew member will be positioned at the wondow to view the module closing and alignment. The CCTV will be monitored at the manipulator

OPERATIONAL PROCEDURE NO. 1-2

	Operation	Performed by:	Rationale
			control console or if the crewman is viewing the operation from the berthing window he will have direct communications with the manipulator operator.
46	Verify elements prepared for transfer of module from cargo bay to assembly element berthing port	Active/ passive	Prior to module transfer, alignment systems including backup must be statused.
47	Manipulator engage module in cargo bay	Active	
48	Verify manipulator/module interface	Active	The purpose of this operation is to verify that the manipulator has full control of the captured element and that the element will not escape during the subsequent transfer operation. The manipulator will apply forces to the captured element simulating the forces that will be applied during the transposition phase.
49	Release module	Active	The module tie downs are released and the manipulator maintains the module in position.
50	Maneuver module to near berthing orientation	Active	The manipulator maneuvers the module into position for berth and aligns the ports.

OPERATIONAL PROCEDURE NO. 1-2

	Operation	Performed by:	Rationale
51	Close at berthing contact velocity and effect mate/verify	Active	The manipulator translates the module directly into a hard berth and maintains pressure on the interface until mate is verified.
52	Disconnect manipulator and stow	Active	Manipulator operations have been completed.
53	Deactivate berthing alignment aids	Active/	Berthing operations have been completed

This completes the mating operation of a module to an MSS utilizing a manipulator. Further operations such as rigidization for prolonged activities or separation are covered in assembly and separation procedures.

OPERATIONAL PROCEDURE NO. 1-3

Mating - Direct Dock, Unmanned Element to an Unmanned Element

This procedure was developed utilizing a space tug and detached RAM (DRAM) for a model.

Assumptions

Both elements can be controlled by a remote base (ground or orbital) utilizing an RF data link. One of the elements is equipped with a television camera mounted for external viewing. The pictures are transmitted to the remote base for analysis of the operations.

Initial Conditions

Rendezvous has been accomplished. Communications between the involved elements (base control, active element, passive element) have been established. Conditions for mate are acceptable (i.e., communications are acceptable and no interference expected, mating element subsystems verified, orbital position is correct).

Final Conditions

The mated elements are ready for maneuver operations.

Description

This procedure directly docks two unmanned elements. Control of the elements is automatic; however, a remote site (base control) will initiate particular commands which can maneuver the elements into any required attitude. Base control will always be able to abort the operation. The procedure assigns one element the active role which is the element that performs attitude maneuvers as commanded by base control. For this procedure, the space tug will assume the active role and the DRAM, the passive. Base control follows the operation by utilizing TV coverage with the TV camera viewing from the space tug. A data link from both elements to base control is also available. The primary operations are as follows:

1. Alignment - includes acquiring the target, guidance and activation, and alignment of the elements

2. Closing - maneuvers to perform mate

3. Contact - includes contact, capture, and attenuation of the docking forces

4. Post contact - involves the rigidization of the interface for subsequent maneuvers. Inhibiting of systems for subsequent mated operations is part of the attached element transport procedure.

OPERATIONAL PROCEDURE NO. 1-3

TITLE: MATING - DIRECT AUTOMATIC DOCK, UNMANNED ELEMENT TO AN UNMANNED ELEMENT

ELEMENT INTERFACES: SPACE-BASED TUG (UNMANNED)/DRAM (UNMANNED)

	Operation	Performed by:	Rationale
1	Activate TV camera/verify	Active	The active element (space tug) TV camera is turned on. Verification is a picture at the receiving station (base control).
2	Illuminate passive element	Passive	The passive element is illuminated such that the TV can acquire the element and base control can verify element attitude. The illumination will include mating ports such that a subsequent inspection of the port can be made.
3	TV camera acquire target	Active	The active element must maneuver to align the camera or the camera is gimballed or both, but whichever, the camera must be maintained on the target such that subsequent operations can be controlled and monitored by base control.
4	Orient elements relative to the sun angle and antenna patterns	Active/ passive	Elements are oriented such that sunlight enhances rather than inhibits TV coverage. Orientation must also be such that when one of the elements closes on the other, the radiated antenna patterns for base control coverage are not interfered with.

OPERATIONAL PROCEDURE NO. 1-3

	Operation	Performed by:	Rationale
10	Verify active element tracks the passive target	Active/ passive	Subsequent steps require that the active vehicle fly down a limited corridor into hard mate on the passive element. The corridor limits are established by the alignment sensor capabilities. For this operation, the passive vehicle can be rotated off alignment and the active vehicle should track its motion to maintain alignment.
11	Active element performs initial closing operation utilizing a minimum deadband translation.	Active	
12	Base control maintains override control of the translation	-	Base control should maintain the capability to stop the closure at any time for further inspection or to assure attitude alignment.
13	Close at contact velocity	Active	This step occurs only if the preceding translation were being performed at a velocity higher than the allowable contact velocity.
14	Contact and continue thrusting until capture and verify	Active	Thrusting is maintained to prevent elements from rebounding away from each other and not effecting capture or acquiring only partial capture. Verification will be a response signal from interface sensors located at the capture interface. Sensed verification will automatically cut off docking thrusters.

OPERATIONAL PROCEDURE NO. 1-3

	Operation	Performed by:	Rationale
5	Passive element acquire attitude hold mode	Passive	Base control commands passive element to acquire mode. The passive element assumes a wide deadband alignment such that the subsequent coarse alignment by the active element can occur.
6	Activate docking guidance aids	Active/ passive	Docking aids that will be utilized for alignment and range/range rate determin- ation between the elements must be activated.
7	Align docking guidance aids	Active	The maneuver will be performed by com- mands transmitted from base control. An option to maneuvering the vehicle would be to maneuver the guidance sensor (laser) until it acquires the target, then track the sensor alignment with the vehicle.
8	Both elements acquire minimum deadband attitude mode (attitude/ rate stabilization)	Active/ passive	The docking alignment criteria allow no more than a minimum deviation from docking port centerline alignment.
9	Inspect passive element docking port	Active	The mating port is inspected to verify it is properly configured for mating operations and was not damaged during the last mate and separation operation.

OPERATIONAL PROCEDURE NO. 1-3

Operation		Performed by:	Rationale
15	Attenuate impact energy	Active	This step occurs in parallel with the previous step. Without impact attenuation, damage to the elements may occur depending on impact velocity.
16	Inhibit ACS of one of the elements	-	This step occurs in parallel with the previous step. If both elements maintain an active ACS, then the elements tend to counteract the forces applied to damp the residual relative motion imparted at docking impact as well as waste propellants.
17	Damp angular and translational applied motions	-	The impact will generate residual relative motion. This relative motion must be damped by the element with the active ACS to within the constraint of the mated elements and the upcoming operations.
18	Mechanically align elements and verify interface	-	Prior to any mated orbital maneuvers, the interface must be rigidized and the vehicle aligned structurally.
19	Verify docking interface	-	Prior to any mated orbital maneuvers, the interface latches must be verified to be engaged and locked.

OPERATIONAL PROCEDURE NO. 1-3

	Operation	Performed by:	Rationale
20	Deactivate docking aids	Active/ passive	The docking operation is complete; the aids may be deactivated to conserve power.
	This completes the direct docking procedure. The mated elements are configured for subsequent orbital operations.		

2.1.2 PROCEDURES APPLICABILITY

Each procedure that was developed was reviewed for applicability to the feasible mating combinations. Figure 2.1-2 shows the results of these analyses in matrix form.

It is possible to mate all element pairs using either the direct dock or manipulator berth approach. However, for this analysis it was assumed that manipulators would not be installed on all elements. Those elements that do not appear to be candidates for manipulators are the OIS, CPS, RNS, and OPD. The first three elements which are booster-type vehicles are not candidates for manipulators in that the secondary advantages gained by manipulators are not applicable to the type missions performed by these vehicles. The OPD is not a candidate in that manipulator operations involve a man-in-the-loop concept and the OPD is an unmanned element. All matings, however, could be performed utilizing manipulators if a third element with a manipulator is available to support the operation.

		SPACE PROGRAM ELEMENTS																
		EOS	TUG		RAM				SATELLITE			EO RESUP. MODS	LOW EO MSS	CPS		RNS CLS	OLS	OPD
			RTN	SPACE BASED	ATT. EOS	DET. EOS	ATT. MSS	DET. MSS	EOS DELIV.	EOS + 3RD ST DELIV.	RETR, RESUP.			OIS	CLS			
	EOS	1, 2	1, ②	1,2	NA	1, ②	① ②	① ②	NA	NA	① ②	① ②	① , 2		① ②	① ②	① , 2	① ②
TUG	RETURNABLE	NA								NA								
	SPACE BASED	NA		1,2,3			① ②	① ② ③		NA	① ② ③	① ② ③	① , 2	① ② ③	① ② ③	① ② ③	① , 2	① ② ③
RAM	ATT. EOS	NA																
	DET. EOS	NA																
	ATT. MSS	NA		NA									① ② [1]					
	DET. MSS	NA		NA									1 ◇2					
SATEL	EOS DELIV.	NA																
	EOS + 3RD ST	NA	NA	NA														
	RETR, RESUP.	NA		NA														
	EO RESUP. MODS	NA		NA								1, 2, 3 [1]	① , 2 [1]		① ② ③ [1]	① ② [1]		① ② ③ [1]
	LOW EO MSS	NA		NA			NA	NA				NA	1 2 [3]					
CPS	OIS			NA											NA	NA	◇1 ◇2 [2]	NA
	CLS	NA		NA								NA		NA	1,2,3 [3]		◇1 ◇2 [2]	① ③
	RNS-CLS	NA		NA								NA		NA		1 2 3 [3]	◇1 ◇2 [2]	① ③
	OLS	NA		NA										NA	NA	NA	1 2 3 [3]	
	OPD	NA		NA								NA		NA	NA	NA		1 2 3 [3]

LEGEND

○ - Indicates the active vehicle or the vehicle with a manipulator is the element identified on the vertical scale.

◇ - Indicates the active vehicle or the vehicle with a manipulator is the element identified on the horizontal scale.

Blank - Either element can be active or have a manipulator.

□ - Refers to the applicable note;

1 - Refers to Procedure 1-1

2 - Refers to Procedure 1-2

3 - Refers to Procedure 1-3

NA - Not Applicable

NOTES:

[1] These elements do not have self-contained propulsive systems, but must be transported and maneuvered into a mate by a logistics element. Therefore, the active-passive designation refers to the transporting element activity relative to what the nonpropulsive element is being mated to.

[2] This element is being assembled on an orbiting booster element for transport to a higher energy orbit. During the assembly it will essentially be inactive and will require a logistics vehicle to maneuver it around; therefore, the preceding note also applies herein.

[3] This mating refers to the assembly of modules. The modules that are being mated do not have propulsive systems and must be maneuvered into mate by a logistics element. Therefore, Note 1 applies herein.

Figure 2.1-2. Operational Procedures Applicability - Interface Activity: Mating

2.2. ORBITAL ASSEMBLY

This section presents the operational procedures for Orbital Assembly, and includes one procedure for each alternate approach identified in Volume II of this report. Also presented and discussed is the applicability of these procedures to each element pair included in the in-depth analysis portion of the Orbital Operations Study.

2.2.1 OPERATIONAL PROCEDURES

Two types of orbital assembly activities must be procedurally evaluated. One is the physical attachment of modules to an element for extended operations. The other is a temporary attachment of modules on an orbiting booster element (CPS, RNS) for subsequent transport to a higher energy orbit.

The primary operations required to achieve the assembly of a module are (1) mate, (2) rigidize the interface, and (3) connect the utilities across the interface. The extended mate operations involve all three operations, but the temporary assembly involves only the first two operations. The mating activity is performed utilizing one of the procedures developed in Section 2.1.1 of this document. The rigidization operation applies to rigidization that is in addition to the rigidizing that occurs through the normal mating function. Rigidization for the orbital assembly activity involves such concepts as installing cable tension ties, rigid stiffening members, interconnect clamps, etc. The operation can be performed IVA, shirtsleeve, or can be an automatic technique as in the case of using a multiple docking adapter to provide rigidization across a number of parallel stacked modules. The development of operations for IVA and shirtsleeve rigidization requires that the rigidization techniques to be employed must be known. That is, the methods used to install cable tension ties would probably be different from those used to install a rigid member. Therefore, the procedures developed herein go only to the depth of preparing for the rigidizing operation and in one step identifies the rigidization operation. Utilities interconnect involves the mating of electrical connectors and fluid couplings and verification of the interface.

As noted, the rigidization operation could be performed IVA, shirtsleeve, or automatically. For the permanent operation, all three concepts are viable; however, for the temporary operation the automatic technique appeared to be the only method that would be universally acceptable. Therefore, the procedure for the temporary assembly operation was developed around an automatic rigidizing technique and the other two techniques were covered under the permanent assembly procedures.

The mating techniques to be utilized could be either the direct dock or the manipulator berth. It was arbitrarily decided that the direct dock concept would be utilized for the temporary assembly and the manipulator berth for the permanent assembly. Since two procedures had to be developed for the permanent assembly in order to cover shirtsleeve and IVA rigidization techniques, the manipulator for one procedure was placed on the element delivering the module for assembly and in the other procedure, the manipulator was placed on the element being assembled.

In order that the full array of assembly operations would be provided for, it was necessary to have a manned element supporting assembly of a manned element and a manned element assemblying an unmanned element.

Finally, it was necessary to identify the supporting elements to model the procedure around. For the permanent assemblies, the EOS orbiter was selected and for the temporary assembly, the space tug would be the assembler.

Table 2.2-1 shows the three procedures that were developed and the variables selected to develop each procedure.

Table 2.2-1. Procedure/Criteria Matrix

Procedure Type	Type of Mate	Model		Manning		Rigidizing Technique
		Assy. Elem.	Support Elem.	Assy. Elem.	Support Elem.	
Permanent	Manipulator on transport element	MSS	EOS orbiter	Unmanned	Manned	Shirtsleeve
Permanent	Manipulator on assembly element	MSS	EOS orbiter	Manned	Manned	IVA
Temporary	Direct dock	OLS on CPS	Space tug	Unmanned	Manned	Automatic

Procedural Comparison

As noted, the orbital assembly procedures have been developed around two different types of assembly operations. One type is the assembly of elements that are of a permanent nature where man is directly involved in the assembly of the interface. Figure 2.2-1 outlines the operations for this type of procedure and shows the deltas if the interface is configured using IVA techniques as opposed to shirtsleeve operations. The single "mate" balloon can be performed using any of the mating concepts. The only real differences between IVA and shirtsleeve operations are the airlock and module depressurization operations.

The second type of assembly is the temporary assembly of an element or portion of an element on an orbiting booster that is used to place an element into a higher energy orbit. This procedure effectively configures interfaces utilizing automatic techniques. As shown by the figure, the automatic technique requires only three operational steps: (1) mate, (2) rigidization, and (3) interface connection/verify.

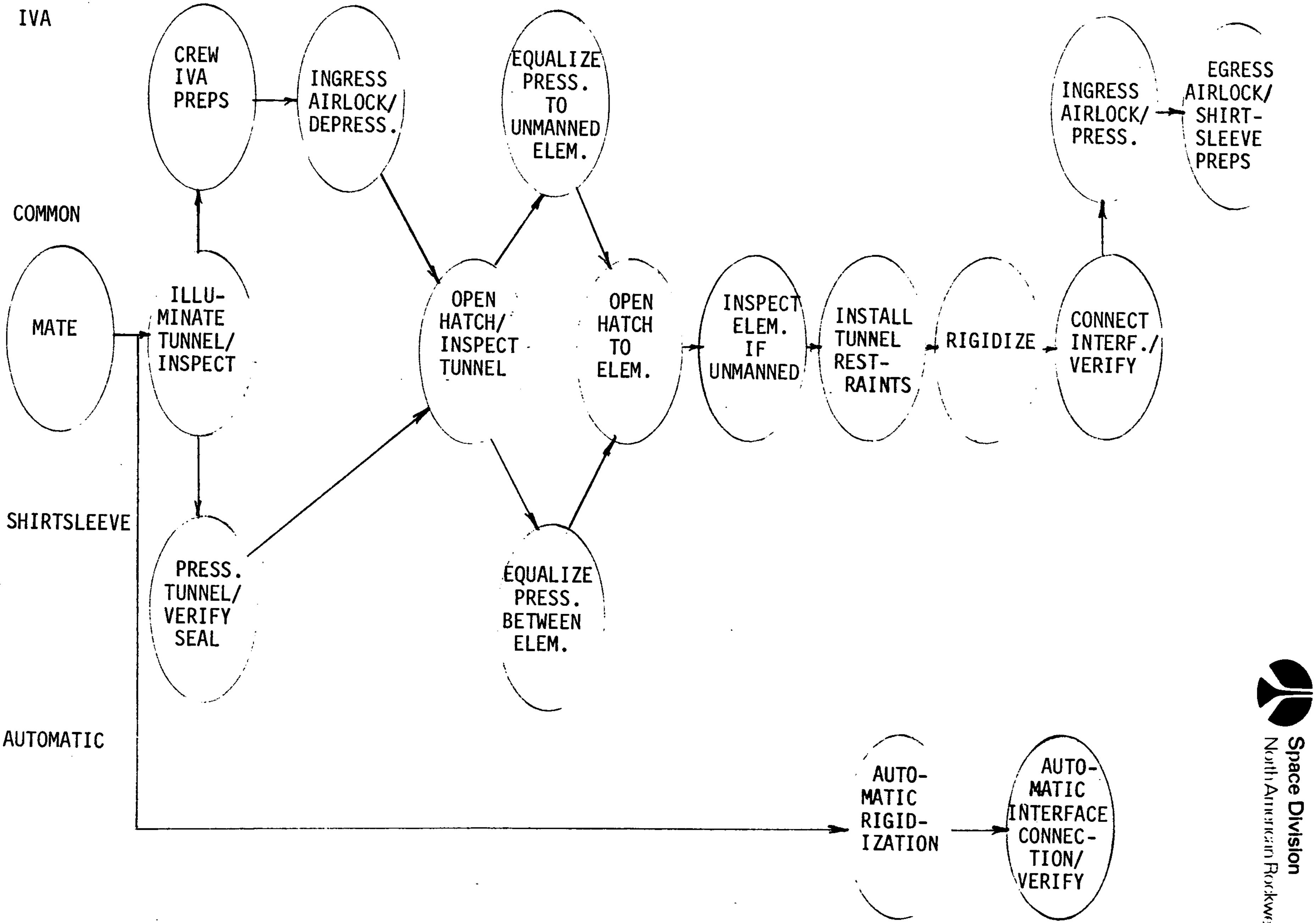

Figure 2.2-1. Procedure Comparison

OPERATIONAL PROCEDURE NO. 2-1

Orbital Assembly--Module to Unmanned Orbital Element - Shirtsleeve Interface Assembly

This procedure was developed utilizing for a model a manned EOS orbiter with a manipulator delivering a module to an unmanned modular space station (MSS) for assembly.

Assumptions

The EOS orbiter equipped with a manipulator does not transfer a module from the cargo bay directly into a mate with a station keeping element; but it first berths that element to a port on the EOS orbiter and then performs the subsequent module transfer operation.

Initial Condition

The EOS orbiter has rendezvoused with the MSS and all preliminary operations for mating activities have been accomplished.

Final Conditions

The MSS with the module fully assembled in position has separated from the EOS orbiter and can perform routine operations.

Description of Procedure

This procedure involves the delivery of a module by a manned transport element (EOS orbiter) to an orbiting unmanned element (MSS). The EOS orbiter is equipped with a manipulator which it will utilize to capture the MSS and berth it to a port on the EOS orbiter. After berthing the MSS, the module in the EOS orbiter cargo bay is transferred and berthed to the MSS. The interface between the MSS and the module is connected and rigidized utilizing shirtsleeve procedures. The installation is checked out and the EOS orbiter separates from the MSS.

To provide a more generic title to the elements such that the procedure can be more universal, the elements will be known as the "active" element which will be the EOS orbiter, the "passive" element which will be the element being assembled (MSS), and "module" for the module being attached.

OPERATIONAL PROCEDURE NO. 2-1

TITLE: ORBITAL ASSEMBLY - MODULE TO UNMANNED ORBITAL ELEMENT, SHIRTSLEEVE INTERFACE ASSEMBLY

ELEMENT INTERFACES: MANNED ORBITER WITH MANIPULATOR/MODULE/UNMANNED MSS

	Operation	Performed by:	Rationale
1	Mate transport element to element being assembled. For this operation, utilize Operations 1 through 43 of Operational Procedure No. 1-2.	Active/ passive	
2	Transfer module from transport element to element being assembled. For this operation, utilize Operations 44 through 53 of Operational Procedure No. 1-2.	Active/ passive/ module	

The next series of steps involve the connection of the electrical and plumbing interfaces between the elements and the rigidization of the interface such that prolonged attached operations can occur. Rigidization applies to the structurally strengthening and stiffening of the element/module interface. The technique can be automatic or manual. Automatic techniques can be a series of succeeding operations to achieve rigidization (one sector rigidized, then the next sector, etc.) or the operation can be performed in a single step. An automatic technique will include clampdown of the mating ports and seating of pressurization seals. If the technique is manual and utilizes IVA methods, then rigidization probably involves hardware that must be manipulated external to the element/module interface tunnel. If the operation can be achieved in a shirtsleeve environment, the hardware and interfaces involved must be located within the tunnel. The following steps assume a shirtsleeve rigidization scheme.

OPERATIONAL PROCEDURE NO. 2-1

	Operation	Performed by:	Rationale
3	Initial rigidization	Passive	Initial rigidization provides the final mating port interlock. It includes pull-down of the interfaces and seating of the pressure seals such that subsequent pressurization and crew transfer can occur.
4	Pressurize tunnel	Passive	The tunnel between the assembly element and the module is pressurized and equalized to the passive element pressure such that the interface hatch can be opened.
5	Verify tunnel seal integrity	Passive	During and subsequent to the pressurization the tunnel seal integrity must be verified.
6	Open hatch to tunnel and inspect mating interface	Passive	The mating port interface is inspected for any damage that may have occurred during the mating operations and also to verify full engagement and lock of latches.
7	Illuminate tunnel	Passive	
8	Equalize module pressure with tunnel	Module/ Passive	Pressure between tunnel/module must be equalized to open hatch
9	Isolate module and verify leak rate	Passive	Verifies that the leak rate of the unmanned element can be supported by the pressurization systems.

OPERATIONAL PROCEDURE NO. 2-1

	Operation	Performed by:	Rationale
10	Verify the module element atmosphere is compatible with the manned element atmosphere	Passive	Prior to entering the module, the atmosphere must be verified to be free of contaminants.
11	Equalize pressure between passive element/module	Passive	For an unmanned element, the pressure will be equalized to that of the passive element.
12	Open hatch to other element	Passive	Final hatch is opened and access between the elements can occur
13	Connect and activate air circulation ducts	Passive	If the environment is to be freely circulated between the elements, air circulation ducting will probably be required.
14	Ingress module and perform initial inspection	Passive	An initial inspection is performed to verify the general condition of the module prior to extensive mated operations.
15	Position tunnel crew restraint devices	Passive	Crew restraint devices are positioned, adjusted or emplaced as required to perform the subsequent operations.
16	Install electrical interfaces	Passive	Those electrical interfaces that are to be installed between the elements to support inter operations will be made.

OPERATIONAL PROCEDURE NO. 2-1

	Operation	Performed by:	Rationale
17	Verify interface mate	Active/ module	Prior to activating the interface, a connector mate verification is required
18	Check out electrical interface	Active/ module	
19	Connect plumbed interfaces and verify seal integrity	Passive	Each interface seal is verified prior to passing fluids to prevent contamination of the area
20	Activate fluid interfaces	Passive/ module	
21	Perform assembly rigidization operations	Passive	This step applies where rigidization between the passive element and the module is required beyond that available at the normal mating interface.
22	Remove tools and restraint aids	Passive	These aids are removed such that they do not interfere with subsequent operations.
23	Separate active element from passive element. For this operation, utilize Operational Procedure No. 3-2.	Active/ passive	

NOTE 1: Items noted refer to functional requirements 1,2,3,11,12,13,31,32,33,34,35,36,37

NOTE 2: Items noted refer to functional requirements 23, 24, 25, 26, 28, 29, 30

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OPERATIONAL PROCEDURE NO. 2-2

Orbital Assembly--Module to a Manned Orbital Element - IVA Interface Assembly

This procedure was developed utilizing for a model a manned EOS orbiter delivering a module to a manned modular space station (MSS) which is equipped with a manipulator.

Assumptions

The MSS is equipped with both manipulator berthing ports and direct docking ports.

Initial Conditions

The EOS orbiter has rendezvoused with the MSS and all preliminary operations for direct docking have been accomplished.

Final Condition

The MSS has separated from the EOS and the module is fully assembled on the MSS and routine operations can continue.

Description of Procedure

This assembly operation involves the addition of a module to an orbiting manned MSS. The MSS for this procedure is equipped with a manipulator, however, particular mating ports have the capability to accept direct dockings. The module will be delivered by an EOS orbiter. Hookup and rigidization operations to secure the interface between the MSS and the module are performed IVA. The IVA procedure assumes an airlock between the module and the MSS proper. Basic procedures for the full operation are as follows:

1. Direct dock EOS orbiter to MSS. The EOS orbiter will function as the "active" element and the MSS as the "passive."

2. The MSS manipulator will remove the module from the EOS orbiter cargo bay and berth the module to a temporary holding port on the MSS.

3. The EOS separates from the MSS utilizing a jet translation method.

4. The MSS manipulator transfers and berths the module to the permanent assembly port.

5. The assembly is rigidized and the interface utilities connected utilizing IVA/shirtsleeve techniques.

OPERATIONAL PROCEDURE NO. 2-2

TITLE: ORBITAL ASSEMBLY - MODULE TO MANNED ORBITAL ELEMENT, IVA INTERFACE ASSEMBLY

ELEMENT INTERFACES: MANNED ORBITER/MODULE/MANNED MSS WITH MANIPULATOR

	Operation	Performed by:	Rationale
1	Direct dock active element to the passive element. For this operation use Operational Procedure No. 1-1.	Active/ passive	
2	Interconnect communications link between transport element and assembly element.	Active/ passive	If the RF communications link cannot be utilized during mated operations, a hardline communications link between the elements must be established. If the hatches between the elements are to be opened, Operations 24 through 32 of Operational Procedure 1-2 apply.
3	Prepare module for transfer	Active	Transport element must prepare the module which includes: positioning the module in a manner that will facilitate capture by the manipulator and disconnect of interfacing hardlines. Module may be deployed out of the cargo bay or remain within the cargo bay.
4	Activate manipulator guidance aids	Passive	TV cameras, targets, special lighting effects, etc. Each aid including backup systems will be verified and the status known prior to starting manipulator activities.

OPERATIONAL PROCEDURE NO. 2-2

	Operation	Performed by:	Rationale
5	Configure passive element for berth of the module	Passive	The assembly crew removes berthing port covers and activates alignment aids (lighting/targets). If a berthing port window is available, a CCTV camera will be installed or a crew member will be positioned at the window to view the module closing and alignment. The CCTV will be monitored at the manipulator control console or if the crewman is viewing the operation from the berthing window he will have direct communication with the manipulator operator.
6	Verify elements prepared for transfer of module from cargo bay to assembly element berthing port	Active/ passive	Prior to module transfer, alignment systems including backup must be statused.
7	Manipulators engage module in cargo bay	Passive	
8	Verify manipulator/module interface	Passive	The purpose of this operation is to verify that the manipulator has full control of the captured element and that the element will not escape during the subsequent transfer operation. The manipulator will apply forces to the captured element simulating the forces that will be applied during the transposition phase.

	Operation	Performed by:	Rationale
9	Release module	Active	The module tie-downs are released and the manipulator maintains the module in position.

Two options are available at this step. The first would be to transport the module to a berthing port on the assembly element. The berthing port could be the final assemblage point or it could be a temporary position utilized until the transport element separates, whereupon it is then transferred to the final assembly position. The second option is to have the manipulator hold the module in a free position while the transport element separates and then position the module at the final assembly point.

For this sequence of operations, the first option will be used and the module will be positioned at a temporary berthing port. The selection of berthing port should be based on ease of berthing operations and the minimum possibilities of interference with the transport element.

	Operation	Performed by:	Rationale
10	Maneuver module to near berthing orientation	Passive	The manipulator maneuvers the module into position for berth and aligns the ports.
11	Close at berthing contact velocity and effect mate/verify	Passive	The manipulator translates the module directly into a hard berth and maintains pressure on the interface until mate is verified.
12	Rigidize the module and the passive element interface	Passive	Rigidization as applied to this step infers clampdown of the mating ports such that mated maneuvers can occur (next step). The seating of interface seals is not required.

OPERATIONAL PROCEDURE NO. 2-2

	Operation	Performed by:	Rationale
	The following operation (separation) may require that the assembly element be maneuvered either attached to or independent of the transport element. If the manipulator cannot remain attached to the module during maneuvers, due to forces that may be applied or to ACS plume impingement contamination, it will have to be disengaged and stowed. For this procedure, it is assumed that the manipulator can remain attached to the module.		
13	Separate active element from passive element. For this operation, utilized Operational Procedure No. 3-1.	Active/ passive	
	The following operations involve the transfer of the module from the temporary port to the final mating port.		
14	Unlock and disconnect rigidization system	Passive	Rigidization as applied to this operation refers to the rigidizing performed at Operation 6.
15	Unlock berthing port capture latches	Passive	Disconnect of final interface between passive element and module.
16	Verify passive element and module interface ports are freed (positive separation)		This step does not require that the mating ports are not in contact. It is a verification that all latches have unlatched and separation can occur without damaging mating port hardware.
17	Manipulator transport module to final assembly port and orient for mate	Passive	

OPERATIONAL PROCEDURE NO. 2-2

	Operation	Performed by:	Rationale
18	Translate the module at contact velocity and effect berth to passive element	Passive	
	The following operations apply to the rigidization of the mated interface. The activities will be performed utilizing IVA techniques.		
19	IVA crewmen don IVA suits and prepare facilities for depressurization of compartment. See Operational Procedure No. 5-2 (section 2.5.5)	Passive	
20	Depressurize compartment until equal with tunnel volume	Passive	Before opening hatch, the pressure across it must be equal.
21	Illuminate tunnel area	Passive	
22	Open hatch to tunnel and inspect interface	Passive	
23	Install restraint aids	Passive	Body restraints, tethers, tools and parts holders, etc., are installed and ready for use.
24	Equalize pressure between module and tunnel	Passive	Before opening module hatch, the pressure across it must be equal.
25	Open hatch to module	Passive	

OPERATIONAL PROCEDURE NO. 2-2

	Operation	Performed by:	Rationale
26	Connect elect. interfaces	Passive/ module	Electrical interfaces are connected as required to provide lighting in the module.
27	Illuminate module	Module	Subsequent operations require the module to be illuminated.
28	Perform preliminary inspection of module	Module	Before doing any interface preparations for an extended mate operation, the module should be inspected to verify its general condition.
29	Connect electrical interfaces	Passive/ module	The electrical interfaces between the passive element and module must be installed.
30	Verify interface connector mate	Passive/ module	Before applying power across the connector(s) (other than power for continuity checks) the mate must be verified.
31	Check out electrical interface	Passive/ module	The electrical interface is verified to the extent that can be accomplished prior to activating liquid cooling systems.
32	Connect plumbed interfaces	Passive/ module	
33	Verify fluid seals	Passive/ module	Before activation of the fluid lines, the coupling seals must be verified to be properly seated.

OPERATIONAL PROCEDURE NO. 2-2

	Operation	Performed by:	Rationale
34	Activate liquid cooling system	Passive/ module	The liquid cooling system is activated in order that final check of the electrical interface can be performed.
35	Complete electrical interface verification	Passive/ module	This operation verifies those electrical interfaces that were not verified at Operation 30.
36	Complete fluid line activation	Passive/ module	
37	Perform assembly rigidization operations	Passive/ module	All additional rigidization that is required for extensive mated operations is installed (i.e., special seals, tension ties, etc.).
38	Remove tools and restraint aids	Passive/ module	All loose equipment must be removed from the tunnel area and stowed.
39	IVA crewmen retreat to passive element	Passive	
40	Close hatch between passive element and tunnel	Passive	
41	Pressurize tunnel and module to required operating pressure and status leak rate	Passive	The leak rate of the tunnel and module is verified to be within tolerance.
42	Pressurize passive element compartment	Passive	

OPERATIONAL PROCEDURE NO. 2-2

	Operation	Performed by:	Rationale
43	Open hatch between passive element and tunnel	Passive	
44	IVA crewmen doff IVA equipment	Passive	IVA activities are completed; subsequent operations can be shirtsleeve.
45	Install air circulation ducts	Passive/ module	Air ducts will be installed to provide air circulation between the passive element and the module.

This completes the orbital assembly interface activity. The module is ready for internal checkout activities.

NOTE 1: For functional requirements applicable to Operations 1 through 18, refer to the activities mating, separation, and payload deployment.

NOTE 2: Items noted refer to functional requirements 1,2,3,11,12,13,31,32,33,34,35,36,37

NOTE 3: Items noted refer to functional requirements 23, 24, 25, 26, 28, 29, 30

OPERATIONAL PROCEDURE No. 2-3

Orbital Assembly--Assembly of Element on an Orbiting Booster Element

This procedure was developed utilizing for a model an orbiting lunar station (OLS) that is to be assembled on a chemical propulsion shuttle (CPS). The assembly is performed using a manned space tug.

Assumptions

The OLS is in a parking orbit fully assembled. The OLS consists of 10 modules of uniform size. The OLS has a central control module which is capable of maintaining attitude control and will respond to commands from the space tug or another remote base control. The CPS is parked in the same orbital plane within close proximity of the OLS. The space tug,without any special navigation (direct flight), can travel between these two elements.

Initial Conditions

The OLS's module utility interfaces have been disconnected (electrical and fluid) and tunnels vented. The multiple docking adapters (MDA) that are to be used in the assembly operation are mated to spare ports on the OLS.

Final Conditions

The OLS is stacked on the CPS and rigidized for subsequent boost to a higher energy orbit.

Description of Operation:

This procedure defines the operations for assembling an orbiting lunar station (OLS) on a CPS for delivery to lunar orbit. The assembly is not the final lunar orbiting configuration, but an arrangement of the modules such that they can be delivered to lunar orbit in a single launch without damaging hardware through excessive g-loading. The operation essentially consists of disassembly of a checked out OLS which is in low earth orbit in close proximity to the CPS and reassembly of the modules on the CPS. The OLS configuration for this operation consists of 10 modules of uniform size. The procedure will be to direct dock a multiple docking adapter (MDA) on the forward port of the CPS, direct dock five of the modules to this adapter, direct dock another MDA on top of these modules, direct dock the five remaining modules to this adapter, and finally direct dock a third MDA to the top of these five modules for additional stiffness. The multiple docking adapters will be delivered by the EOS orbiter and stowed at the OLS assembly until use. During disassembly of the OLS either a special control unit (unmanned) which is docked to the assembly will be maintaining OLS flight attitude, or the final module to be retrieved and docked to the CPS will be capable of providing full control of the station. The CPS is also equipped with an active attitude control system. Both elements can be commanded by ground or the space tug to assume selected attitude modes. Figure 2.2-2 shows an overview of the total procedure. To provide the procedure with a more generic nature, the elements will be referred to as "booster" element, "assembly" element, and "tug" element.

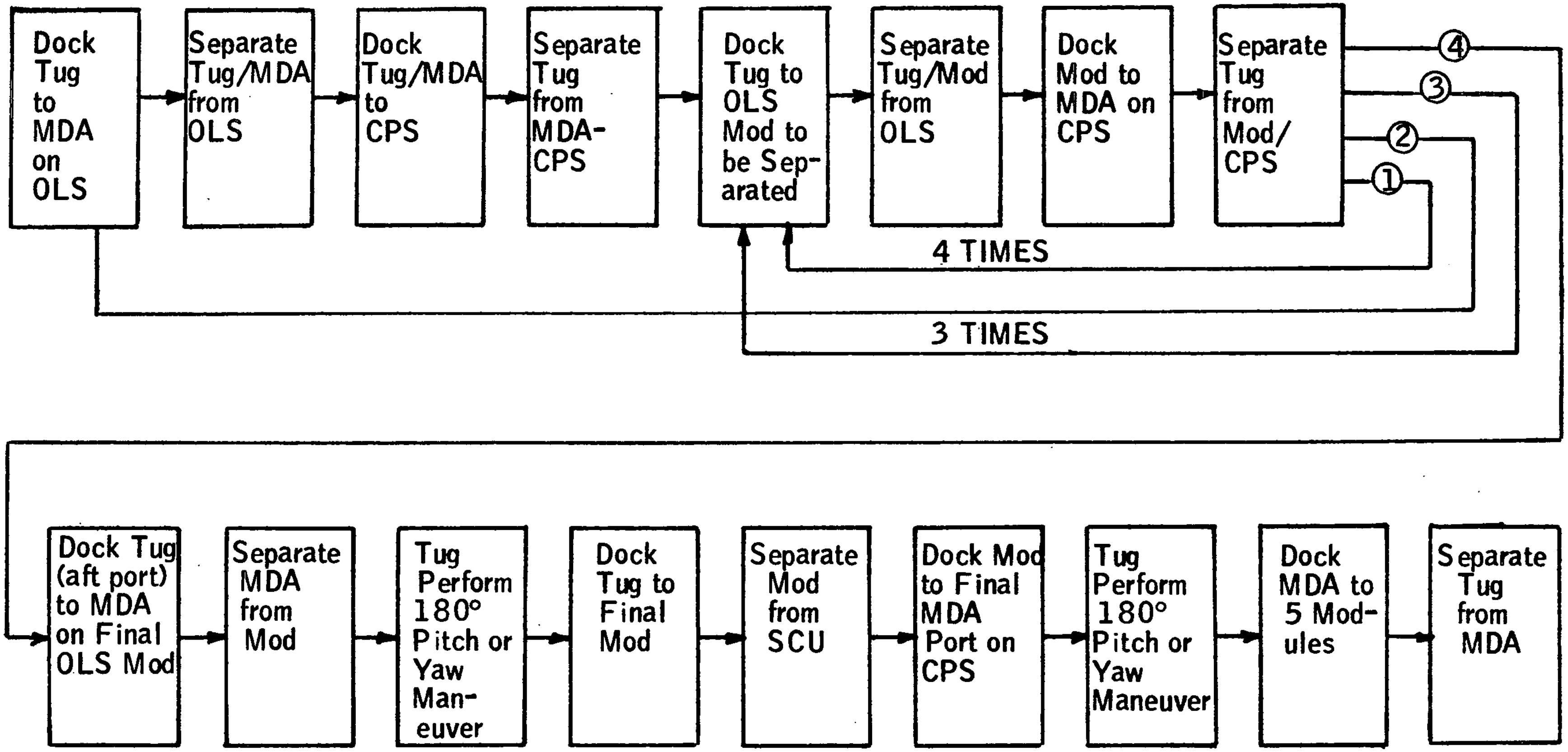

Figure 2.2-2. Orbital Assembly Procedure No. 3 - Flow Chart

OPERATIONAL PROCEDURE NO. 2-3

TITLE: ORBITAL ASSEMBLY - MODULAR ELEMENT ON ORBITING BOOSTER ELEMENT

ELEMENT INTERFACES: OLS/CPS/SPACE TUG

	Operation	Performed by:	Rationale
1	Illuminate booster and assembly elements	Booster/ assembly	Illumination of the elements is required to the extent that the tug can always quickly determine their attitude. The tug must be equipped with flood-lights if illumination available, including sunlight, does not adequately illuminate docking interfaces and docking targets.
2	Verify communications between the involved elements	Booster/ assembly/ tug	The tug will be transmitting commands to the booster/assembly elements and receiving data transmitted by the elements.
3	Direct dock tug to MDA No. 1. For this operation, utilize Operational Procedure No. 1-1, Operations 2 through 21	Tug	Three MDA's have previously been mated to the OLS element. The first MDA to be removed has five docking ports on one side that will interface with OLS modules and one docking port on the opposite side that will mate with the CPS. The tug docks to one of the OLS ports to transport the MDA to the booster element.

OPERATIONAL PROCEDURE NO. 2-3

Operation		Performed by:	Rationale
4	Separate MDA No. 1 from the assembly element. For this operation, utilize Operational Procedure No. 3-1, Operations 18 through 26.	Tug	
5	Direct dock MDA No. 1 to the booster element. For this operation utilize Operational Procedure No. 1-1, Operations 2 through 21.	Tug	
6	Separate tug from MDA. For this operation utilize Operational Procedure No. 3-1, Operations 18 through 26.	Tug	
7	Direct dock tug to module on assembly element. For this operation, utilize Operational Procedure No. 1-1, Operations 2 through 21.	Tug	
8	Separate tug with module from assembly element. For this operation, utilize Operational Procedure No. 3-1, Operations 18 through 26.	Tug	

OPERATIONAL PROCEDURE NO. 2-3

	Operation	Performed by:	Rationale
9	Direct dock module to MDA on booster element. For this operation, utilize Operational Procedure No. 1-1, Operations 2 through 21.	Tug	
10	Separate tug from module on MDA For this operation, utilize Operational Procedure No. 3-1, Operations 18 through 26.	Tug	
11	Repeat Operations 7 through 10 four times	Tug	
	At completion of this step the booster element has an MDA mated to it and the MDA, in turn, has five modules mated to it.		
12	Direct dock tug to MDA No. 2 on the assembly element. For this operation, utilize Operational Procedure No. 1-1, Operations 2 through 21.	Tug	MDA No. 2 is equipped with 10 docking ports, five on each side. The tug will utilize one of the ports to transport the MDA to the booster element.
13	Separate MDA No. 2 from the assembly element. For this operation, utilize Operational Procedure No. 3-1, Operations 18 through 26.	Tug	

OPERATIONAL PROCEDURE NO. 2-3

	Operation	Performed by:	Rationale
14	Direct dock MDA No. 2 to the five modules stacked on MDA No. 1. For this operation, utilize Operational Procedure No. 1-1, Operations 2 through 21.	Tug	
15	Repeat Operation 6	Tug	
16	Repeat Operations 7 through 10 four times	Tug	
17	Direct dock aft port of space tug to MDA No. 3.	Tug	MDA No. 3 is equipped with five docking ports on one side and one transport port on the opposite. The tug must pick up the final MDA because it has no attitude control system and when the final module is removed the MDA would be left in free drift.
18	Separate MDA No. 3 from final assembly module. For this operation, utilize Operational Procedure No. 3-1, Operations 18 through 26.	Tug	
19	Rotate tug 180 degrees	Tug	Tug is rotated in preparation of docking the forward port to the final module.

OPERATIONAL PROCEDURE NO. 2-3

	Operation	Performed by:	Rationale
20	Direct dock tug to final module. For this operation, utilize Operational Procedure No. 1-1, Operations 2 through 21.	Tug	
21	Deactivate assembly module systems	Tug/ assembly	The assembly module will no longer be required to perform attitude hold and the systems can be deactivated.
22	Repeat Operation 9	Tug	
23	Repeat Operation 10	Tug	
24	Rotate tug 180 degrees	Tug	Tug is rotated in preparation of docking MDA No. 3 to the five modules on MDA No. 2.
25	Direct dock MDA No. 3 to the five modules mated to MDA No. 2. For this operation, utilize Operational Procedure No. 1-1, Operations 2 through 21.	Tug	
26	Repeat Operation No. 6		

This completes the orbital assembly procedure.

NOTE 1: For functional requirements applicable to the operations herein, see the mating and separation activities (direct docking and jet translation separation).

2.2.2 PROCEDURES APPLICABILITY

Each procedure that was developed was reviewed for its applicability to support the feasible assembly conditions. Figure 2.2-3 shows the results of these analyses in matrix form.

Those interfaces identified by "M" represent an interface where the operational assembly is solely one of mating. That is, the logistics vehicle which will assist in the assembly activity by transporting and mating modules to the identified element. The "SS" identification indicates a shirtsleeve technique for manual assemblage of an interface between modules. This technique is applicable where the modules are equipped with life support hardware. The IVA identification extends the manual assembly capability to modules that are not equipped to provide a shirtsleeve environment. Finally, the "A" identifies those assembly operations where interfaces must be connected automatically because IVA or shirtsleeve operations cannot be performed. It can be seen that in some cases more than one concept is viable.

This matrix is a reduced version of the previous matrices presented in Volume II. The reduction was due to the deletion of eight elements as discussed in Section 4.0 of Volume I. It can be seen that those elements utilizing automatic assembly techniques are the vehicles that will be assembled in a temporary complex aboard a booster element rather than in their final configuration. Also, the modular RNS vehicle which can be assembled in low earth orbit is an element which, because of its design, does not permit crew travel to the assemblage point. Those elements that are built up into the final configuration in low earth orbit can be assembled using either shirtsleeve or IVA techniques.

		SPACE PROGRAM ELEMENTS																
			TUG		RAM				SATELLITE					CPS				
		EOS	RTN	SPACE BASED	ATT. EOS	DET. EOS	ATT. MSS	DET. MSS	EOS DELIV.	EOS + 3RD ST DELIV.	RETR, RESUP.	EO RESUP. MODS	LOW EO MSS	OIS	CLS	RNS CLS	OLS	OPD
	EOS	NA	NA	1, 3 M	NA	NA	1, 2, 3 A-IVA-SS	2, 3 M	NA	NA	NA	1, 2, 3 A-IVA-SS	1, 2, 3 A-IVA-SS		1, 2, 3 M	1, 2, 3 M	1, 2, 3 M	1, 2, 3 M
TUG	RETURNABLE	NA								NA								
TUG	SPACE BASED	NA		3 M			1, 2, 3 A-IVA-SS	2, 3 M		NA	NA	1, 2, 3 M	1, 2, 3 M	NA	2, 3 M	2, 3 M	2, 3 M	2, 3 M
RAM	ATT. EOS	NA																
RAM	DET. EOS	NA																
RAM	ATT. MSS	NA		NA									1, 2, 3 A-IVA-SS					
RAM	DET. MSS	NA		NA									2, 3 M					
SATEL	EOS DELIV.	NA																
SATEL	EOS + 3RD ST	NA	NA	NA														
SATEL	RETR, RESUP.	NA		NA														
	EO RESUP. MODS	NA		NA								NA	1, 2, 3 A-IVA-SS		NA	2, 3 M		NA
	LOW EO MSS	NA		NA			NA	NA				NA	1, 2, 3 A-IVA-SS					
CPS	OIS			NA											NA	NA	NA	NA
CPS	CLS	NA		NA								NA		NA	2, 3 M		2, 3 M	NA
	RNS-CLS	NA		NA								NA		NA		2, 3 M	2, 3 M	NA
	OLS	NA		NA										NA	NA	NA	2, 3 M	
	OPD	NA		NA								NA		NA	NA	NA		2, 3 M

LEGEND

M - Indicates the assembly activity between the elements is solely a mating event.
IVA - Indicates the rigidization assembly activity can be performed IVA.
SS - Indicates the rigidization assembly activity can be performed shirtsleeve.
A - Indicates the rigidization assembly activity can be performed automatic.
1 - Refers to Procedure 2-1
2 - Refers to Procedure 2-2
3 - Refers to Procedure 2-3
NA - Not Applicable

Figure 2.2-3. Operational Procedures Applicability - Interface Activity: Orbital Assembly

2.3 SEPARATION

This section presents the operational procedures for separation, and includes one procedure for each alternate approach identified in Volume II of this report. Also presented and discussed is the applicability of these procedures to each element pair included in the in-depth analysis portion of the Orbital Operations Study.

2.3.1 OPERATIONAL PROCEDURES

Separation can occur between manned elements, between unmanned elements, and between manned and unmanned elements. Therefore, it was necessary to develop procedures that encompassed these three possibilities. Because two different separation concepts are being evaluated, i.e., jet translation separation and manipulator separation, it was necessary that these concepts be applied in the procedures development. If jet translation and manipulator separation are both applicable for the three types of manned and unmanned separations, it would appear that a total of six procedures should be developed. However, by applying the following logic the number was reduced. The first reduction was the elimination of a manipulator separation of two unmanned elements. The need for this procedure was eliminated because the manipulators presently being conceived are for man-in-the-loop operations. Also, those elements that appear to be candidates for built-in manipulators are elements that would probably be manned. The jet translation separation is performed with one element essentially performing a passive roll in that it will probably only hold attitude while the other element separates and translates clear. Therefore, the operations for a manned element separating from a manned element should be very similar to those of a manned element separating from an unmanned element, and the two procedures could be combined. After developing the initial procedures it was found that the manipulator separation of a manned element from a manned element was very similar to manipulator separation of a manned element from an unmanned element. Therefore, these procedures, like the direct docking procedures, were also combined.

Before preparing any procedure it was necessary to select a pair of elements to use as a representative model. By doing this, the procedure would not become so generic that it could fail to uncover detailed ambiguities of specific elements that may affect design concepts or be insensitive to particular design requirements. For the manned element separations, the EOS Orbiter was selected as one of the elements because this vehicle would be separating from all of the study elements. The Modular Space Station was selected as the other element in that it presented the most stringent criteria, particularly with alignment problems and the always present interfering appendages that must be avoided during the separation. For the unmanned separating elements, a Space Tug and a detached Research and Applications Module (RAM), both candidates for unmanned operations, were selected for the representative model.

The following matrix shows the final selection for operational procedures development:

Approach	Manned From Manned	Manned From Unmanned	Unmanned From Unmanned
Jet Translation	One procedure EOS Orbiter to MSS		Space tug to DRAM
Manipulator Separation	One procedure EOS Orbiter to MSS		X

Procedural Comparison

The separation procedures include configuring of the element-to-element interface for separation, the physical separation of the ports, and the mechanical extension or jet translation operation to provide a safe separation distance between the elements.

Figure 2.3-1 is a general comparison of a manipulator separation procedure with a jet translation separation procedure. The central bubbles represent common operations with the bubbles on the upper and lower portion of the page representing procedural differences. It can be seen that the only real difference occurs after separation of the mating ports in that the manipulator then performs the separation by extending the arm, whereas, for a jet translation separation, the separation is achieved through jet thrusting by one of the elements until a safe separation distance is achieved.

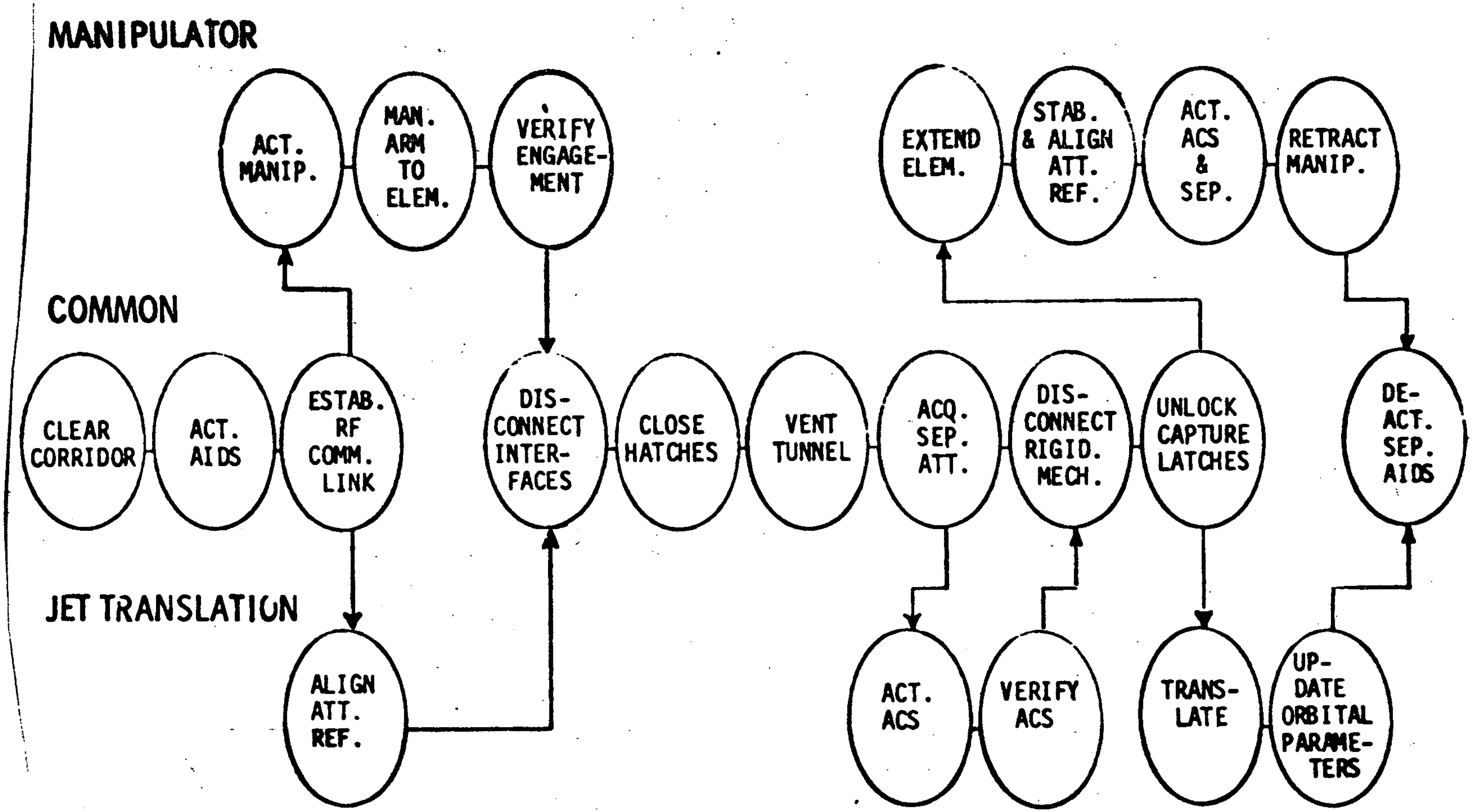

Figure 2.3-1. Separation Procedural Comparison

OPERATIONAL PROCEDURE NO. 3-1

Separation - Jet Translation Separation of a Manned Element From a Manned or Unmanned Element

This procedure was developed utilizing an EOS Orbiter and a Modular Space Station (MSS) for the model.

Assumptions

Compatible RF communications and data links are available between the elements.

Initial Conditions

All checkout of subsystems required for separation and for operations subsequent to separation have been performed.

Final Conditions

The elements are separated a sufficient distance where safe and relatively independent operations can occur.

Description

This procedure includes two primary operations, (1) mating port configuring and (2) jet translation separation activity. Mating port configuring includes the disconnect of all interfaces, hatch closure and the necessary checks to verify that physical separation can proceed. Jet translation activity includes the release of the mating port latches and the active translation by one of the elements (for this procedure the EOS Orbiter will perform the translation). Prior to separation only one elements' ACS is active. Activation of the other elements' ACS is performed just prior to physical separation.

In order to identify individual element activities, one element will be referred to as the active element and the other element, the passive. The active element will be the manned element when one of the elements is unmanned. When both elements are manned, the active element will be the element that performs the translation operation. This procedure has the EOS Orbiter identified as the "active" element and the MSS will assume the "passive" role.

D

OPERATIONAL PROCEDURE NO. 3.1

TITLE: SEPARATION - JET TRANSLATION - MANNED ELEMENT FROM MANNED OR UNMANNED ELEMENT

ELEMENT INTERFACES: EOS ORBITER/MSS

	Operation	Performed by:	Rationale
1	Verify ground communications link with unmanned element (required with unmanned element only)	Passive	The ground will monitor/track the unmanned element after separation.
2	Verify corridor clear to begin separation activity	Active	Prior to initiation of separation procedures, the separation corridor must be verified to be clear of other orbital elements (i.e., experiment modules, space tugs) and will remain clear throughout the operations to prevent possible collision with another element.
3	Activate separation guidance aids	Active/ Passive	Those aids utilized for alignment during separation must be activated.
4	Verify readiness of elements for separation	Active/ Passive	All subsystems required during separation including backup systems must be verified as well as subsystems that are to be utilized for operations after separation that were deactivated during mated operations. Some activities may require that the mated elements perform some limited maneuvers (i.e., verification of an attitude control system requires attitude maneuvers).

OPERATIONAL PROCEDURE NO. 3.1

	Operation	Performed by:	Rationale
5	Isolate plumbed interfaces, purge the interface lines, and equalize line pressures	Active/ Passive	Prior to disconnection of an interfacing fluid line, the lines must be deadfaced to protect against spillage, the lines must be purged to eliminate hazardous residue that remains at the interface. The line pressure must be equalized to prevent damage to hardware or personnel at separation.
6	Disconnect plumbing lines	Active/ Passive	
7	Verify integrity of coupling interface seals	Active/ Passive	The interface couplings are checked to verify seals are not leaking such that they may create a future hazard.
8	Stow interconnect linkages	Active/ Passive	Interconnect linkages must be properly stowed such that residuals that may remain in the linkages cannot create future hazards.
9	Verify RF link between the passive element and the active element	Active/ Passive	After the electrical interfaces between elements have been severed, communications between the elements must be RF. For the manned elements, duplex voice is required and for the manned and unmanned separation, a data link is required.
10	Deadface electrical interface connectors	Active/ Passive	Prior to disconnecting electrical interfaces, the connectors must be deadfaced on both sides to prevent possible electrical shorts or electrical shock to crewmen.

OPERATIONAL PROCEDURE NO. 3.1

	Operation	Performed by:	Rationale
11	Disconnect electrical interfaces	Active/ Passive	
12	Stow electrical interconnects	Active/ Passive	
13	Remove and stow all loose equipment utilized at the interface hatches	Active/ Passive	No equipment such as restraint aids or tool holders unless they are of permanent installation type shall be left in the interface tunnel. Loose items may damage mating ports or door seals if they interfere with door closure.
14	Close and secure hatch between passive element and tunnel	Active	
15	Close hatch between active element and tunnel	Active	
16	Vent tunnel and verify seals	Active	Tunnel venting is required to prevent a captured pressure at the interface from imparting a noticeable delta-V to the separating elements. Hatch seals are verified to be properly functioning at this time so that a seal failure will not be catastrophic in that the tunnel can be repressurized and the seals checked or the door recycled for proper seating.

OPERATIONAL PROCEDURE NO. 3.1

	Operation	Performed by:	Rationale
17	Align attitude reference systems	Active/ Passive	Attitude reference alignment is necessary to prevent control systems from fighting each other when the ACS of the passive vehicle is activated. Common attitude reference will also prevent any radical vehicle movement at time of separation.
18	Illuminate elements	Active/ Passive	Elements are illuminated to aid in viewing separation characteristics of the elements.
19	Acquire separation attitude	Active	Proper vehicle orientation can provide the best sunlight angles to enhance TV coverage. Also, proper orientation may conserve propellant during operations subsequent to separation.
20	Stabilize connected elements	Active	Mated elements are stabilized in a minimum deadband mode (rates/attitude) to provide the least deviation off centerline of the mated interfaces at time of separation.
21	Verify elements prepared for separation	Active/ Passive	Final verification prior to separation. Communications between mated elements is via RF links.
22	Activate passive element ACS	Passive	Passive element ACS is activated such that it can maintain attitude hold at separation.

OPERATIONAL PROCEDURE NO. 3.1

	Operation	Performed by:	Rationale
23	Verify passive element ACS	Active/ Passive	Prior to separation, the passive element ACS must be verified to be properly operating. A failure of the ACS could result in a catastrophic accident.
24	Unlock and disconnect rigidization system and release stored energy	Active	This step applies where rigidization between mated elements is required beyond that available in the normal mating port capture latches. It can include such things as pull-down devices, special rigidization latches, and mechanical alignment aids. Any stored energy in the form of seals, tension ties, pull-down devices, shock attenuators will be released to prevent any noticeable delta-V being applied to the elements at separation.
25	Unlock capture latches	Active	This is the disconnect of the final physical interface between elements. Reconnection of this interface may require that elements be separated and latches recocked or at the very least reconnection will require that the elements be forced together.
26	Verify positive separation has occurred	Active	Prior to performing a jet translation the elements must be fully separated; that is, no latches remain engaged.

OPERATIONAL PROCEDURE NO. 3.1

	Operation	Performed by:	Rationale
27	Actuate translation jets	Active	To complete the separation procedure, a minimum distance between the elements must be established. The active element performs the translation maneuver and the passive element maintains attitude hold.
28	Complete separation maneuver	Active	The separation maneuver is performed in a minimum deadband mode which is maintained until the minimum clearance has been obtained.
29	Update orbital parameters	Active/ Passive	Small delta-V errors created by the release of stored energy in the mating mechanism at time of separation could cause errors in subsequent flight trajectories.
30	Deactive separation guidance aids	Active/ Passive	These aids can be deactivated to conserve power.
31	Configure mating port for subsequent operations	Active/ Passive	Mating ports may require special configuring for quiescent operations (i.e., environmental covers provided to protect the mechanisms).
	This completes the jet translation separation activity. Elements can now resume independent orbital operations.		

OPERATIONAL PROCEDURE NO. 3-2

Separation - Manipulator Separation of a Manned Element From a Manned or Unmanned Element

This procedure was developed utilizing an EOS Orbiter and a Modular Space Station (MSS) for the model.

Assumptions

Compatible RF communications and data links are available between the elements. The active element ACS is being utilized for attitude control, the passive element ACS is inhibited.

Initial Conditions

All checkout of subsystems required for separation and for operations subsequent to separation have been performed.

Final Conditions

The elements are separated a sufficient distance where safe and relatively independent operations can occur.

Description

This operation begins with a manned or unmanned element (MSS) mated to manned element (EOS Orbiter). The primary operations that occur are configuring the mating ports for separation, manipulator interconnect with the MSS, physical separation of the MSS utilizing the manipulator, and final release. The MSS is a totally passive element (attitude control wise) until just prior to release by the manipulator.

In order to identify individual element activities, one element will be referred to as the active element and the other element, the passive. The active element will always be the element with the manipulator.

OPERATIONAL PROCEDURE NO. 3-2

TITLE: SEPARATION - MANIPULATOR, MANNED ELEMENT FROM MANNED OR UNMANNED ELEMENT

ELEMENT INTERFACES: EOS ORBITER (WITH MANIPULATOR)/MSS

	Operation	Performed by:	Rationale
1	Verify corridor clear to begin separation activity	Active	Prior to initiation of separation procedures, the separation corridor must be verified to be clear of other orbital elements (i.e., experiment modules, space tug) and will remain clear throughout the operations to prevent possible collision with another element.
2	Activate RF communications and other data links	Active/ passive	The subsequent steps will sever the hardlines between the elements. Communications between the elements will still be required.
3	Verify RF communications and data links	Active/ passive	The RF link between the elements must be verified. Duplex voice is required between manned elements. Between manned and unmanned elements a data link is required. The unmanned element must also acquire a link with ground for subsequent operations.
4	Verify readiness of elements for separation	Active/ passive	All subsystems required during separation including backup systems must be verified as well as subsystems that are to be utilized for operations after separation that were deactivated during mated operations. Some activities may

OPERATIONAL PROCEDURE NO. 3-2

	Operation	Performed by:	Rationale
			require that the mated elements perform some limited maneuvers (i.e., verification of solar array sun tracking may require attitude maneuvers).
5	Isolate plumbed interface, purge the interface lines, and equalize line pressures	Active/ passive	Prior to disconnection of an interfacing fluid line, the lines must be deadfaced to protect against spillage. The lines must be purged to eliminate hazardous residuals that remain at the interface. The line pressure must be equalized to prevent damage to hardware or personnel at separation.
6	Disconnect plumbing lines	Active/ passive	
7	Verify integrity of coupling interface seals	Active/ passive	The interface couplings are checked to verify seals are not leaking such that they may create a future hazard.
8	Stow interconnect linkages	Active/ passive	Interconnect linkages must be properly stowed such that residuals that remain in the linkages cannot create future hazards.
9	Deadface electrical interface connectors	Active/ passive	Prior to disconnecting electrical interfaces the connectors must be deadfaced on both sides to prevent possible electrical shorts or electrical shock to crewmen.

OPERATIONAL PROCEDURE NO. 3-2

	Operation	Performed by:	Rationale
10	Disconnect electrical interfaces	Active/ passive	
11	Stow electrical interconnects	Active/ passive	
12	Remove and stow all loose equipment utilized at the interface hatches	Active/ passive	No equipment such as restraint aids or tool holders, unless they are permanent installations, shall be left in the interface tunnel. Loose items may damage mating ports or door seals if they interfere with door closure.
13	Close and secure hatch between passive element and tunnel	Active	
14	Close hatch between active element and tunnel	Active	
15	Vent tunnel and verify seals	Active	Tunnel venting is required to prevent a captured pressure at the interface from imparting a noticeable delta-V to the separating elements. Hatch seals are verified to be properly functioning at this time so that a seal failure will not be catastrophic in that the tunnel can be repressurized and the seals checked or the door recycled for proper seating.

OPERATIONAL PROCEDURE NO. 3-2

	Operation	Performed by:	Rationale
16	Activate manipulator system/ verify	Active	Manipulator system must be activated and statused for subsequent operations
17	Activate manipulator guidance and alignment aids	Active/ passive	CCTV, general and special lighting effects, etc., are activated and verified.
18	Maneuver manipulator end effector to receptacle on element to be separated and verify positive engagement	Active	All forces that may be applied in any direction during the separation shall be tested to verify the end effector will remain affixed to the passive element receptacle during the subsequent maneuver operations.
19	Activate stationkeeping aids	Active/ passive	If stationkeeping is to be performed after separation the necessary aids will be activated/verified at this time. See stationkeeping requirements and procedures for type of aids.
20	Acquire separation attitude	Active	Proper vehicle orientation can provide the best sunlight angles to enhance visual acuity. Also, proper orientation may conserve propellant during operations subsequent to separation.

OPERATIONAL PROCEDURE NO. 3-2

Operation		Performed by:	Rationale
21	Stabilize connected elements	Active	This step is required only if the manipulator is to place the element in a specific orbital position, otherwise a slow attitude drift rate may be acceptable. Mated elements are rate and attitude stabilized with the mode being maintained until the minipulator releases the element.
22	Unlock and disconnect rigidization system and released stored energy	Active	This step applies where rigidization between mated elements is required beyond that available in the normal mating port capture latches. It can include such things as pull-down devices, special rigidization latches, and mechanical alignment aids. Any stored energy in the form of seals, tension ties, pull-down devices, shock attenuators will be released to prevent any noticeable delta-V being applied to the elements at separation.
23	Unlock capture latches	Active	This is the disconnect of the final physical interface between elements except through the manipulator. Reconnection of this interface may require that elements be separated and latches recocked or at the very least reconnection will require that the elements be forced together.

OPERATIONAL PROCEDURE NO. 3-2

	Operation	Performed by:	Rationale
24	Verify mating ports are freed (positive separation)	Active	This step does not require that the mating ports not be in contact. It is a verification that all latches have unlatched and separation can occur without damaging hardware.
25	Manipulator maneuver passive element to required separation distance	Active	The required separation distance includes the distance required to null out the separating velocity (next step)
26	Stabilize separated element	Active	Manipulator must damp the applied separation velocities prior to separating the element.
27	Align attitude reference systems	Active/ passive	Attitude reference alignment is necessary to prevent control systems from bucking each other when the ACS of the passive element is activated. Common attitude reference will also prevent any radical vehicle movement at time of separation.
28	Place passive element in wide deadband mode	Passive	Wide deadband mode is selected to reduce possibility of engines firing until after separation.
29	Activate passive element ACS and verify	Passive	Passive element ACS is activated such that it can maintain attitude hold at separation. Verification may require that a programmed movement out of the deadband range may be performed to verify ACS.

OPERATIONAL PROCEDURE NO. 3-2

	Operation	Performed by:	Rationale
30	Verify elements prepared for separation	Active/ passive	Final verification prior to independent operations
31	Disconnect/retract manipulator	Active	MSS remains in attitude hold until manipulator has cleared MSS volume of influence.
32	Maneuver active element to safe separation distance	Active	The active element maneuvers to the required separation distance prior fully independent operations.
33	Activate inhibited systems	Active/ passive	Those systems that were inhibited for mated operations due to interference or contamination problems (i.e., solar array tracking, venting) can be reactivated.
34	Deactivate separation system	Active/ passive	This completes the separation activity, the manipulator system and guidance aids can be deactivated.
35	Configure mating port for subsequent operations	Active/ passive	Mating ports may require special configuring for quiescent operations (i.e., environmental covers provided to protect the mechanisms).
	This completes the manipulator separation activity. Elements can now resume independent orbital operations.		

OPERATIONAL PROCEDURE NO. 3-3

Separation - Jet Translation Separation of Two Unmanned Elements

This procedure was developed utilizing a Space Tug and a detached Research and Applications Module (DRAM) for the model.

Assumptions

An RF data link exists between the ground or a remote base control and each element.

Initial Conditions

The checkout of subsystems required for separation and for operations subsequent to separation have been performed.

Final Conditions

The elements are separated a sufficient distance for safe, independent operations.

Description

This procedure separates two unmanned elements which are docked to a common mating port. The only interface existing between the elements is a mechanical coupling. A remote site (base control) continuously monitors the operation and transmits commands as required. A TV camera is strategically located on the space tug to enable base control to view critical operations. For this operation, one element assumes the passive role in that it does no maneuvering except attitude hold maneuvers which it performs only after separation. The other element assumes the active role performing all maneuvers for the mated couple as well as the translation away from the other element when separation occurs.

OPERATIONAL PROCEDURE NO. 3-3

TITLE: SEPARATION - JET TRANSLATION SEPARATION OF TWO UNMANNED ELEMENTS

ELEMENT INTERFACES:

	Operation	Performed by:	Rationale
1	Verify elements prepared for separation	-	All subsystems required during separation activities including backup systems must be statused.
2	Activate TV camera(s)	Active/ passive	The TV camera(s) mounted on the one or both elements will be utilized during the separation procedure.
3	Illuminate elements	Active/ passive	The element that is to be viewed during the separation activity is illuminated to provide adequate lighting for the TV cameras or to highlight particular reference points on the vehicle(s).
4	Activate separation guidance aids	Active/ passive	All separation guidance aids that may be utilized during separation will be activated.
5	Acquire separation attitude	Active	Proper vehicle orientation can provide the best sunlight angles to enhance TV coverage. Also, proper orientation may conserve propellant during operations subsequent to separation.

OPERATIONAL PROCEDURE NO. 3-3

	Operation	Performed by:	Rationale
6	Align attitude reference systems	Active/ passive	Attitude reference alignment is necessary to prevent control systems from fighting each other when the ACS of the passive vehicle is activated. Common attitude reference will also prevent any radical vehicle movement at time of separation.
7	Verify elements prepared for separation	Active/ passive	Final verification prior to separation. Communications between mated elements is via RF link.
8	Stabilize connected elements	Active	Mated elements are stabilized in a minimum deadband mode (rates/attitude) to provide the least deviation off centerline of the mated interfaces at time of separation.
9	Activate passive element ACS	Passive	Passive element ACS is activated such that it can maintain attitude hold at separation.
10	Verify passive element ACS	Active/ passive	Prior to separation, the passive element ACS must be verified to be properly operating. A failure of the ACS could result in a catastrophic accident.

OPERATIONAL PROCEDURE NO. 3-3

Operation		Performed by:	Rationale
11	Unlock and disconnect rigidization system and release stored energy	Active/ Passive	This step applies where rigidization between mated elements is required beyond that available in normal mating port capture latches. It can include such things as pull-down devices, special rigidization latches, and mechanical alignment aids. Any stored energy in the form of seals, tension ties, pull-down devices, shock attenuators will be released to prevent any noticeable delta-V being applied to the elements at separation.
12	Unlock capture latches	Active/ passive	This is the disconnect of the final physical interface between elements. Reconnection of this interface may require that elements be separated and latches recocked or at the very least, reconnection will require that the elements be forced together.
13	Verify positive separation has occurred	Active/ passive	Prior to performing a jet translation, the elements must be fully separated, that is no latches remain engaged.
14	Actuate translation jets	Active	To complete the separation procedure a minimum distance between the elements must be established. The active element performs the translation maneuvers and the passive element maintains attitude hold.

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OPERATIONAL PROCEDURE NO. 3-3

	Operation	Performed by:	Rationale
15	Complete separation maneuver	Active	The separation maneuver is performed in a minimum deadband mode which is maintained until the minimum clearance has been obtained.
16	Update orbital parameters	Active/ passive	Small delta-V errors created by the release of stored energy in the mating mechanism at the time of separation could cause errors in subsequent flight trajectories.
17	Deactivate separation guidance aids	Active/ passive	These aids can be deactivated to conserve power.

This completes the jet translation separation activity of two unmanned elements. The elements can now resume independent orbital operations.

2.3.2 PROCEDURES APPLICABILITY

Each procedure that was developed was reviewed for applicability to the feasible separating combinations. Figure 2.3-2 shows the results of these analyses in matrix form.

It is possible to separate all element pairs using either the jet translation or manipulator approach. However, for this analysis it was assumed that manipulators would not be installed on all elements. Those elements that do not appear to be candidates for manipulators are the OIS, CPS, RNS, and OPD. The first three elements which are booster type vehicles are not candidates for manipulators because the secondary advantages gained by manipulators are not applicable to the type missions performed by these vehicles. The OPD is not a candidate because manipulator operations involve a man-in-the-loop concept and the OPD is an unmanned element. All separations, however, could be performed utilizing manipulators if a third element with a manipulator is available to support the operation.

		SPACE PROGRAM ELEMENTS																
		EOS	TUG		RAM				SATELLITE			EO RESUP. MODS	LOW EO MSS	CPS		RNS CLS	OLS	OPD
			RTN	SPACE BASED	ATT. EOS	DET. EOS	ATT. MSS	DET. MSS	EOS DELIV.	EOS + 3RD ST DELIV.	RETR, RESUP.			OIS	CLS			
	EOS	1, 2	1, ②	1, 2	NA	1, ②	① ②	① ②	① ②	① ②	① ②	① ②	①, 2		① ②	① ②	①, 2	① ②
TUG	RETURNABLE	NA								NA								
	SPACE BASED	NA		1,2,3			① ②	① ② ③		① ② ③	① ② ③	① ② ③	①, 2	① ② ③	① ② ③	① ② ③	①, 2	① ② ③
RAM	ATT. EOS	NA																
	DET. EOS	NA																
	ATT. MSS	NA		NA									① 2 [1]					
	DET. MSS	NA		NA									1, 2					
SATEL	EOS DELIV.	NA																
	EOS + 3RD ST	NA		NA														
	RETR, RESUP.	NA		NA														
	EO RESUP. MODS	NA		NA								1,2,3 [1]	①, 2 [1]		① ② ③ [1]	① ② ③ [1]		① ② ③ [1]
	LOW EO MSS	NA		NA			NA	NA				NA	①, 2 [3]					
CPS	OIS			NA											1, 3	1, 3	① ◇2 ③ [2]	① ③
	CLS	NA		NA								NA		NA	1, 3 [3]		① ◇2 ③ [2]	① ③
	RNS-CLS	NA		NA								NA		NA		① ③ [3]	① ◇2 [2]	① ③
	OLS	NA		NA										NA	NA	NA	① 2 ③ [3]	
	OPD	NA		NA								NA		NA	NA	NA		① ② ③ [3]

LEGEND

○ - Indicates the active vehicle or the vehicle with a manipulator is the element identified on the vertical scale.

◇ - Indicates the active vehicle or the vehicle with a manipulator is the element identified on the horizontal scale.

Blank - Either element can be active or have a manipulator.

□ - Refers to the applicable note;

1 - Refers to Procedure 3-1

2 - Refers to Procedure 3-2

3 - Refers to Procedure 3-3

NA - Not Applicable

NOTES:

[1] These elements do not have self-contained propulsive systems, but must be separated by a logistics element. Therefore, the active-passive designation refers to the logistic element activity relative to what the nonpropulsive element is mated to.

[2] This element is being disassembled and reassembled on an orbiting booster element for transport to a higher energy orbit. During the disassembly it will essentially be inactive and will require a logistics vehicle to separate the modules; therefore, the preceding note also applies herein.

[3] This separation refers to the disassembly of modules. The modules that are being demated do not have propulsive systems and must be maneuvered by a logistics element. Therefore, Note 1 applies herein.

Figure 2.3-2. Operational Procedures Applicability - Interface Activity: Separation

2.4 CARGO TRANSFER

This section presents the operational procedures for cargo transfer, and includes one procedure for each alternate approach identified in Volume II of this report. Also presented and discussed is the applicability of these procedures to each element pair included in the in-depth analysis portion of the Orbital Operations Study.

2.4.1 OPERATIONAL PROCEDURES

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

For the manual aided and the fluid transfer operational procedures, numbers 4 and 5, respectively, the shirtsleeve crew operational mode was selected as the most representative. Furthermore, the differences for these procedures between the shirtsleeve, IVA, and EVA modes would be similar to the differences for the manual unaided approach, i.e., procedures 1, 2, and 3.

Common operations and procedural deltas between the manual unaided and the manual aided/automatic are shown in Figure 2.4-1. Procedural deltas for shirtsleeve and IVA/EVA modes are described under the crew transfer activity (see Figure 2.5-1). Since the fluid cargo transfer activity has its unique operations, it was not included in the comparison described in Figure 2.4-1.

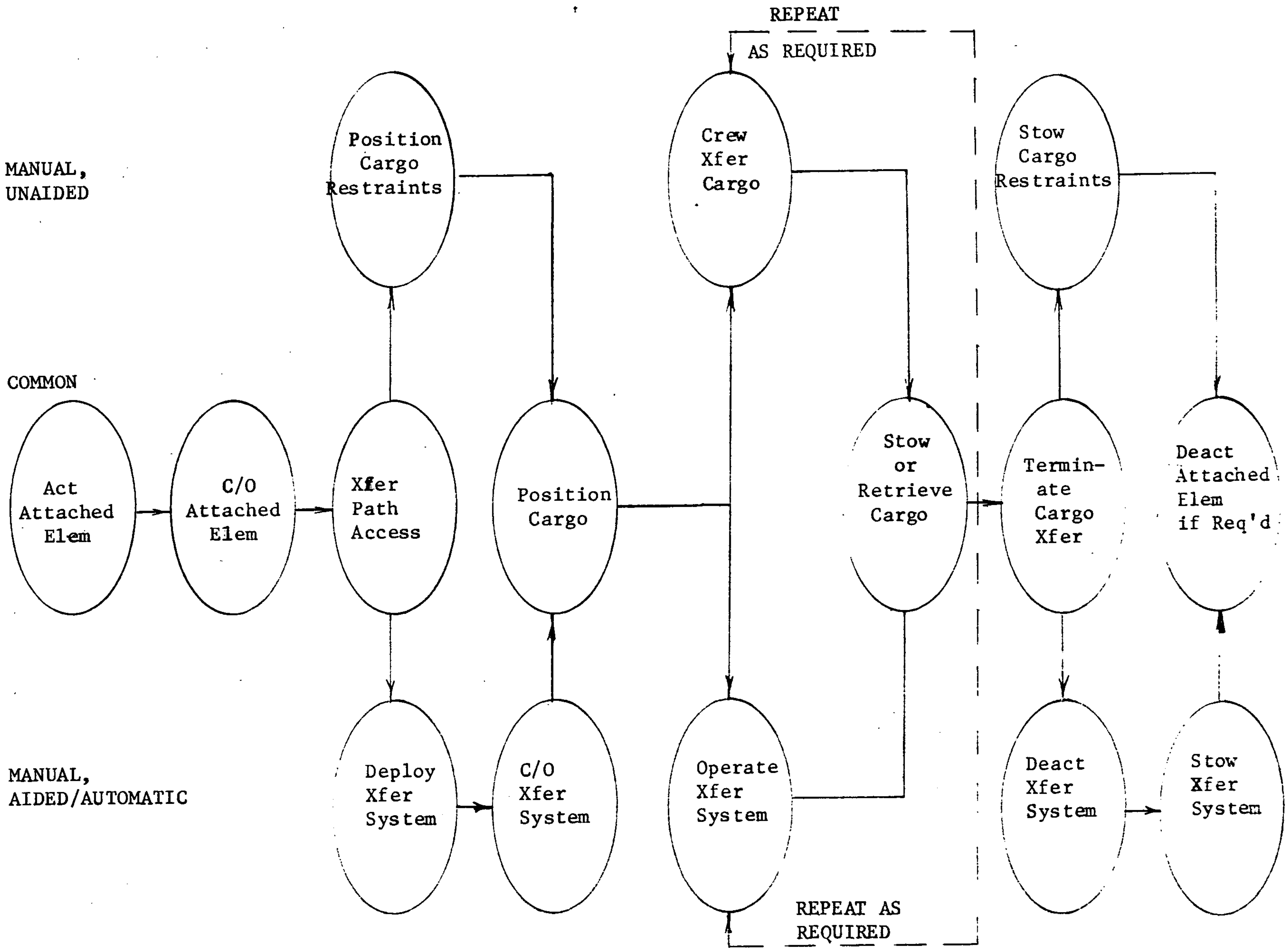

Figure 2.4-1. Cargo Transfer Procedural Comparison

Operational Procedure No. 4-1

Cargo Transfer - Manual Unaided in Shirtsleeve Mode

Assumptions

1. Airlock is available at orbiter interface but is not required for shirtsleeve operations.

2. The detached RAM is pressurizable and is capable of supporting shirtsleeve crew operations.

3. Cargo transfer requirements are within the capabilities of manual unaided transfer methods, i.e., transfer items are small and quantity of items is few.

4. All subsystems necessary to support crew habitability during transfer operations are provided by element subsystems (i.e., no portable equipment).

Initial Conditions

1. EOS orbiter (manned) has mated with an unmanned detached RAM and is in a stabilized attitude mode.

2. Mating operations of elements have been completed.

Final Conditions

Servicing, checkout, and cargo transfer operations have been completed, and the elements are in a condition for separation.

Description

Manual unaided cargo transfer in a shirtsleeve mode includes operations associated with manual retrieval, transport, and stowage of cargo items between elements. This involves such operations as:

1. Activation and checkout of unmanned element and hatchway controls and displays.

2. Positioning of cargo restraints and cargo.

3. Transfer of cargo and stowage.

4. Retrieval of resupply cargo and return.

5. Stowage of cargo and restraints.

6. Deactivate unmanned element and hatchway controls and displays.

OPERATIONAL PROCEDURE NO. 4-1

TITLE: Cargo Transfer - Manual unaided in Shirtsleeve Mode

ELEMENT INTERFACES: EOS Orbiter (Manned)/Detached RAM (Unmanned)

	Operation	Performed by:	Rationale
1.	Activate hatchway controls/ displays	Manned	Hatchways controls/displays are utilized for checkout of unmanned element and for monitoring and controlling pressurizing operations.
2.	Activate and verify communication subsystem	Manned	Continuous communication with manned element control center/flight station is required.
3.	Verify data link to unmanned element	Manned	Manned element control of unmanned element subsystems, i.e, radiation level monitoring, is required.
4.	Activate lighting in unmanned element	Manned	Adequate illumination is required for visual checkout and crew transfer so that crew positioning and visual orientation are not inhibited.
5.	Confirm interface passageway is accessible for crew transfer operations	Manned	Transfer passageway must be free of obstructions which would inhibit crew movement.
6.	Make initial check of unmanned element atmosphere	Manned	To verify that shirtsleeve operations can proceed.
7.	Pressurize tunnel between elements	Manned	

OPERATIONAL PROCEDURE NO. 4-1

	Operation	Performed by:	Rationale
8	Test tunnel leak rate	Manned	Tunnel seal must be checked prior to opening hatch
9	Equalize pressure between tunnel and EOS	Manned	Any pressure difference must be equalized prior to opening hatch
10	Open airlock hatch to tunnel and inspect mating interface	Manned	Mating port interface must be inspected for any damage and to verify all latches have engaged and are locked.
11	Connect electrical interfaces, as required	Unmanned/ Manned	
12	Verify interface connector mate	Unmanned/ Manned	Connector mate integrity must be verified prior to applying power other than continuity check current.
13	Checkout electrical interface as required	Unmanned/ Manned	
14	Connect plumbed interfaces and verify seal integrity as required	Unmanned/ Manned	Prior to activation plumbed interfaces will be purged for seal integrity.
15	Activate fluid interfaces as required	Unmanned/ Manned	
16	Activate subsystems necessary for crew habitability	Unmanned	Direct workspace lighting, environmental system, etc.
17	Prepare interface as required for pressurization of unmanned element	Manned/ Unmanned	Hardware/subsystems must be prepared for pressurization operations (i.e., interface pressurization controls or remote monitoring/control subsystem).

OPERATIONAL PROCEDURE NO. 4-1

	Operation	Performed by:	Rationale
18	Pressurize unmanned element	Manned/ Unmanned	To provide a shirtsleeve environment.
19	Test unmanned element leak rate	Manned/ Unmanned	Leak rate must be within tolerance that can be supported.
20	Verify the unmanned element atmosphere is compatible with the manned element atmosphere	Manned	Prior to opening hatch the atmosphere must be verified to be free of contamination
21	Equalize pressure in unmanned element to that of manned element	Manned	Pressure between elements must be equalized prior to opening the final interface hatch.
22	Open hatch between tunnel and unmanned element	Manned/ Unmanned	
23	Connect and activate air circulation ducts	Unmanned/ Manned	Air circulation is required for shirt-sleeve operations.
24	Ingress unmanned elements and perform initial inspection	Unmanned	Initial inspection will be made prior to performing subsequent operations.
25	Position tunnel crew restraint devices	Unmanned/ Manned	For crew stabilization during inter-face connection and verification operations.
26	Obtain cargo transfer items	Manned	Transfer items will be restrained in storage/use location.

OPERATIONAL PROCEDURE NO. 4-1

	Operation	Performed by:	Rationale
27.	Verify cargo transfer items are in condition for transport	Manned	Individual cargo items will be restrained to prevent movement.
28.	Adjust crew restraint devices	Manned	To position crewman during cargo handling.
29.	Affix cargo items to crewman cargo restraints	Manned	To provide positive control of cargo items.
30.	Release from crew restraint devices and maneuver cargo to unmanned element	Manned/ Unmanned	Manual transfer will utilize crew mobility aids.
31.	Adjust crew restraint devices	Unmanned	To position crewman during cargo handling at unmanned element worksite.
32.	Remove cargo items from crewman cargo restraints	Unmanned	Temporary worksite restraints may be utilized.
33.	Position transfer items in work-site or storage locations	Unmanned	Transfer items must be positively controlled.
34.	Perform unmanned element resupply operations	Unmanned	Refer to operational procedure No. 12-2.
35.	Retrieve cargo transfer items	Unmanned	Transfer items will be restrained in storage/use location.
36.	Affix cargo transfer items to crewman cargo restraints	Unmanned	To provide positive control of cargo items.
37.	Crewman release himself from crew restraint devices and maneuver cargo to manned element worksite.	Manned	Manual transfer will utilize crew mobility aids.

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OPERATIONAL PROCEDURE NO. 4-1

	Operation	Performed by:	Rationale
38	Adjust crew restraint devices	Manned	To position crewman during cargo handling at manned element worksite.
39	Remove cargo items from crewman cargo restraints and position at worksite	Manned	Transfer items must be positively controlled.
40	Repeat operations 26 through 39 as required	Manned/ Unmanned	To complete unmanned element cargo transfer and resupply operations.
41	Verify all equipment is in EOS and hatchways are clear	Manned/ Unmanned	Confirmation of retrieval of all loose equipment and hatch clearance
42	Deactivate subsystems necessary for crew habitability	Unmanned	Subsystems support to crew operations are no longer necessary.
43	Close hatch between unmanned element and tunnel	Manned/ Unmanned	
44	Disconnect plumbed interfaces	Manned/ Unmanned	Interface disconnection required prior to closing hatch.
45	Disconnect electrical interfaces	Manned/ Unmanned	Interface disconnection required prior to closing hatch.
46	Disconnect air circulation ducts	Manned/ Unmanned	Interface disconnection required prior to closing hatch.
47	Close hatch between EOS and tunnel	Manned/ Unmanned	
48	Perform verification of readiness for separation and depressurize tunnel	Manned	Confirm hatch sealing and preparation for element separation,

OPERATIONAL PROCEDURE NO. 4-1

	Operation	Performed by:	Rationale
49.	Confirm EOS and unmanned element sealing	Manned	Leak rates must be checked to verify sealing.
50.	Deactivate crew transfer control link/subsystems of unmanned element as required	Manned	Unmanned element subsystems which support crew operations can be deactivated.
51.	Deactivate hatchwal controls/ displays	Manned	Hatchway controls/displays can be deactivated with termination of crew operations.

Operational Procedure No. 4-2

Cargo Transfer - Manual Unaided in an IVA Mode

Assumptions

1. The EOS cargo bay doors will remain open for normal heat rejection mode of operation.

2. An EOS airlock will be provided so that IVA operations can occur between the EOS and the external surface of the satellite.

3. Cargo transfer requirements are within the capabilities of a manual unaided, IVA suited mode.

4. A second crewman will be employed for backup during IVA operations.

Initial Conditions

1. An unmanned satellite has been retrieved by the EOS orbiter and positioned and stabilized into the cargo bay by the manipulator.

2. The manipulator has positioned a hardline interconnect between the elements to allow EOS orbiter monitoring and safing of satellite subsystems.

3. Mobility aids and restraint devices are prepositioned along transfer path and at cargo bay/satellite.

4. IVA operations will utilize 3.7 psig umbilically supported pressure suits. This will provide the worse case IVA operations, i.e., utilizing suits of 8.0 and above psig will eliminate equipment and operations required for prebreathing.

Final Conditions

The satellite cargo transfer and resupply operations have been completed and interface access has been terminated.

Description

Manual unaided cargo transfer in an IVA mode includes operations associated with manual retrieval, transport, and stowage of cargo items between elements in an IVA pressure suited mode. This involves such operations as:

1. Activation and checkout of unmanned element, and airlock and hatchway controls/displays.

2. Donning of suits, prebreathing, and performing depressurization operations and checkout.

3. Transfer of cargo items and stowage.

4. Retrieval of resupply cargo and return to airlock.

5. Stowage of cargo and restraints and perform pressurization operations.

6. Deactivation of unmanned element.

7. Removal and service of suits, and deactivation of airlock and hatchway controls/displays.

OPERATIONAL PROCEDURE NO. 4-2

TITLE: CARGO TRANSFER - MANUAL UNAIDED IN IVA MODE

ELEMENT INTERFACES: EOS ORBITER (MANNED)/SATELLITE (UNMANNED) POSITIONED IN CARGO BAY

	Operation	Performed by:	Rationale
1.	Activate airlock and hatchway controls/displays	Manned	Airlock and hatchway controls/displays will be utilized for checkout of unmanned element and for monitoring and controlling pressurizing operations.
2.	Activate and verify communication subsystem	Manned	Continuous communication with manned element control center/flight station is required.
3.	Verify data link to unmanned element	Manned	Manned element control of unmanned element subsystems, i.e., radiation level, is required.
4.	Activate lighting of unmanned element	Manned	Adequate illumination is required for visual/TV checkout of unmanned element.
5.	Confirm interface passageway is accessible for crew transfer operations	Manned	Transfer passageway must be free of obstructions which would inhibit crew movement.
6.	Verify environmental contamination levels in unmanned element are within limits	Manned	Contamination levels in unmanned element must be checked to indicate possible danger to IVA crewman.
7.	Deactivate lighting of unmanned element	Manned	Since the unmanned element has been visually checked and prebreathing operations may take up to 3 hours, lighting can be deactivated to conserve power.

OPERATIONAL PROCEDURE NO. 4-2

	Operation	Performed by:	Rationale
8.	Verify cargo transfer items are stowed in airlock	Manned	Items to be transferred must be in airlock or pre-positioned outside manned element.
9.	Don face masks and initiate prebreathing	Manned	3.7 psig space suits require crew to prebreath oxygen to accomplish denitrogenation.
10.	Primary and backup crewman unstow and don IVA space suits excluding helmet and gloves.	Manned	Suits are vented from umbilical connection
11.	Checkout and prepare IVA equipment	Manned	All equipment use in the IVA operation will be checked out prior to use and all crew transfer equipment stowed outside airlock must be brought into airlock.
12.	Enter airlock	Manned	
13.	Activate lighting in unmanned element	Manned	Lighting must be reactivated for crew transfer so that crew positioning and visual orientation are not inhibited.
14.	Close airlock hatch and initiate N_2 purge	Manned	
15.	Terminate prebreathing and don helmet and gloves	Manned	Crewmen are entirely supported by umbilicals from airlock subsystems.
16.	Perform space suit operation and integrity checks	Manned	Space suit sealing, communications, coolant flow, etc. must be verified.

OPERATIONAL PROCEDURE NO. 4-2

Operation		Performed by:	Rationale
17.	Depressurize airlock	Manned	
18.	Confirm operation of space suit systems	Manned	Confirmed in depressurized airlock prior to opening hatch.
19.	Equalize pressure between airlock and unmanned element	Manned	Pressure differential across airlock hatch must be equalized prior to opening.
20.	Open airlock hatch to unmanned element	Manned	
21.	Approach unmanned element and perform initial inspection	Unmanned	Initial inspection will be made prior to performing subsequent operations.
22.	Position cargo on cargo restraints	Manned	Positive control of cargo items is required during transfer.
23.	Primary IVA crewman traverse to unmanned element worksite	Unmanned	
24.	Backup IVA crewman monitor IVA operation and control primary crewman umbilical	Manned	To ensure against umbilical entanglement and be available for rescue operations.
25.	Adjust worksite crew restraint devices	Unmanned	To position crewman during cargo handling at unmanned element worksite.
26.	Transfer cargo items between IVA crewman and unmanned element	Unmanned	Cargo items will be removed from crew cargo restraints and installed on unmanned element

OPERATIONAL PROCEDURE NO. 4-2

	Operation	Performed by:	Rationale
27.	Position cargo items temporary restraints, as required	Unmanned	Positive control of cargo items is required at all times.
28.	Transfer cargo items between unmanned element and IVA crewman crew cargo restraints.	Unmanned	Cargo items to be transferred to manned element will utilize crew cargo restraints.
29.	Crewman release himself from worksite crew restraint devices and return to airlock.	Unmanned	
30.	Adjust crew restraint device at airlock hatch	Manned	Positive crew control required during transfer of cargo items to backup crewman at airlock.
31.	Transfer cargo items to backup crewman	Manned	Primary IVA crewman will remain at unmanned element until completion of cargo transfer operation.
32.	Stow cargo items in airlock	Manned	Cargo items will be positively restrained to prevent damage.
33.	Perform unmanned element resupply operations	Unmanned	Refer to operational procedure No 12-2.
34.	Repeat steps 22 thru 33 as required	Manned/ Unmanned	To complete unmanned element cargo transfer and resupply operations.
35.	Verify all IVA equipment is in airlock and hatchway is clear	Manned	Confirmation of retrieval of all loose equipment and hatch clearance.
36.	Close hatch between airlock and unmanned element and prepare for repressurization	Manned	

OPERATIONAL PROCEDURE NO. 4-2

	Operation	Performed by:	Rationale
37.	Repressurize airlock and verify	Manned	Airlock integrity will be verified during and subsequent to repressurization.
38.	Deactivate crew transfer control link/subsystems of unmanned element	Manned	Unmanned element subsystems which support crew operations can be deactivated.
39.	Equalize pressure between airlock and manned element	Manned	Must be accomplished prior to opening hatch.
40.	Open hatch between airlock and manned element	Manned	
41.	Remove space suits, and service and stow all IVA equipment	Manned	
42.	Deactivate airlock and hatchway controls/displays	Manned	Airlock and hatchway controls/displays can be deactivated with termination of crew operations.

Operational Procedure No. 4-3

Cargo Transfer - Manual Unaided in an EVA Mode

Assumptions

1. Cargo items to be transferred are within the handling capabilities of a manual unaided, EVA suited mode.

2. EVA operations will be conducted using a 3.7 psig pressure suit and a portable life support system (PLSS). This allows for the worse case conditions as an 8.0 and above psig suit will eliminate equipment and operations required for prebreathing, and utilizing umbilicals will eliminate donning of the PLSS (back packs).

3. A second crewman will be employed for backup during EVA operations.

Initial conditions

1. The tug has established a hardline interconnect with the satellite to monitor subsystem status.

2. The satellite is positioned within reach of an EVA crewman without requiring free space transfer.

3. A space base tug (manned) has retrieved an unmanned satellite by an onboard manipulator and positioned it adjacent to the EVA airlock egress hatch.

Final Conditions

EVA operations to the satellite have been completed and the satellite is in a condition for separation.

Description

Manual unaided cargo transfer in an EVA mode includes operations required for retrieval, transport, and stowage of cargo items between elements in an EVA suited mode. This includes such operations as:

1. Activation and checkout of unmanned element, airlock and hatchway controls/displays, and external EVA lighting.

2. Donning of suits and back packs, prebreathing, and performing depressurization operations and checkout.

3. Transfer of cargo item and stowage.

4. Retrieval of resupply cargo items and return to airlock

5. Stowage of cargo and restraints and perform pressurization operations.

6. Deactivation of unmanned element.

7. Removal and service of suits and back packs and deactivation of airlock and hatchway controls/displays.

OPERATIONAL PROCEDURE NO. 4-3

TITLE: CARGO TRANSFER - MANUAL UNAIDED IN EVA MODE

ELEMENT INTERFACES: SPACE BASED TUG (MANNED)/SATELLITE (UNMANNED)

	Operation	Performed by:	Rationale
1.	Activate airlock and hatchway controls/displays	Manned	Airlock and hatchway controls/displays will be utilized for checkout of unmanned element and for monitoring and controlling pressurizing operations
2.	Activate and verify communication subsystem	Manned	Continuous communication with manned element control center/flight station is required.
3.	Verify data link to unmanned element	Manned	Manned element control of unmanned element subsystems is required.
4.	Activate external lighting, as required	Manned	External lighting will be required to visually inspect satellite worksite depending upon solar illumination and shadowing.
5.	Confirm interface passageway is accessible for crew transfer operations	Manned	Transfer passageway must be free of obstructions which would inhibit crew movement.
6.	Deactivate external lighting	Manned	Upon verification of worksite access, lighting will be extinguished during EVA preparation.
7.	Verify cargo transfer items are stowed in airlock	Manned	Items to be transferred must be in airlock or prepositioned outside manned element.

OPERATIONAL PROCEDURE NO. 4-3

	Operation	Performed by:	Rationale
8.	Don face mask and initiate pre-breathing	Manned	3.7 psig space suit require crew to prebreath oxygen to accomplish denitrogenation.
9.	Primary and backup crewman unstow and don EVA space suits, excluding helmet and gloves	Manned	Suits are vented from an umbilical connection
10.	Checkout and prepare EVA equipment	Manned	All equipment used in the EVA operation will be checked out prior to use and all transfer equipment stowed outside airlock must be brought into airlock.
11.	Enter airlock	Manned	
12.	Activate external lighting, as required	Manned	Lighting must be reactivated for transfer so that crew positioning and visual orientation are not inhibited.
13.	Close airlock hatch and initiate N_2 purge	Manned	
14.	Life support system (back pack) donning and checkout	Manned	Confirm back pack interface with crewman and initiate purge flow.
15.	Terminate prebreathing and don helmets and gloves	Manned	Crewman are entirely supported by umbilicals from airlock.
16.	Perform EVA space suit operation and integrity check	Manned	Space suit sealing, communication, coolant flow, etc. must be verified.
17.	Depressurize airlock	Manned	
18.	Confirm operation of EVA space suit systems	Manned	Confirmed in depressurized airlock prior to opening hatch.

OPERATIONAL PROCEDURE NO. 4-3

	Operation	Performed by:	Rationale
19.	Equalize pressure between airlock and unmanned element	Manned	Pressure differential across airlock hatch must be equalized prior to opening
20.	Open airlock hatch to unmanned element	Manned	
21.	Egress airlock hatch and perform initial worksite inspection	Unmanned	
22.	Position unmanned element cargo items on crew cargo restraints	Manned	Positive control of cargo item is required during transfer
23.	Backup EVA crewman monitor EVA operation and control primary crewman tether	Manned	To ensure against tether entanglement and be available for rescue operations.
24.	Primary crewman maneuver cargo items to manipulator held satellite	Unmanned	Crew mobility aids (hand holds/rails) will be used for translation control.
25.	Adjust worksite crew restraint devices	Unmanned	Crew restraint device may be on unmanned element or on manned element within reach of manipulator held satellite.
26.	Transfer cargo items between EVA crewman and unmanned element	Unmanned	Cargo items will be removed from crew cargo restraints and installed on unmanned element.
27.	Position cargo items temporary restraints, as required	Unmanned	Positive control of cargo items is required at all times.

OPERATIONAL PROCEDURE NO. 4-3

	Operation	Performed by:	Rationale
28.	Transfer cargo items between unmanned element and EVA crewman crew cargo restraints	Unmanned	Cargo items to be transferred to manned element will utilize crew cargo restraints.
29.	EVA crewman release himself from worksite crew restraint device and maneuver cargo items to manned element airlock	Unmanned	
30.	Adjust crew restraint device at airlock hatch	Manned	Positive crew control required during transfer of cargo items to backup crewman at airlock.
31.	Transfer cargo items to backup crewman in airlock	Manned	Primary EVA crewman will remain outside airlock until completion of cargo transfer operation.
32.	Stow cargo items in airlock	Manned	Cargo items will be positively restrained to prevent damage.
33.	Perform unmanned element resupply operation	Unmanned	Refer to operational procedure No. 12-2
34.	Repeat steps 22 thru 33 as required	Manned/	To completion of unmanned element cargo transfer and resupply operations.
35.	Verify all EVA equipment is in airlock and hatchway is clear	Manned	Confirmation of retrieval of equipment and hatch clearance.
36.	Close airlock hatch and prepare for repressurization	Manned	

OPERATIONAL PROCEDURE NO. 4-3

	Operation	Performed by:	Rationale
37.	Repressurize airlock and verify	Manned	Airlock integrity will be verified during and subsequent to repressurization.
38.	Deactivate crew transfer control link/subsystems of unmanned element	Manned	Unmanned element subsystems which support crew operations can be deactivated.
39.	Equalize pressure between airlock and manned element	Manned	Must be accomplished prior to opening hatch.
40.	Open hatch between airlock and manned element	Manned	
41.	Remove space suits, and service/stow all EVA equipment	Manned	
42.	Deactivate airlock and hatchway controls/displays	Manned	Airlock and hatchway controls/displays can be deactivated with termination of crew operations.

Operational Procedure No. 4-4

Cargo Transfer - Manual aided in a Shirtsleeve Mode

Assumptions

1. A guide rail system will be utilized as the mechanical aid for transfer of cargo items between elements. Manual translation will provide energy for movement of cargo items.

2. The RAM is pressurizable and is capable of supporting shirtsleeve crew operations.

3. Cargo transfer requirements are within the capabilities of manual aided transfer methods.

Initial Conditions

1. An unmanned detached RAM has mated with a manned modular space station (MSS).

2. Mating operations of elements have been completed.

3. Element has been pressurized, hatches are open, and subsystems necessary to support crew habitability have been activated and verified.

Final Conditions

Unmanned element is in a condition where subsystems required to support shirtsleeve operations can be terminated.

Description

Manual aided cargo transfer in a shirtsleeve mode includes those operations required to prepare and checkout the transfer mechanism, and to position, transfer, and stow cargo items between elements. This involves such operations as:

1. Deployment and checkout of transfer mechanism.

2. Positioning cargo and operating transfer mechanism.

3. Retrieval of cargo.

4. Deactivating and stowage of transfer mechanism.

OPERATIONAL PROCEDURE NO. 4-4

TITLE: CARGO TRANSFER - MANUAL AIDED IN SHIRTSLEEVE MODE

ELEMENT INTERFACES: MSS (MANNED) DETACHED RAM (UNMANNED)

	Operation	Performed by:	Rationale
1.	Verify crew restraint devices are positioned at element and interface worksites	Manned/ Unmanned	To provide crewman body position control at worksite locations.
2.	Retrieve transfer system guide rails	Manned	Guide rails for interface connection will be installed by crew.
3.	Deploy transfer system guide rails.	Manned	
4.	Align transfer system guide rails	Manned	Guide rails will accommodate docking port misalignment.
5.	Adjust transfer system crew mobility aids	Manned/ Unmanned	Crew mobility aids will be used to maneuver cargo along transfer system.
6.	Retrieve transfer system carriage assembly	Manned	The carriage assembly allows interconnection of cargo to transfer system guide rails.
7.	Position transfer system carriage on guide rails	Manned	
8.	Verify carriage braking system	Manned	Fail safe braking system is actuated from control handles.
9.	Checkout transfer system guide rail/carriage interface	Manned	To verify alignment and clearances along transfer route

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OPERATIONAL PROCEDURE NO. 4-4

	Operation	Performed by:	Rationale
10.	Release from crew restraint devices and transfer carriage assembly to unmanned element cargo stowage area	Unmanned	
11.	Set carriage assembly brake	Unmanned	
12.	Adjust crew restraint devices	Unmanned	To position crewman for cargo loading operations.
13.	Deploy carriage assembly cargo retainer	Unmanned	Cargo items will be loaded into cargo retainer
14.	Retrieve cargo items from stowage location	Unmanned	
15.	Position cargo items in cargo retainer	Unmanned	Individual cargo items mass, cg and volume will be identified
16.	Record mass of cargo items loaded into cargo retainer	Unmanned	Transfer system mass handling capability must not be exceeded.
17.	Secure cargo retainer net restraints	Unmanned	Positive control of cargo items within transfer system is required.
18.	Release from crew restraint devices and release carriage brake	Unmanned	
19.	Maneuver cargo carriage utilizing push/pull control handles	Unmanned	Control handles afford leverage point for push/pull maneuvering and carriage braking.

OPERATIONAL PROCEDURE NO.4-4

	Operation	Performed by:	Rationale
20.	At delivery site set carriage assembly brake	Manned	
21.	Adjust crew restraint device	Manned	To position crewman for cargo unloading operations.
22.	Loosen cargo retainer net restraints.	Manned	
23.	Retrieve cargo from cargo retainer	Manned	Cargo items size and mass will determine whether one or two man operation
24.	Transfer cargo and position in stowage location	Manned	At delivery worksite cargo items will be restrained in use/stowage location.
25.	Repeat steps 14 thru 24 as required	Manned/ Unmanned	To complete cargo transfer operations.
26.	Collapse carriage cargo retainer	Manned	Preparatory to restowing carriage assembly.
27.	Restow transfer system carriage assembly	Manned	
28.	Retrieve transfer system mobility aids	Manned	Mobility aids used specifically for cargo transfer will be removed and stowed.
29.	Adjust crew restraint devices at element interface	Manned	To position crewman for interface disassembly.

OPERATIONAL PROCEDURE NO. 4-4

	Operation	Performed by:	Rationale
30.	Retrieve guide rails from interface	Manned	
31.	Restow interface guide rails.	Manned	
	See Procedure 4-1 for closeout of unmanned module		

Operational Procedure No. 4-5

Cargo Transfer - Fluid (plumbed) in a Shirtsleeve Mode - Manual Unaided Temporary Interconnect

Assumptions

1. Crew access between elements can occur, i.e., both elements are manned.

Initial Conditions

1. The EOS orbiter (active) has positioned the attached RAM.

2. Crew restraint devices are pre-positioned at interface worksite.

3. All subsystems have been activated to support crew habitability at interface.

Final Condition

Fluid transfer operations have been completed.

Description

Fluid transfer in a shirtsleeve mode includes those operations required for crew connection of lines at the interface worksite, and control and monitor of the fluid flow between elements. This involves such operations as:

1. Positioning and adjustment of crew restraint devices at worksite.

2. Alignment and verification of electrical and fluid interconnections.

3. Extend and engage gaseous and liquid flow lines.

4. Purge of compressor and transfer lines and monitor.

5. Perform fluid transfer and monitor expulsion/fill rate.

6. Terminate fluid transfer and purge lines.

7. Disengage and retract interconnects.

OPERATIONAL PROCEDURE NO. 4-5

TITLE: CARGO TRANSFER - FLUID (PLUMBED) IN SHIRTSLEEVE MODE

ELEMENT INTERFACES: MANNED EOS ORBITER (ACTIVE)/MANNED ATTACHED RAM (PASSIVE)

	Operation	Performed by:	Rationale
1.	Verify crew restraint devices are positioned at interface worksite	Active	To provide crewman body position control at interface worksite.
2.	Retrieve tools and equipment for interconnection operations	Active	Necessary equipment for operation will be prepositioned at worksite.
3.	Adjust crew restraint device	Active	Restraints adjusted to allow crewman ability to perform interconnection operations.
4.	Align and verify electrical and fluid interconnectors	Active/ Passive	Interconnectors are within recesses at element interface, coding and indexing is utilized to prevent misconnection.
5.	Connect electrical interfaces	Active/ Passive	Connector mating integrity must be verified prior to applying power other than continuity check current.
6.	Verify operational readiness of meters, controls and monitoring sensors	Active/ Passive	Assures control of transfer functions in both elements.
7.	Extend and engage gaseous flow lines	Active/ Passive	Physical connection of gaseous lines across interface.
8.	Extend and engage liquid flow lines	Active/ Passive	Physical connection of liquid lines across interface.

OPERATIONAL PROCEDURE NO. 4-5

	Operation	Performed by:	Rationale
9.	Purge compressor and transfer lines	Active/ Passive	Interconnections and transfer system will be cleared of contaminants.
10.	Monitor interconnectors and valves for leaks	Active/ Passive	Transfer system integrity will be verified prior to operation.
11.	Initiate combined element controlled acceleration	Active	Linear acceleration is utilized for liquid transfer ullage control.
12.	Initiate pressurization and chill down of liquid transfer system	Active	
13.	Initiate fast liquid fill	Active	After transfer system has reached press/temp levels for normal operation.
14.	Terminate liquid flow	Active/ Passive	Quantity gaging in passive element will establish fill termination.
15.	Drain liquid from transfer lines	Active/ Passive	Valves are reset to permit compressor to expel gasses through liquid transfer lines.
16.	Purge compressor and transfer lines	Active/ Passive	Preparatory to safe disconnection.
17.	Depressurize transfer subsystem	Active/ Passive	
18.	Terminate Acceleration	Active	
19.	Pressurize water transfer system	Active/ Passive	Positive water tank bladder pressure will provide pressure head for water transfer.

OPERATIONAL PROCEDURE NO. 4-5

	Operation	Performed by:	Rationale
20.	Monitor expulsion/fill rate	Active/ Passive	Correlate with receiving element.
21.	Depressurize water transfer system	Active	Equalize bladder pressure between elements.
22.	Purge liquid from interconnecting lines	Active	Remove all liquid from interconnectors to prevent liquid spillage.
23.	Disengage and retract hazardous liquid/gas interconnectors	Active/ Passive	Hazardous liquid/gas (i.e., hydrogen) transfer systems will be independently disconnected.
24.	Vent and purge hazardous liquid/ gas interconnectors	Active/ Passive	To prevent buildup of hazardous conditions.
25.	Disengage and retract nonhazardous liquid/gas interconnectors	Active/ Passive	Preparatory to separation, interconnectors are drawn back into protective recess.
26.	Verify shutdown of control valves meters and monitoring sensors	Active/ Passive	Final check prior to disengagement of hardware connection used for fluid/ gas transfer information exchange.
27.	Disengage and retract electrical connectors	Active Passive	Preparatory to separation, connectors are drawn back into protective recess.

2.4.2 PROCEDURES APPLICABILITY

Figure 2.4-2 presents the cargo transfer procedure applicability for each of the element-to-element interfaces. The matrix indicates where the manual unaided (shirtsleeve, IVA, and EVA) and manual aided procedures apply for manned-to-unmanned and manned-to-manned interfaces. In general, all the manned-to-unmanned element cargo transfer applicable interfaces with an air-lock can support shirtsleeve and IVA manual unaided, manual aided, and fluid transfer.

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

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

		SPACE PROGRAM ELEMENTS																
			TUG		RAM				SATELLITE					CPS				
		EOS	RTN	SPACE BASED	ATT. EOS	DET. EOS	ATT. MSS	DET. MSS	EOS DELIV.	EOS + 3RD ST DELIV.	RETR, RESUP.	EO RESUP. MODS	LOW EO MSS	OIS	CLS	RNS CLS	OLS	OPD
	EOS	* 1,4,5	NA	1,2,4,5	1,2,4,5	1,2,4,5	NA	NA	NA	NA	1,2,3 4,5	1,2,4,5	1,2,4,5		1,2,4,5	1,2,4,5	1,2,4,5	1,2,4,5
TUG	RETURNABLE	NA								NA								
TUG	SPACE BASED	1,4,5		1,2,4,5 / 1,4,5			NA	NA		NA	1,2,3, 4,5	1,2,4,5	1,2,4,5	NA	1,2,4,5	1,2,4,5	1,2,4,5	1,2,4,5
RAM	ATT. EOS	1,4,5																
RAM	DET. EOS	NA																
RAM	ATT. MSS	NA		1,4,5									** 1,4,5					
RAM	DET. MSS	NA		NA									** 1,4,5					
SATEL	EOS DELIV.	NA																
SATEL	EOS + 3RD ST	NA	NA	NA														
SATEL	RETR, RESUP.	NA		NA														
	EO RESUP. MODS	NA		NA								NA / NA	** 1,4,5		NA	NA		NA
	LOW EO MSS	1,4,5		1,4,5			1,4,5	NA				NA	1,4,5 / 1,4,5 **					
CPS	OIS			NA											NA	NA	NA	NA
CPS	CLS	1,4,5		1,4,5								NA		NA	NA / NA		NA	NA
	RNS-CLS	1,4,5		1,4,5								NA		NA		NA / NA	NA	NA
	OLS	1,4,5		1,4,5										NA	NA	NA	1,4,5 / 1,4,5 **	
	OPD	1,4,5		1,4,5								NA		NA	NA	NA		NA / NA

LEGEND

- * Assumed to be always a manned-to-manned interface
- ** No airlock at interface
- 1 - Manual unaided - shirtsleeve
- 2 - Manual unaided - IVA
- 3 - Manual unaided - EVA
- 4 - Manual aided - shirtsleeve
- 5 - Manual unaided - shirtsleeve - fluid
- NA - Not Applicable

NOTES:

Space Element Manning

(1) Upper/right half of chart:
One element assumed unmanned

(2) Lower/left half of chart:
Both elements assumed manned

Figure 2.4-2. Operational Procedures Applicability - Interface Activity: Cargo Transfer

2.5 CREW TRANSFER

This section presents the operational procedures for crew transfer, and includes one procedure for each alternate approach identified in Volume II of this report. Also presented and discussed is the applicability of these procedures to each element pair included in the in-depth analysis portion of the Orbital Operations Study.

2.5.1 OPERATIONAL PROCEDURES

Crew transfer operational procedures are included for shirtsleeve and IVA alternate approaches. The shirtsleeve procedure considers the transfer operation between an EOS orbiter (manned) and an unmanned detached RAM. This element pair requires pressurization of the unmanned element to establish a habitable environment. These operations would be in addition to those required for two manned elements which would involve activation checkout, and pressurization of the interfacing tunnel, and crew movement and performance of work tasks.

The procedure for the IVA alternate approach involves crew transfer in an IVA suited mode between an EOS orbiter (manned) and an unmanned modular space station (MSS). In lieu of module pressurization, operations required for shirtsleeve crew transfer, operations for airlock depressurization/ pressurization and suit operations are required for the IVA mode. The procedural deltas between the shirtsleeve and IVA procedures are presented in Figure 2.5-1.

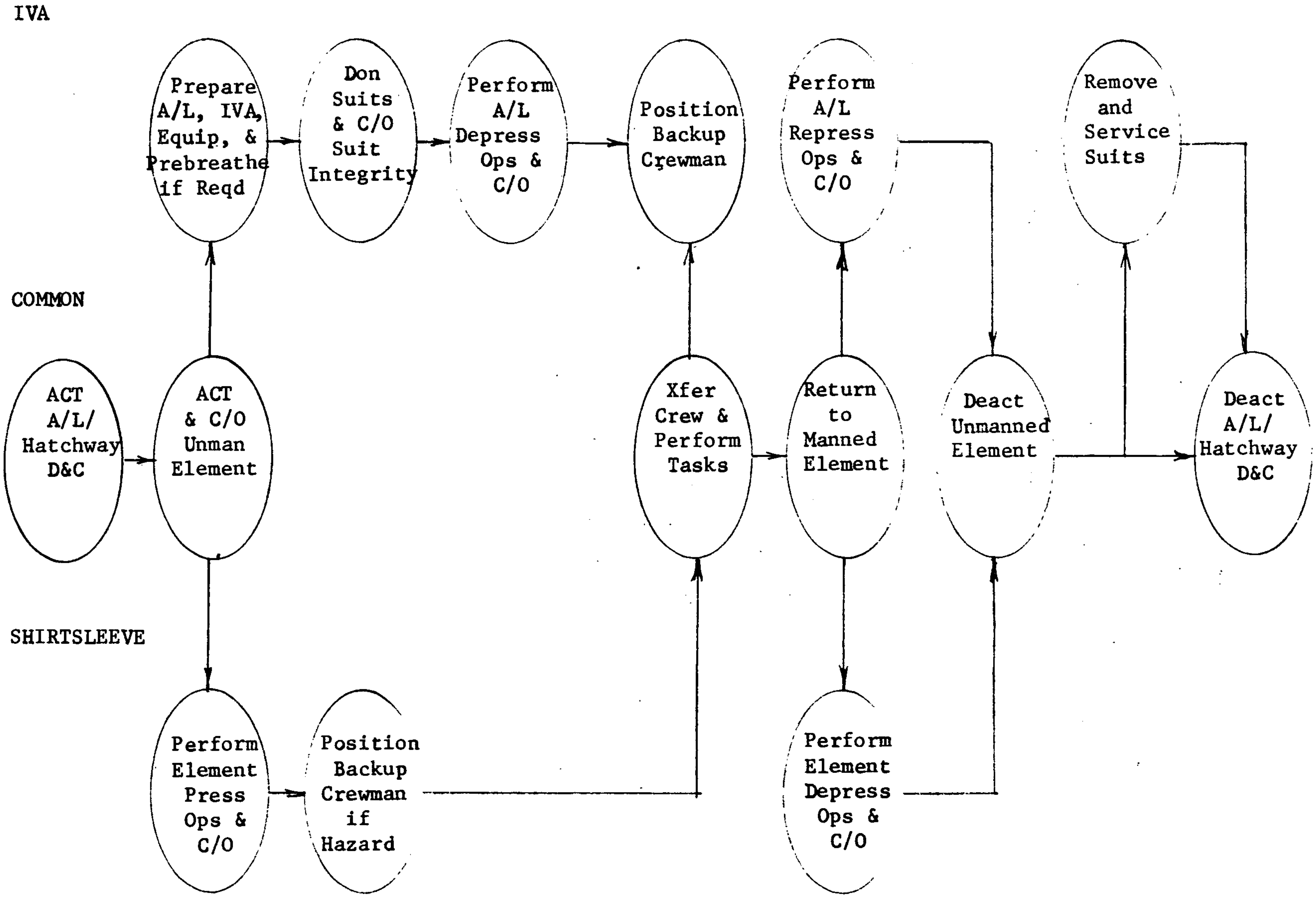

Figure 2.5-1. Crew Transfer Procedural Comparison (Manned Element to Unmanned Element)

Operational Procedure No. 5-1

Crew Transfer - Shirtsleeve

Assumptions

1. A second crew member will be employed as a backup if operations are hazardous.
2. Airlock will be available at EOS interface but is not required for shirtsleeve operations.
3. All subsystems necessary to support crew habitability during transfer operations are provided by element subsystems (i.e., no portable equipment).
4. Detached RAM is pressurizable and can support shirtsleeve crew operations compatible with that of the EOS orbiter.

Initial Conditions

1. EOS orbiter has mated with an unmanned detached RAM.
2. Mating operations of elements have been completed.

Final Conditions

Elements are in a condition for separation.

Description

Shirtsleeve crew transfer includes those operations associated with crew movement from one element to a worksite of the other element to perform a required task and returning. This would include such operations as:

1. Activation of hatchway controls/displays
2. Activation and checkout of unmanned element.
3. Perform pressurization operations of tunnel and unmanned element.
4. Use of a backup crew member if hazardous.
5. Transfer to worksite and perform required tasks.
6. Return to manned element and perform depressurization operations and checkout.
7. Deactivation of unmanned element and hatchway controls/displays displays.

OPERATIONAL PROCEDURE NO. 5-1

TITLE: CREW TRANSFER - SHIRTSLEEVE

ELEMENT INTERFACES: EOS ORBITER (MANNED)/DETACHED RAM (UNMANNED)

	Operation	Performed by:	Rationale
1	Activate hatchway controls/displays.	Manned	Hatchway controls/displays will be utilized for checkout of unmanned element and for monitoring and controlling pressurization operations.
2	Activate and verify airlock communication subsystem.	Manned	Continuous communication with manned element control center/flight station is required.
3	Verify data link to unmanned element.	Manned	Manned element control of unmanned element subsystems, e.g., radiation level monitoring, is required.
4	Activate lighting in unmanned element.	Manned	Adequate illumination is required for visual checkout of unmanned element and for crew transfer so that crew positioning capabilities and visual orientation are not inhibited.
5	Confirm interface passageway is accessible for crew transfer operations.	Manned	Transfer passageway must be free of obstructions which would inhibit crew movement.
6	Make initial check of unmanned element atmosphere.	Manned	Must be made so that shirtsleeve operations can proceed.
7	Pressurize tunnel between elements.	Manned	

OPERATIONAL PROCEDURE NO. 5-1

	Operation	Performed by:	Rationale
8	Test tunnel leak rate.	Manned	Tunnel seal must be checked prior to opening hatch
9	Equalize interface pressures between tunnel and EOS		Any pressure difference between tunnel and EOS must be equalized prior to opening hatch
10	Open EOS hatch to tunnel and inspect mating interface.	Manned	Mating port interface must be inspected for any damage that may have occurred during the docking and to verify that all latches have engaged and are locked.
11	Prepare interface as required for pressurization of unmanned element.	Manned/ Unmanned	Hardware/subsystems (i.e., monitor/ control functions) of manned and/or unmanned element must be prepared for pressurization operations.
12	Pressurize unmanned element.	Manned/ Unmanned	To provide a shirtsleeve environment..
13	Isolate unmanned element and verify leak rate.	Manned/ Unmanned	Leak rate must be within tolerance that can be supported.
14	Verify the unmanned element atmosphere is compatible with the manned element atmosphere.	Manned	Prior to opening the hatch to the unmanned element the atmosphere in the unmanned element must be verified to be free of contamination.
15	Equalize pressure in unmanned element to that of manned element.	Manned	The pressure between the two elements must be equalized prior to opening the final interface hatch.
16	Open hatch between tunnel and unmanned element.	Manned/ Unmanned	

OPERATIONAL PROCEDURE NO. 5-1

Operation		Performed by:	Rationale
17	Connect and activate air circulation ducts.	Manned/ Unmanned	Air circulation is required for shirt-sleeve operations.
18	Ingress unmanned element and perform initial inspection.	Unmanned	Initial inspection will be made prior to performing subsequent operations.
19	Position tunnel crew restraint devices.	Manned/ Unmanned	Restraint devices must be positioned for crew stabilization during interface connection and verification operations.
20	Connect electrical interfaces, as required.	Manned/ Unmanned	
21	Verify interface connector mate.	Manned/ Unmanned	Connector mate integrity must be verified prior to applying power other than continuity check current.
22	Checkout and activate electrical interface	Manned/ Unmanned	
23	Connect plumbed interface and verify seal integrity, as required.	Manned/ Unmanned	Prior to activation, plumbed interfaces will be tested for seal integrity.
24	Activate fluid interfaces as required.	Manned/ Unmanned	
25	Activate subsystems necessary for crew habitability.	Unmanned	To support crew operations in unmanned element, e.g., direct worksite lighting, ECS trim.
26	Crewman traverse to unmanned element worksite.	Unmanned	

OPERATIONAL PROCEDURE NO. 5-1

	Operation	Performed by:	Rationale
27	Adjust worksite crew restraint devices.	Unmanned	Restraint devices must be positioned for crew stabilization for performing tasks at worksite.
28	Perform work tasks as required.	Unmanned	
29	Crewman release himself from worksite crew restraint devices and return to tunnel/airlock.	Unmanned	
30	Operations 26 through 29 can be repeated as required.	Unmanned	
31	Deactivate subsystems necessary for crew habitability.	Unmanned	Subsystems support to crew operations in unmanned element are no longer necessary.
32	Disconnect plumbed interfaces.	Manned/ Unmanned	Plumbed interfaces are no longer necessary and must be disconnected prior to closing hatch.
33	Disconnect electrical interfaces.	Manned/ Unmanned	Electrical interfaces are no longer necessary and must be disconnected prior to closing hatch.
34	Disconnect air circulation ducts.	Manned/ Unmanned	Air circulation ducts are no longer necessary since shirtsleeve crew operations in unmanned element have terminated and must be disconnected prior to closing hatch.
35	Verify all equipment is in airlock and hatchways are clear.	Manned/ Unmanned	All equipment will be returned to airlock, and hatchways must be clear prior to closing hatches.

OPERATIONAL PROCEDURE NO. 5-1

	Operation	Performed by:	Rationale
36	Close hatch between unmanned element and tunnel.	Manned/ Unmanned	
37	Close hatch between EOS tunnel.	Manned	
38	Depressurize tunnel.	Manned	Tunnel depressurization is required for confirming hatch sealing and preparation for element separation.
39	Confirm EOS and unmanned element sealing.	Manned	Leak rates must be checked to verify pressure sealing.
40	Deactivate crew transfer control link/subsystems of unmanned element as required.	Manned	Unmanned element subsystems which support crew operations can be deactivated.
41	Deactivate hatchway controls/displays.	Manned	The hatchway controls/ displays are no longer necessary and can be deactivated with termination of crew transfer operations.

Operational Procedure No. 5-2

Crew Transfer - IVA

Assumptions

1. Airlock is provided as an interface between elements.
2. IVA operations will utilize 3.7 psig umbilically supported pressure suits. The 3.7 suit will show the worse case IVA operations, i.e., utilizing suits of 8.0 and above psig will eliminate equipment and operations required for pre-breathing.
3. Permanently installed lighting is provided along transfer routes and at worksite(s). Portable lighting may be used for some operations but is not recommended.
4. A second crewman will be employed as a backup.

Initial Conditions

1. EOS orbiter has mated with an unmanned Modular Space Station (MSS).
2. Hard mating operations of elements have been completed.
3. Mobility aids and restraint devices are prepositioned along transfer path and at worksites.

Final Conditions

Elements are in a condition for separation.

Description

IVA crew transfer includes those operations associated with pressure suit IVA movement from an airlock of one element to a worksite of the other element to perform a required task and returning. This would include such operations as:

1. Activation of airlock/hatchway controls and displays.
2. Activation and checkout of unmanned element.
3. Donning of suits, pre-breathing, and performing depressurization operations and checkout.
4. Transfer to worksite and perform required tasks.
5. Return to airlock and perform pressurization operations.
6. Deactivation of unmanned element subsystems.
7. Removal and service of suits, and deactivation of airlock/hatchway controls and displays.

OPERATIONAL PROCEDURE NO. 5-2

TITLE: CREW TRANSFER - IVA

ELEMENT INTERFACES: EOS ORBITER (MANNED)/MSS (UNMANNED)

	Operation	Performed by:	Rationale
1	Activate airlock and hatchway controls/displays.	Manned	Airlock and hatchway controls/displays will be utilized for checkout of unmanned element and for monitoring and controlling depressurization/pressurization operations.
2	Activate and verify airlock communication subsystem.	Manned	Continuous communication with manned element control center/flight station is required.
3	Verify data link to unmanned element.	Manned	Manned element control of unmanned element subsystems, e.g., for radiation level monitoring, is required.
4	Activate lighting in unmanned element.	Manned	Adequate illumination is required for visual/TV checkout of unmanned element.
5	Confirm interface passageway is accessible for crew transfer operations.	Manned	Transfer passageway must be free of obstructions which would inhibit crew movement.
6	Verify environmental contamination levels in unmanned element are within limits.	Manned	Contamination levels in unmanned must be checked to indicate possible danger to IVA crewmen.
7	Deactivate lighting in unmanned element.	Manned	Since the unmanned element has been visually checked out and pre-breathing operations may take as long as 3 hours, lighting in unmanned element can be deactivated to conserve power.

OPERATIONAL PROCEDURE NO. 5-2

	Operation	Performed by:	Rationale
8	Don face masks and initiate pre-breathing.	Manned	3.7 psig space suits require crew to pre-breathe oxygen for a sufficient length of time to accomplish denitrogenation.
9	Primary and backup crewmen unstow and don IVA space suits excluding helmets and gloves.	Manned	
10	Checkout and prepare IVA equipment.	Manned	All equipment used in the IVA operation will be checked out prior to use and all crew transfer equipment stowed outside of airlock must be brought into airlock.
11	Enter airlock.	Manned	
12	Activate lighting in unmanned element.	Manned	Lighting in unmanned element must be reactivated for crew transfer so that crew positioning capabilities and visual orientation are not inhibited.
13	Close airlock hatch.	Manned	
14	Terminate pre-breathing and don helmets and gloves.	Manned	Pre-breathing masks must be removed and helmets and gloves donned so that crewmen are entirely supported by umbilicals from airlock subsystems.
15	Perform space suit operation and integrity checks.	Manned	Prior to depressurization, integrity of space suit sealing, communications, coolant flow, etc., must be verified.
16	Depressurize airlock.	Manned	

OPERATIONAL PROCEDURE NO. 5-2

Operation		Performed by:	Rationale
17	Confirm operation of space suit systems.	Manned	Operation of space suits must be confirmed in depressurized airlock prior to opening hatch.
18	Equalize pressure between tunnel and airlock.	Manned	Any pressure difference between tunnel and airlock must be equalized prior to opening hatch.
19	Open airlock hatch to tunnel and inspect mating interface.	Manned	Mating port interface must be inspected for any damage that may have occurred during the docking and to verify that all latches have engaged and are locked.
20	Equalize pressure between tunnel and unmanned element.	Manned/ Unmanned	Must be accomplished prior to opening final interface hatch.
21	Open hatch between tunnel and unmanned element.	Manned/ Unmanned	
22	Ingress unmanned element and perform initial inspection.	Unmanned	Initial inspection will be made prior to performing subsequent operations.
23	Position tunnel crew restraint devices.	Manned/ Unmanned	Restraint devices must be positioned for crew stabilization during interface convection and verification operations.
24	Connect electrical interface as required.	Manned/ Unmanned	
25	Verify interface connector mate.	Manned/ Unmanned	Connector mate integrity must be verified prior to applying power other than continuity check current.

OPERATIONAL PROCEDURE NO. 5-2

Operation		Performed by:	Rationale
26	Checkout electrical interface as required.	Manned/ Unmanned	
27	Connect plumbed interface and verify seal integrity as required.	Manned/ Unmanned	Prior to activation, plumbed interfaces will be purged for seal integrity.
28	Activate fluid interfaces as required.	Manned/ Unmanned	
29	Primary IVA crewman traverse to unmanned element worksite.	Unmanned	
30	Backup IVA crewman monitor IVA operation and control primary crewman umbilical.	Manned/ Unmanned	IVA crewman will playout/retrieve primary crewman umbilical to ensure against entanglement, and be available for rescue operations.
31	Adjust worksite crew restraint devices.	Unmanned	Restraint devices must be positioned for crew stabilization for performing tasks at worksite.
32	Perform work tasks as required.	Unmanned	
33	Crewman release himself from work-site crew restraint devices and return to tunnel/airlock.	Unmanned	
34	Operations 29 through 33 can be repeated as required.	Unmanned	
35	Disconnect plumbed interfaces.	Manned/ Unmanned	Plumbed interfaces are no longer necessary and must be disconnected prior to closing hatch.

OPERATIONAL PROCEDURE NO. 5-2

	Operation	Performed by:	Rationale
36	Disconnect electrical interfaces.	Manned/ Unmanned	Electrical interfaces are no longer necessary and must be disconnected prior to closing hatch.
37	Verify all IVA equipment is in airlock and hatchways are clear.	Manned/ Unmanned	All equipment will be returned to airlock, and hatchways must be clear prior to closing hatches.
38	Close hatch between unmanned element and tunnel.	Manned/ Unmanned	
39	Close hatch between airlock and tunnel and prepare for repressurization.	Manned	
40	Repressurize airlock and verify.	Manned	Airlock integrity will be verified during and subsequent to repressurization.
41	Deactivate crew transfer control link/subsystems of unmanned element as required.	Manned	The control link/subsystems of unmanned element that are no longer necessary can be deactivated.
42	Equalize pressure between airlock and manned element.	Manned	Must be accomplished prior to opening hatch.
43	Open hatch between airlock and manned element.	Manned	
44	Remove space suits, and service and stow all IVA equipment.	Manned	
45	Deactivate airlock and hatchway controls/displays.	Manned	The airlock and hatchway controls/displays are no longer necessary and can be deactivated with termination of IVA operations.

2.5.2 PROCEDURES APPLICABILITY

Figure 2.5-2 presents the crew transfer procedure applicability for each of the element-to-element interfaces. The matrix indicates where shirtsleeve and IVA operational procedures apply for manned-to-unmanned and manned-to-manned interfaces. In general, all manned-to-unmanned element crew transfer applicable interfaces with an airlock will accommodate both shirtsleeve and IVA transfer operations; those interfaces without an airlock can only accommodate the shirtsleeve mode. All manned-to-manned crew transfer applicable interfaces will have the shirtsleeve crew transfer operational procedure apply.

		SPACE PROGRAM ELEMENTS																
		EOS	TUG		RAM				SATELLITE			EO RESUP. MODS	LOW EO MSS	CPS		RNS CLS	OLS	OPD
			RTN	SPACE BASED	ATT. EOS	DET. EOS	ATT. MSS	DET. MSS	EOS DELIV.	EOS + 3RD ST DELIV.	RETR, RESUP.			OIS	CLS			
	EOS	1 *	NA	1,2	1,2	1,2	NA	NA	NA	NA	NA	1,2	1,2		1,2	1,2	1,2	1,2
TUG	RETURNABLE	NA								NA								
TUG	SPACE BASED	1		1,2 / 1			NA	NA		NA	NA	1,2	1,2	NA	1,2	1,2	1,2	1,2
RAM	ATT. EOS	1																
RAM	DET. EOS	NA																
RAM	ATT. MSS	NA		1									1 **					
RAM	DET. MSS	NA		NA									1 **					
SATEL	EOS DELIV.	NA																
SATEL	EOS + 3RD ST	NA	NA	NA														
SATEL	RETR, RESUP.	NA		NA														
	EO RESUP. MODS	NA		NA								NA / NA	1 **		NA	NA		NA
	LOW EO MSS	1		1			1	NA				NA	1** / 1					
CPS	OIS			NA											NA	NA	NA	NA
CPS	CLS	1		1								NA		NA	NA / NA		NA	NA
	RNS-CLS	1		1								NA		NA		NA / NA	NA	NA
	OLS	1		1										NA	NA	NA	1,2 / 1	
	OPD	1		1								NA		NA	NA	NA		NA / NA

LEGEND

- * - Assumed to always be a manned-to-manned interface
- ** - No airlock at interface
- 1 - Shirtsleeve
- 2 - IVA
- NA - Not Applicable

NOTES: Space Element Manning

(1) Upper/right half of chart:
One element assumed unmanned

(2) Lower/left half of chart:
Both elements assumed manned

Figure 2.5-2. Operational Procedures Applicability - Interface Activity: Crew Transfer

2.6 PROPELLANT TRANSFER

This section presents the operational procedures for propellant transfer, and includes one procedure for each alternate approach identified in Volume II of this report. Also presented and discussed is the applicability of these procedures to each element pair included in the in-depth analysis portion of the Orbital Operations Study.

2.6.1 OPERATIONAL PROCEDURES

Introduction

Essentially, two general procedures are indicated for delivery of propellants to elements in earth orbit. These are delivered by fluid transfer through propellant lines or by transfer of the propellant and its container (tank or module) as an integral unit. Any combination forms of delivery will still be based upon these two fundamental delivery procedures. Whichever method of transfer is used, the transfer may be made directly from a source element (e.g., orbiter tanker) to a user element (e.g., space-based tug). Other source and receiver elements and intermediate transfers to a depot may also be utilized to accomplish either of the two delivery procedures. The use of a depot can involve storage for later retransfer; if such transfer is by container, it may be transferred later to a user vehicle by modular transfer, or pumped through the depot to the user vehicle by fluid transfer.

Essential differences between the two delivery procedures involve basically the operations involved in transferring the propellant after initial mating of the two elements is accomplished. In fluid transfer, propellant and system lines are extended through the mating interface, controlled flow is implemented through ullage, pressurization, settling, chilling down, and filling operations. In modular transfer, a number of tank matings and separations may be involved, utilizing deployment mechanism operations and the use of a temporary tank holding port on one of the elements during the transfer procedure.

The procedures for direct fluid and module transfer from an orbiter tanker to a space-based tug are described in the following procedures, No. 6-1 and No. 6-2. Mating is a prerequisite to initiating propellant transfer, and communications during all transfer operations is a supporting procedure.

Operational Procedure NO. 6-1

Propellant Transfer - Direct Fluid Transfer - Orbiter Tanker To Space-Based Tug

1. Concept involves direct transfer of liquid hydrogen and oxygen propellants at low earth orbit from an Orbiter Tanker to a Space-Based Tug for refueling to continue performing its payload mission.

2. It is assumed that all activities and operations prior to actual propellant transfer operation have been made and both vehicles are ready for transfer.

3. It is assumed that the orbiter tanker will be the control center for all transfer operations involving either or both interfacing elements.

Initial Conditions

1. Mating between the space tug to be refueled and the orbiter tanker has been completed.

2. The orbiter is maintaining attitude hold and the tug is in free drift mode.

3. Rigidity and alignment of connections have been checked out.

Final Conditions

1. After completion of propellant transfer, the elements are ready to separate.

Description

1. This procedure commences after hard docking the vehicles and rigidizing with the docking fixtures. The docking interfaces are provided with line interconnect fixtures. A triangular moveable rack on the orbiter fixutre is extended toward the tug stationary fixture and indexing probes are engaged. The extension is continued until the electrical connectors on the fixtures are engaged. Then by means of line extension bellows, the propellant and system lines are extended and all connections verified for engagement and alignment. The operational sequence for propellant transfer may now be made and basically consists of transfer preparation and checkout, propellant settling (e.g., spinup), pressurization, purging and chilldown, transfer, transfer line draining, depressurization, spindown, checkout and secure. During these operations sensors monitor operation, controls initiate and terminate the sequences based on the sensor outputs, and appropriate

physical and operational means are provided for safety. Disengagement and separation take place after the transfer is completed and verified. Figure 2.6-1 shows a block flow diagram of the procedure involved.

2. The operational sequences for direct propellant transfer between other vehicles and between an OPD and a vehicle are basically the same, differing mainly in transfer time, rate of transfer and number of flights and refills required.

3. Operational Procedure Number 6-1 shows the detailed sequence of operations for direct fluid propellant transfer from a source element (orbiter) to a receiving element (tug), including the element performing the operation, the rationale for the operation, and the reference to the functional requirements supported by this operation.

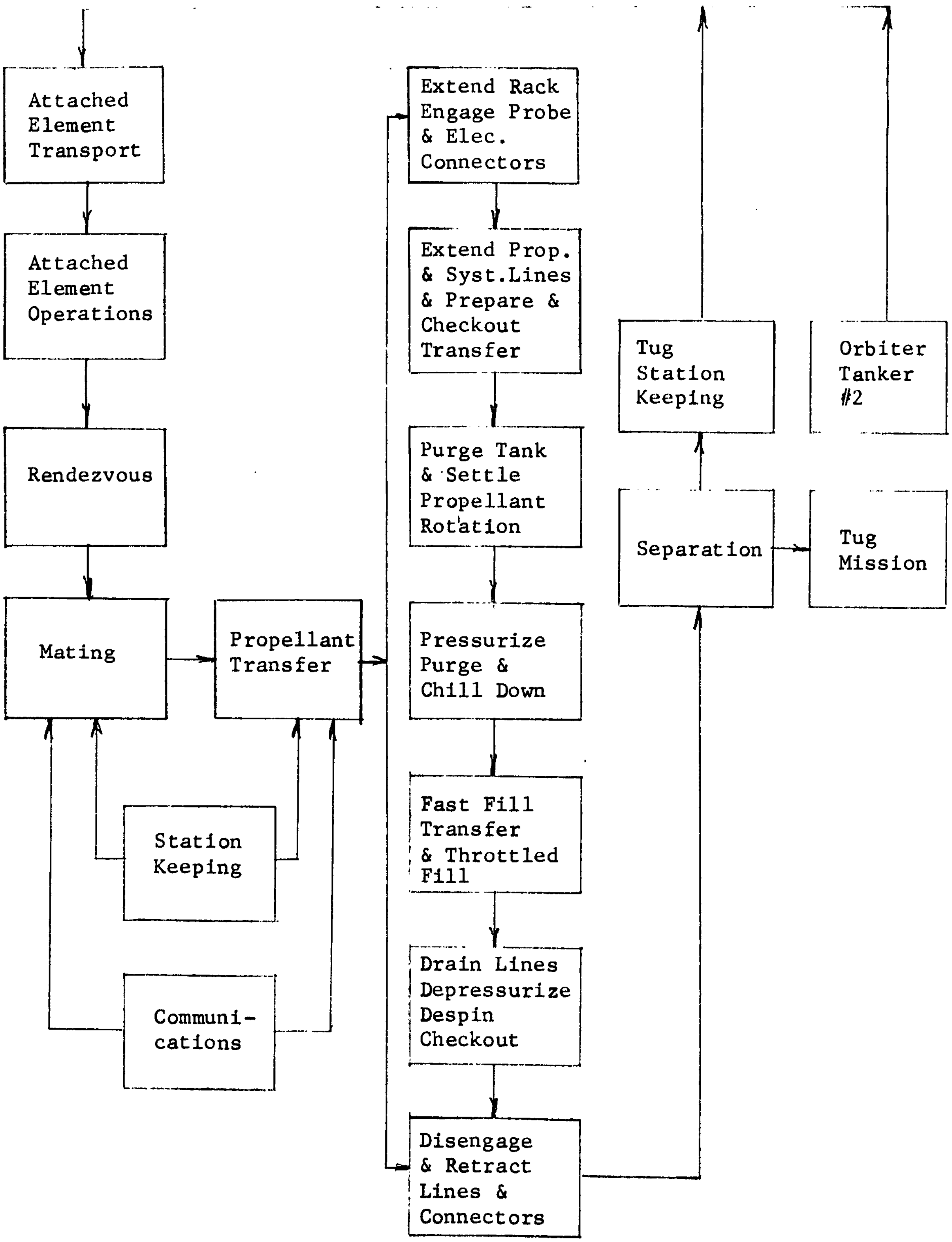

Figure 2.6-1. Block Diagram of Propellant Transfer Procedure
Direct Fluid Transfer--Orbiter Tanker to Space-Based Tug

OPERATIONAL PROCEDURE NO. 6-1

TITLE: PROPELLANT TRANSFER - DIRECT FLUID TRANSFER

ELEMENT INTERFACES: ORBITER TANKER TO SPACE-BASED TUG
(SOURCE ELEMENT) TO (RECEIVER ELEMENT)

	Operation	Performed by:	Rationale
1	Extend moveable line interconnect fixture (rack) and engage indexing probes	Source Element	To meet stationary rack on tug and for alignment by engaging tapered probes into tapered drogues, throughout mating interface.
2	Continue extension to engage electrical connectors	Source Element	Conduit encased electrical lines through the extension system make contact with receptacles on tug rack.
3	Extend propellant and system lines	Source Element	Separate LH_2 and LO_2 lines and non-propellant lines, insulated by panels in rack, are stretched by means of bellows to meet corresponding line receptacles on tug rack.
4	Rigidize interconnections and verify	Source Element	To prevent leakage or grounding, assure continuity.
5	Transfer preparation and checkout	Source Element	To prepare and checkout normal long time controls, checkout equipment, sensors, meters, and assure functional and safe readiness.
6	Purge propellant tank and lines	Source Element	To assure removal of any contamination and to clean lines before use
7	Initiate controlled acceleration (ullage)	Source Element	For ullage control to force propellant out of partially empty tank.

OPERATIONAL PROCEDURE NO. 6-1

Operation		Performed by:	Rationale
7a	By means of linear acceleration	Orbiter	
7b	By means of centrifugal (rotation) acceleration	Tug, OPD	
8	Verify propellants settled	Source Element	After acceleration, assure settling by means of cap probes and point sensors
9	Start propellant transfer cycle with pressurization and slow fill chill down.	Source Element	To assure appropriate pressure and temperature levels reached through slow transfer and monitoring.
9a	Set flow control valves for gas flow		To measure line and tug tank temperature and pressure
9b	Gas generator on, push gas propellant into orbiter tanker at slow rate		Increase in pressure forces liquid propellant to flow to tug tank; increased temperature creates more gas and more pressure.
9c	Regulate pressurant flow and measure ullage pressure		To monitor and maintain pressure level, by means of sensors, controls and/or venting to prevent rupture or flow stoppage
10	Initiate fast fill	Source Element	At appropriate pressure/temperature levels and operation normal, flow rate is increased to effective maximum.
11	Continue monitoring, control and regulation of flow	Source Element	To maintain normal operating conditions with fast fill, utilizing meters, cap probes and point sensors

OPERATIONAL PROCEDURE NO. 6-1

	Operation	Performed by:	Rationale
12	Throttle the fluid flow	Source Element	To slow down the flow prior to transfer termination, by flow control valves and measured by point sensors at tank outlet; when meter measurements show tug tank nearing fill
13	Terminate fluid flow with pump shutdown valve closure	Source Element	When tug tank is full or orbiter tanker is empty; flowmeters, cap probes and point sensors verify termination
14	Drain liquid from transfer lines by resettling valves for compressor gas propellant into transfer lines.	Source Element	To reduce propellant losses, assure safety from leakage and contamination
15	Purge compressor and transfer lines	Source Element	To assure safety from contamination
16	Depressurize the transfer system by turning gas generator off and venting valves	Source Element	To return pressure/temperature levels and operations to normal engine feed levels
17	Continue taking ullage pressure measurements	Source Element	To assure normal pressure/temperature levels
18	Discontinue acceleration for ullage control	Source Element	To return conditions to normal
19	Checkout post-transfer conditions	Source Element	Assure secure system

OPERATIONAL PROCEDURE NO. 6-1

Operation		Performed by:	Rationale
20	Disengage and retract propellant and system lines	Source Element	Preparatory to separation, moveable rack and interconnected lines return to orbiter rack receptacles
21	Monitor/measure open propellant lines and interface and vent/purge if necessary	Source Element	To assure safety from hazardous vapors around open lines and interface
22	Close meters, valves, sensors after final checkout	Source Element	Preparation to separation, to assure appropriate conditions for safe separation
23	Disengage and retract electrical connectors and moveable rack	Source Element	Preparatory to separation, return rack and electrical interconnectors to orbiter for end of transfer procedure

Operational Procedure No. 6-2

Propellant Transfer - Direct Modular Transfer - EOS Orbiter to Space-Based Tug

Assumptions

1. Concept involves direct modular transfer of liquid hydrogen and oxygen propellants at low earth orbit from an Orbiter to a Space-Based Tug for refueling to continue performing its payload mission.

2. It is assumed that all activities and operations prior to actual propellant transfer have been made and both vehicles are ready for the transfer.

3. It is assumed that the orbiter will be the control center for all transfer operations involving either or both interfacing elements.

4. It is assumed that a combination of manipulator arm and pivoting platform mechanisms are available for deployment and retrieval of the full and empty propellant module tanks to and from internal (cargo bay) or external attachments or holding ports on the orbiter and tug.

5. It is assumed that the propellant tank sets (modules) are equipped with compatible neuter docking mechanisms on both ends to facilitate multiple transfer maneuvers.

Initial Conditions

1. The tug must be coasting with empty tank set attached to the nose of the propulsion and control stage when the orbiter mates with it.

2. Rigidity and alignment of mating connections have been checked out.

Final Conditions

1. After completion of propellant module transfer the elements are ready to separate.

Description

1. This procedure commences after the vehicles rendezvous and maintain requisite attitude for mating and propellant module transfer. Orbiter maneuvers to place its docking mechanism directly opposite that on the end of the tug empty tank set, then uses its manipulator arms to attach and mate the empty tank set to a temporary holding port. The elements separate with the orbiter holding the empty tank set on a temporary holding port. The orbiter then uses the pivoting platform to deploy the full tank set from the cargo bay and maneuvers to place it in docking position to tug. The manipulator arms will detach from the empty tank set to attach to the tug and assist in alignment and mating of the full tank set to the tug. The orbiter

separates again and attaches the manipulator arms to the empty tank set, then maneuvers to mate the empty tank set on the orbiter temporary port to the full tank set on tug and the orbiter separates leaving both tanks attached to the tug. Now the orbiter maneuvers to bring the pivoting mechanism in line with and to mate with the empty tank set on tug. After this mating operation, the orbiter separates with the empty tank set and retracts the pivoting platform to stow the empty tank set into the cargo bay, leaving the tug with the full tank set to proceed on its mission or to stationkeep while awaiting a second propellant module transfer. Figure 2.6-2 shows a block diagram of the procedures involved.

2. The operational sequences for direct propellant module transfer between other vehicles and between a depot and vehicle are basically the same, differing mainly in transfer time, rate of transfer, and number of flights and modules required.

3. Operational Procedure 6-2 shows the detailed sequence of operations for direct propellant module transfer from a source element (orbiter) to a receiving element (tug), including the element performing the operation, the rationale for the operation, and the reference to the functional requirements supported by this operation.

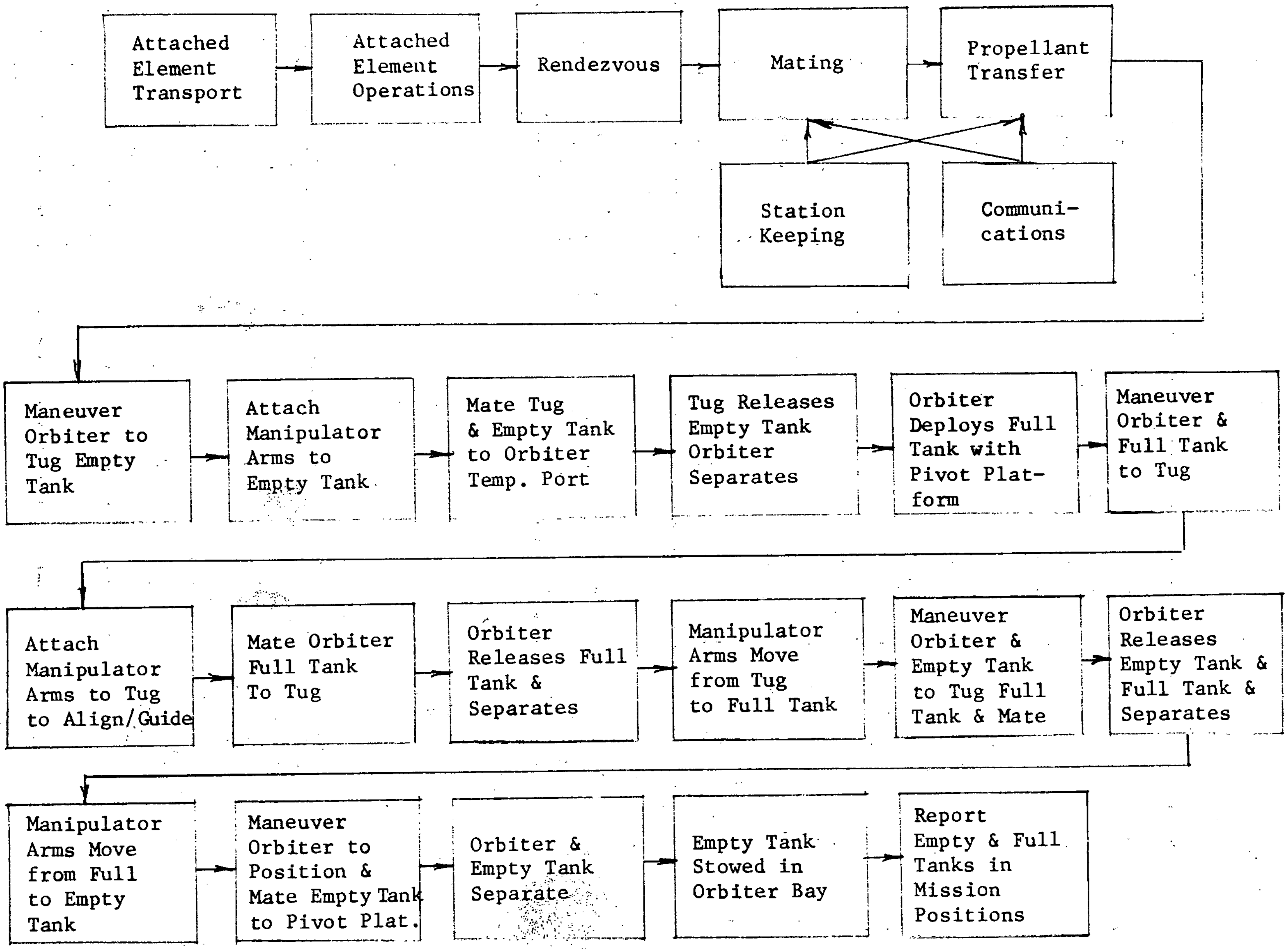

Figure 2.6-2. Block Diagram of Propellant Transfer Procedure
Direct Modular Transfer--EOS Orbiter to Space-Based Tug

OPERATIONAL PROCEDURE NO. 6-2

TITLE: PROPELLANT TRANSFER--DIRECT MODULAR TRANSFER

ELEMENT INTERFACES: EOS ORBITER TO SPACE-BASED TUG (SOURCE ELEMENT) TO (RECEIVER ELEMENT)

	Operation	Performed by:	Rationale
1	Maneuver orbiter to tug empty tank	Source Element	To line up docking mechanism of orbiter temporary holding port directly opposite docking mechanism of exposed end of empty tank set
2	Activate manipulator control station and attach manipulator arms to tug empty tank	Source Element	To prepare for mating the tug empty tank set to orbiter temporary holding port
3	Mate tug and empty tank set to orbiter temporary holding port	Source Element	Empty tank set remains attached to tug and mated to temporary holding port
4	Verify attachment of empty tank set	Source Element	To assure that empty tank set will remain attached during maneuvers following
5	Command release of empty tank set	Source Element	To prepare for separation of tug and orbiter
6	Release empty tank set	Receiver Element	To allow separation
7	Maneuver for separation	Source Element	To separate short distance while manipulator helps hold empty tank set during maneuver
8	Report attachment of empty tank set and separation	Source Element	To inform mission control

OPERATIONAL PROCEDURE NO. 6-2

	Operation	Performed by:	Rationale
9	Deploy full tank set	Source Element	Full tank set is deployed out of orbiter
10	Maneuver orbiter and full tank set to tug	Source Element	Orbiter translates until docking mechanism on full tank set is directly opposite that on tug
11	Attach manipulator arms to tug	Source Element	Manipulator arms are detached from empty tank set to attach to tug to assist in the alignment and guidance of the docking mechanisms and interconnect fixtures
12	Verify alignment of interconnectors	Source Element	To prevent subsequent damage to and/or malfunction of interconnectors when extended
13	Mate orbiter full tank set to tug	Source Element	Mating completed by engaging both docking mechanisms, keeping both interconnect fixtures aligned
14	Verify electrical grounding across physical interface	Source Element	Grounding needed to prevent static discharge near propellant feed lines
15	Report full tank mating to tug	Source Element	To inform mission control
16	Command engagement of electrical feed lines and venting of interconnectors	Source Element	Commands to tug and full tank set to extend and engage interconnectors and lines preparatory to propellant use
17	Release full tank set and separate	Source Element	Preparatory to separate short distance

OPERATIONAL PROCEDURE NO. 6-2

	Operation	Performed by:	Rationale
18	Detach manipulator arms from tug and attach to full tank set	Source Element	Preparatory to guiding a docking of full tank set with empty tank set
19	Maneuver to align docking mechanism of empty tank set on orbiter to that of full tank set on tug	Source Element	Maneuvering until docking mechanism of empty tank set on orbiter temporary holding port is directly opposite that of full tank set on tug to prepare for mating
20	Mate empty tank set to full tank set	Source Element	Mating with aid of manipulator arms to guide docking
21	Release empty tank set and separate	Source Element	To remove empty tank set from orbiter temporary holding port in preparation for separation to short distance
22	Detach manipulator arms from full tank set and attach to empty tank set	Source Element	Preparatory to separation of empty tank set and mating to orbiter
23	Maneuver to align docking mechanism of empty tank set directly opposite that or orbiter pivoting platform	Source Element	Maneuvering to get docking mechanisms opposite each other to prepare for mating
24	Mate empty tank set to orbiter pivoting platform	Source Element	Mating with aid of manipulator to guide alignment for mating

OPERATIONAL PROCEDURE NO. 6-2

	Operation	Performed by:	Rationale
25	Command release of docking mechanism between full and empty tank sets	Source Element	Preparatory to separation
26	Separate empty tank from full tank set	Source Element	Move away safe distance from tug and full tank set
27	Stow empty tank set in orbiter bay	Source Element	To place empty tank set in position for deorbit
28	Report empty and full tank sets in position	Source and Receiver Elements	Mission control informed that both tanks are in readiness position for respective tug and orbiter missions

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North American Rockwell

2.6.2 PROCEDURES APPLICABILITY

Figure 2.6-3 summarizes the procedures developed for each of the two alternate approaches for propellant transfer. The two procedures have essentially nothing in common other than the initial operation of mating the tanker (supplier) to the user element. The fluid transfer procedure involves the unique operations of connecting fluid lines between the elements, providing the ullage force, transferring the propellants through lines and terminating fluid transfer operations. The modular transfer procedure involves a series of matings, separations, and maneuvers related to the handling of the module.

Figure 2.6-4 presents in matrix format the procedures applicable to the interfacing elements in the space vehicle inventory. Moving to the right in the upper half of the figure is the list of potential recipients of large quantities of propellant, supplied by one of the elements in the vertical list. Moving downward in the bottom half of the figure is the list of potential suppliers of large quantities of propellant to one of the elements in the horizontal list. Of the 17 elements listed, at least 4 are potential suppliers and/or recipients of large quantities of propellants. Recipients include the space-based propulsive vehicles (space-based tug, CPS/CLS, RNS) and the OPD. Suppliers include the EOS orbiter, space-based tug, earth orbit resupply module, and OPD. The OPD and the space-based tug may act either as supplier or receiver of propellant.

Within each coordinate box in the matrix an entry is shown, indicating the applicable propellant transfer procedure for the pair of interfacing elements involved. Of 14 interfacing element pair interactions identified for propellant transfer, the 4 involving the EO resupply module (acting only as a supplier to space-based tug, CPS/CLS, RNS and OPD) may be serviced only by a direct fluid transfer procedure (Procedure Number 6-1). The other 10 element pairs may be serviced by either a direct fluid transfer (Procedure Number 6-1) or by a direct modular transfer procedure (Procedure Number 6-2), of which 7 will involve tanker delivery (4 by EOS orbiter, 3 by space-based tug), while 3 will involve transfer from an OPD.

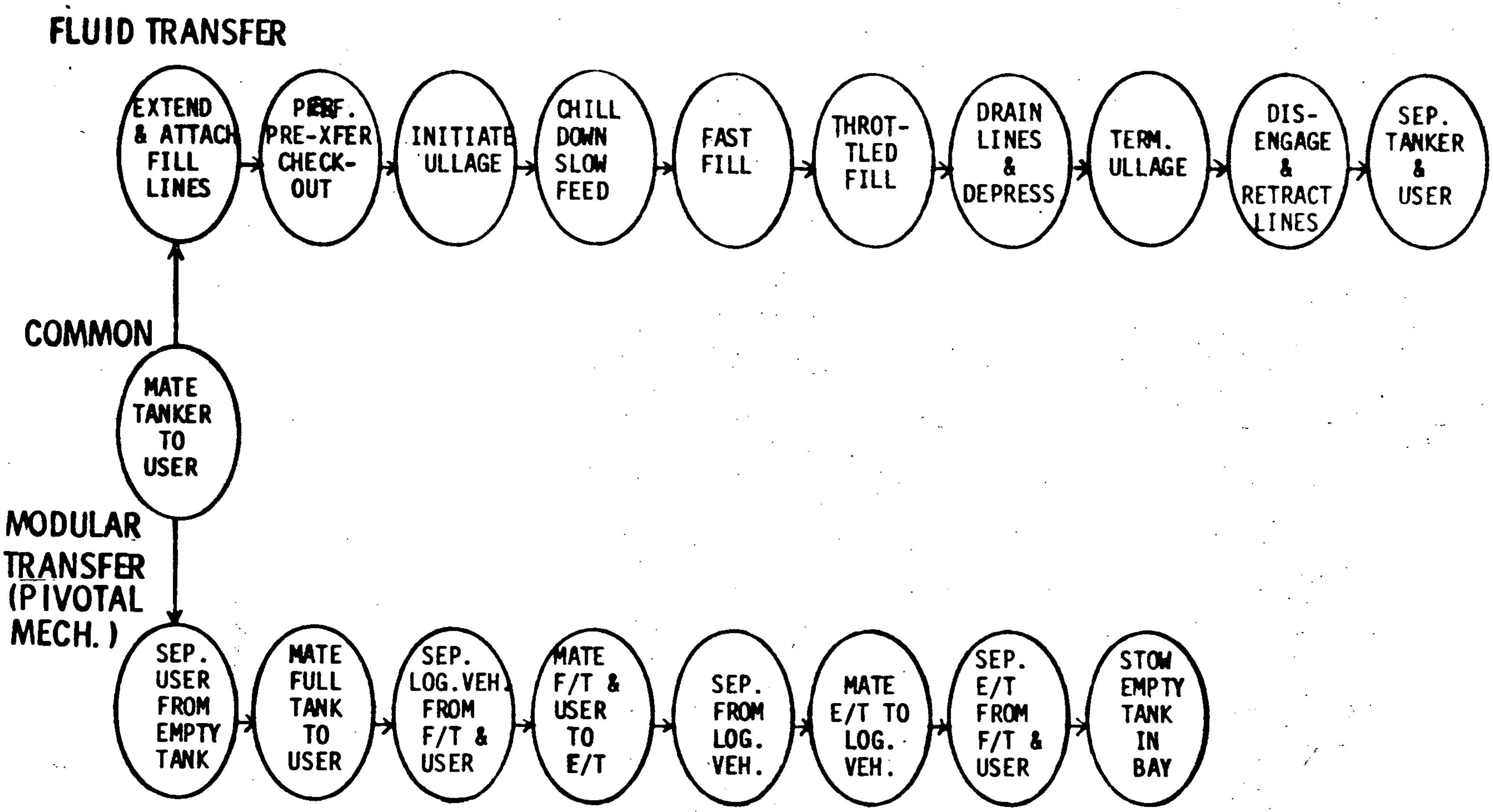

Figure 2.6-3. Propellant Transfer Procedural Comparison

SUPPLIER \ RECEIVER		SPACE PROGRAM ELEMENTS																
		EOS	TUG		RAM				SATELLITE			EO RESUP. MODS	LOW EO MSS	CPS		RNS CLS	OLS	OPD
			RTN	SPACE BASED	ATT. EOS	DET. EOS	ATT. MSS	DET. MSS	EOS DELIV.	EOS + 3RD ST DELIV.	RETR, RESUP.			OIS	CLS			
	EOS	NA	NA	1,2	NA	NA	NA	NA	NA	NA	NA	NA	NA		1,2	1,2	NA	1,2
TUG	RETURNABLE	NA								NA								
TUG	SPACE BASED	NA		NA			NA	NA		NA	NA	NA	NA	NA	1,2	1,2	NA	1,2
RAM	ATT. EOS	NA																
RAM	DET. EOS	NA																
RAM	ATT. MSS	NA		NA									NA					
RAM	DET. MSS	NA		NA									NA					
SATEL	EOS DELIV.	NA																
SATEL	EOS + 3RD ST	NA		NA														
SATEL	RETR, RESUP.	NA		NA														
	EO RESUP. MODS	NA		1								NA	NA		1	1		1
	LOW EO MSS	NA		NA			NA	NA				NA	NA					
CPS	OIS			NA											NA	NA	NA	NA
CPS	CLS	NA		NA								NA		NA	NA		NA	NA
	RNS-CLS	NA		NA								NA		NA		NA	NA	NA
	OLS	NA		NA										NA	NA	NA	NA	
	OPD	NA		1,2								NA		NA	1,2	1,2		NA

LEGEND

NA - Not Applicable

Figure 2.6-4. Operational Procedures Applicability - Interface Activity: Propellant Transfer

2.7 EOS PAYLOAD DEPLOYMENT

This section presents the operational procedures for EOS Payload Deployment, and includes one procedure for each alternate approach identified in Volume II of this report. Also presented and discussed is the applicability of these procedures to each element pair included in the in-depth analysis portion of the Orbital Operations Study.

2.7.1 OPERATIONAL PROCEDURES

Two operational procedures were developed for EOS payload deployment, one for each of the conceptual approaches. Procedure number 7-1 applies to the EOS equipped with a manipulator. Procedure number 7-2, is applicable to the EOS with a pivoting mechanism in the cargo bay.

Assumptions

The following major assumptions were used in developing the operational procedures. The second assumption applies to the manipulator concept only:

(a) Solar illumination not available or inadequate. The procedure was developed with contingencies being planned to handle the situation when either insufficient solar illumination existed or the procedure was required during the night part of an orbit.

(b) Second manipulator arm for backup only. The EOS models utilized in the development of this procedure had a manipulator concept with two arms. All procedural steps were designed capable of being accomplished with a single failure. Each manipulator arm was considered to be a single failure. Therefore, the assumption was made that the operations would be developed with the second arm being considered for backup only.

Initial Conditions

The following initial conditions are applicable to both procedures.

(a) Communication and data links have been established between the EOS and any program element that the payload is being delivered to.

(b) The final phases of rendezvous are completed. The procedure is subsequent to rendezvous of the shuttle to the system receiving the payload or after specific payload deployment position (attitude, inclination) has been acquired.

(c) The EOS cargo bay doors are open to permit active thermal control via door mounted radiators.

Final Conditions

The following two major final conditions apply to both procedures.

(a) Payload separation complete on a manner that does not preclude retrieval of the payload just released or a subsequent payload. Separation of plumbing and wiring connections shall leave them in a state such that they can be reused. Some missions require retrieval of the same payload as deployed on that mission (e.g., ground based tug missions). In these cases, hardware communication links and propellant purge and vent lines would be reconnected.

(b) Verification of payload operational status--after the release of the payload and prior to the EOS return to Earth the EOS will have to utilize communication links and possible visual observation to determine the operational status of the payload.

Description of Procedures

The procedures for EOS Payload Deployment were written utilizing two approaches. Each of these approaches is developed with one of selected alternatives; manipulation (procedure 7-1) and the pivot mechanism (procedure 7-2). Both procedural approaches have operations that potentially involve other interfacing activities (mating [2.1] attached element operations [2.12] and separation [2.3]). These interfaces were handled by reference only. The following two sections are descriptions of each procedure.

A. Procedure No. 7-1 (Manipulator Approach)

This procedure contains 30 operations that commence with activation of the manipulator subsystems through the stowing of the manipulator and the deactivation of the subsystem. There are three BY-PASSES (see Figure 2.7-1 in the logic flow. These By-Passes relate to the adapter and are utilized if the intention of the mission is strictly payload deployment without a requirement for crew ingress. The charts that follow the flow diagram contain remarks and rationale relating to each operations step of the procedure. The procedure was written to handle all activities associated with deployment of EOS cargo bay compatible payloads. It also has a recycle feature designed to the payload to facilitate the missions that involve multiple payload deployments.

B. Procedure No. 7-2 (Pivot Mechanism)

This procedure (7-2) contains 9 operations that commence with reading the cargo bay for deployment through the securring of the pivot mechanism for Earth return. As in the procedure that was developed for the manipulator approach this procedure contains a By-Pass that is utilized if no crew ingress is required prior to deployment. It also contains a recycling to allow for multiple deployments. A description of the remarks and rationale for each operation of the procedure is contained on the pages that follow the flow diagram, Figure 2.7-2.

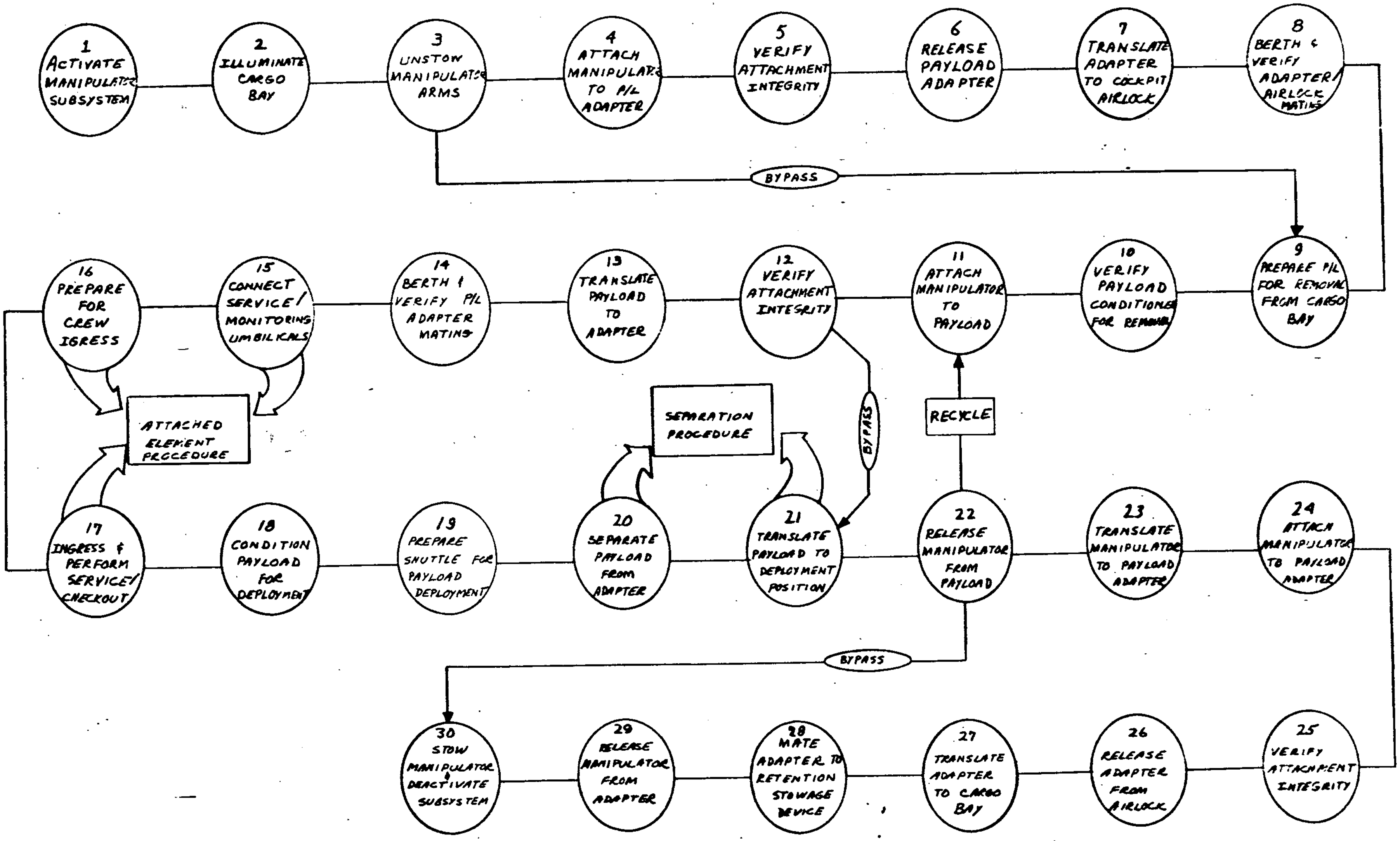

Figure 2.7-1. Description of Procedure No. 7-1
EOS Payload Deployment (Manipulator Approach)

OPERATIONAL PROCEDURE NO. 7-1

TITLE: EOS PAYLOAD DEPLOYMENT - MANIPULATOR

ELEMENT INTERFACES: EOS Orbiter, with Manipulator (Active)/Payload (Passive)

Operation		Performed by:	Rationale
0	Initial Conditions	EOS	This procedure is subsequent to rendezvous of the shuttle to the system receiving the payload or after the specific payload deployment position (altitude, inclination) has been acquired. The EOS cargo bay doors are open to permit active thermal control via door-mounted radiators. Communication links required have been secured.
1	Activate manipulator subsystem	EOS	A control center in the crew compartment must be brought to an operational status from either a powered-down or a standby mode. Dependent upon the type of payload and degree of automation, either a manual or preprogrammed mode may be selected. The manipulator arm and its effector end are in a stowed position to prevent damage to the manipulator and/or the payloads. Therefore, this activation does not include physical movement of the arm. However, TV, floodlight and force feedback sensors will provide verification of arm activation.

OPERATIONAL PROCEDURE NO. 7-1

	Operation	Performed by:	Rationale
2	Illuminate cargo bay	EOS	This is a precursor to subsequent activities and required to allow TV coverage of the cargo bay activities. The shuttle can maneuver to a sunlight orientation of cargo bay, or floodlights may be employed.
3	Unstow manipulator arm	EOS	Captive latches can be released via a hardwire signal from the control center. However, a manual force override is required for contingency to prevent a single failure from discontinuation of the retrieval operation. The physical movement of the shoulder, wrist, extension, and effector end can now be verified. TV coverage via cargo bay and direct visual can be employed.
4	Attach manipulator to payload adapter	EOS	Certain payloads may require an adaptor to provide either reach or interface compatibilities between the EOS airlock and the payload. The adapter is stowed in the cargo bay with its manipulator attachment points visible by either cargo bay TV, or direct from the crew compartment. This alternative viewing is required as a backup to the manipulator arm mounted TV. The effector end is physically engaged with either of the redundant attachment points.

OPERATIONAL PROCEDURE NO. 7-1

Operation		Performed by:	Rationale
5	Verify attachment integrity	EOS	The manipulator arm applies the simulated normal operations forces to the interface prior to release of the retention mechanism. Visual and touch sensor feedback to the control centers are required to verify the integrity of the interface connection.
6	Release payload adapter	EOS	Captive latches can be released via a hardwire signal from the control center. However, a manual release must be provided for contingency. If the force requirement for pullaway (must exceed that of step 5 and the launch forces) exceeds practical manipulator design, an alternate procedure must be employed either using the redundant manipulator arm or EVA.
7	Translate adapter to cockput airlock	EOS	After release the adapter is translated to a position in direct alignment with the airlock. If a cooperative arm mode is utilized, arm #2 can enhance the operation by providing illumination and TV coverage. In addition the mating interfaces can be inspected and capture latches armed. In the single arm mode the inspection and latch arming (if required) would be sequenced prior to step 4.

OPERATIONAL PROCEDURE NO. 7-1

Operation		Performed by:	Rationale
8	Berth and verify adapter/airlock mating	EOS	The mating velocity is imparted to the adapter via the manipulator and physical contact acquired. Verification of the mating is required prior to release of the manipulator arm. A force is applied to test the interface with TV and touch sensor feedback sent to the control center for verification. Dependent upon the design concept, additional rigidizing of the interface may be required. This rigidizing can be accomplished externally with the manipulator or internally. Release of the manipulator from the adapter can be sequenced at this point or just prior to step 11. Failure to release the manipulator can result in mission discontinuation, therefore alternative procedures must be employed.
9	Prepare payload for removal from cargo bay	EOS	Monitoring and service umbilicals must be disconnected and deadfaced. Subsystem equipment may require activation (thermal control, electrical power) or change in operational state.
10	Verify payload conditioned for removal	EOS	TV inspection and illumination required to assure all physical attachments removed from payload. The payload retention/stowage mechanism may be required to erect to a predetermined position to provide cargo bay clearance.

OPERATIONAL PROCEDURE NO. 7-1

	Operation	Performed by:	Rationale
11	Attach manipulator to payload	EOS	The effector end is extended to engage one of the redundant attachment points. Illumination and TV coverage can be supplied by the manipulator. However, the shuttle and payload can be positioned to enable sun illumination and direct visual as a contingency mode. A second manipulator arm also can be employed as a backup.
12	Verify attachment integrity	EOS	After engagement of the effector end with the payload attachment point, the manipulator provides forces equal to the subsequent translation maneuver's magnitude to verify attachment. The forces are applied in a direction that will not lead to shuttle impact if the attachment is not fully secured. Visual and touch sensor feedback are provided to the control center.
13	Translate payload to adapter	EOS	The payload is translated within close proximity to the EOS with the berthing port aligned with the airlock. If either of the two berthing interfaces require cocking of capture latches, the cocking will be accomplished by the manipulator at step 10. The latch cocking, if required, can also be accomplished via the redundant manipulator arm at this step.

OPERATIONAL PROCEDURE NO. 7-1

	Operation	Performed by:	Rationale
14	Berth and verify payload/adapter mating	EOS	The mating velocity is imparted to the payload via the manipulator and physical contact acquired. Verification of the mating is required prior to release of the manipulator arm. A force is applied to test the interface with TV and touch sensor feedback to the control center. Dependent upon the design concept, additional rigidizing of the interface may be required.
15	Connect service/monitoring umbilicals	EOS	The connection of umbilicals will be accomplished either shirtsleeve or IVA via the cockpit airlock. The shirt-sleeve case will require the adapter to be pressurized and equalized before the airlock external hatch is opened.
16	Prepare for crew ingress to payload	EOS	The operational activities associated with this step are detailed in the Attached Element Operation procedure. Briefly, the following types of activities are required: (a) sense payload atmosphere (toxic, humidity, temperature, pressure, etc.); (b) dump, purge, pressurize, equalize pressure; (c) open hatches, verify latches, rigidize; (d) connect IVA umbilicals and communication/instrumentation lines.
17	Ingress and perform service/checkout	EOS	The operational activities associated with this step are detailed in the Attached Element Operations procedure.

OPERATIONAL PROCEDURE NO. 7-1

	Operation	Performed by:	Rationale
18	Condition payload for deployment	EOS	Subsystem equipment must be placed in their operational status. Appendages such as solar arrays, antennas, and airlocks require deployment. Protective covers must be removed from windows, airlocks and sensors.
19	Prepare shuttle for payload deployment	EOS	Selected subsystem and scientific sensor equipment are sensitive to contamination; therefore, the shuttle will be required to inhibit engine firing and manage the venting of effluents. The shuttle will be required to conduct orbital maneuvers to enable closed-loop check of orientation devices and attitude control.
20	Separate payload from adapter	EOS	This operational activity is detailed in the separation procedure. Failure of the release mechanism is a mission continuation hazard. For the payloads that do not require an adapter and are berthed to the airlock, failure of the release mechanism is a safety critical problem that can potentially prevent reentry. Alternate means of accomplishing the release must be provided.
21	Translate payload to deployment position	EOS	The deployment position for specific payloads is a function of: (a) external appendages, (b) sensitivity to solar orientation for arrays, sensors and thermal control, (c) minimizing propulsive impingement on either the payload or the shuttle, and (d) antenna view angles.

OPERATIONAL PROCEDURE NO. 7-1

	Operation	Performed by:	Rationale
22	Release manipulator from payload	EOS	Failure to release the effector end is a critical mission continuation failure; therefore, redundant means to effect the physical separation must be provided.
23	Translate manipulator to payload adapter	EOS	The payload adapter must be removed from the airlock prior to configuring the shuttle for earth return. The payload adapter can be returned to the cargo bay for reuse or left on-orbit. The MSS buildup currently plans for the adapter to be placed on the end of a module for subsequent shuttle revisits.
24	Attach manipulator to payload adapter	EOS	The adapter must be returned to the cargo bay for stowage. Any external rigidizing must be removed prior to engaging the effector end of the manipulator to either of the redundant attachment points.
25	Verify attachment integrity	EOS	Force is applied via the manipulator with TV and touch sensor feedback sent to the control center.
26	Release adapter from cockput airlock	EOS	Automatic release of capture mechanism is possible, however manual backup is required due to the criticality of a release failure.

OPERATIONAL PROCEDURE NO. 7-1

	Operation	Performed by:	Rationale
27	Translate adapter to cargo bay	EOS	The manipulator provides the translation positioning the adapter in line with its retention/stowage mechanism. Cargo bay illumination and TV coverage requiréd as a backup.
28	Mate adapter to retention/ stowage device	EOS	The mating velocity is imparted via the manipulator. If captive latches need cocking, the activity is performed prior to step 26 or by the redundant manipulator arm.
29	Release manipulator from payload adapter	EOS	Release of the effector end is accomplished only after verification of attachment integrity. Redundant means of release must be provided.
30	Stow manipulator and deactivate subsystem	EOS	The manipulator arms are physically restrained in the cargo bay to prevent damage and eliminate a hazard to the payload(s). The control center conducts a normal shutdown sequence after verification of stowage.

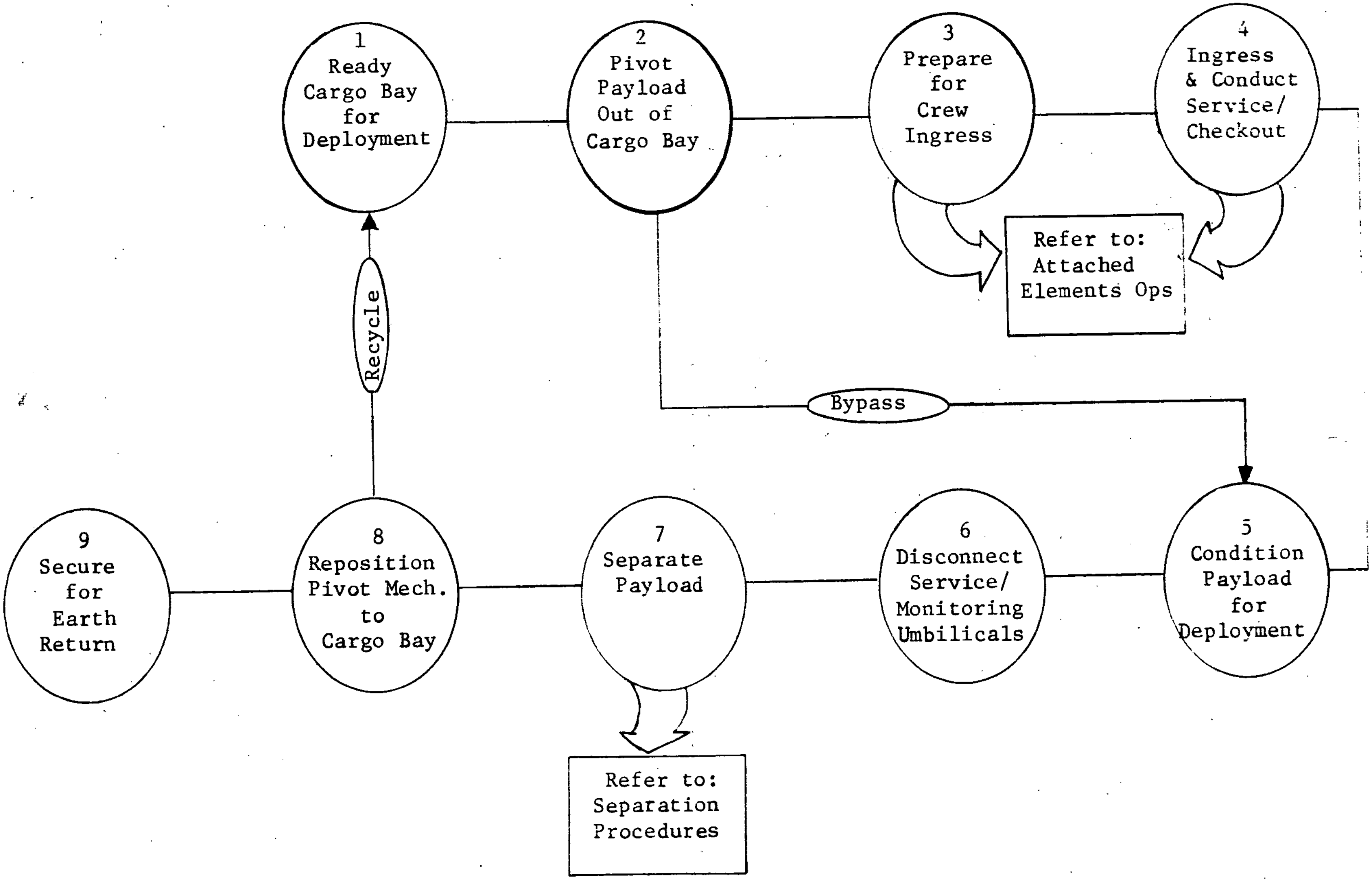

Figure 2.7-2. Description of Procedure No. 7-2
EOS Payload Deployment
(Pivot Mechanism Approach)

OPERATIONAL PROCEDURE NO. 7-2

TITLE: EOS PAYLOAD DEPLOYMENT--PIVOT MECHANISM

ELEMENT INTERFACES: EOS ORBITER, WITH PIVOT MECHANISM (ACTIVE/PAYLOAD (PASSIVE))

	Operation	Performed by:	Rationale
1.	Ready Cargo Bay for Payload Deployment	EOS	Multiple payloads may be installed in the cargo bay. Repositioning of one payload may be required prior to removing the payload to be deployed. The payload mating interface (pivot mechism) is secured in a stowed position to eliminate hazards from loads induced during launch and orbit insertion. Therefore, retention devices must be activated. The docking mechanism may require re-engagement. Disengagement may be required to preclude absorption of payload induced structural loads. A manual backup is required for all release operations to prevent a mission discontinuation.
2.	Pivot Payload Out of Cargo Bay	EOS	Current designs imploy an electrical motor to drive the erection mechanism. A manual means must also be provided as both a backup and an override. The payload is positioned 90 degrees maximum in pitch with minimum roll and yaw excursions.

OPERATIONAL PROCEDURE NO. 7-2

	Operation	Performed by:	Rationale
3.	Prepare for Crew Ingress	EOS	The operational activities associated with this step are detailed in the attached Elements Operations Procedure. Briefly the following types of activities are required: (a) sense payload atmosphere, (b) dump, purge, pressurize and equalize pressure, (c) open hatches. NOTE: Crew ingress is possible when the payload is stowed in the cargo bay and may have preceded this point in the procedure.
4.	Ingress and Perform Service/ Checkout	EOS	The operational activities associated with this step are detailed in the Attached Elements Procedure.
5.	Condition Payload for Deployment	EOS	Subsystem equipment must be placed in their operational state. Appendages such as solar arrays antenna, and airlocks require deployment. Protective covers must be removed from windows, airlocks and sensors. Selected subsystem and scientific equipment are sensitive to contamination and direct impingement of engines. Therefore, the EOS will be required to selectively inhibit engine firings and manage the venting of cabin effluents.

OPERATIONAL PROCEDURE NO. 7-2

	Operation	Performed by:	Rationale
			The EOS will be required to conduct orbital maneuvers to enable closed loop verification of orientation devices and attitude control prior to separation.
6.	Disconnect Service/Monitoring Umbilical	EOS	The complexity of the interface between EOS and respective payloads will vary. For the minimum complexity case automatic disconnect can be employed, however manual backup must also be provided.
7.	Separate Payload	EOS	The operational activities associated with this step are detailed in the separation procedure. Redundant means to effect physical separation must be provided.
8.	Reposition Pivot Mechanism to Cargo Bay	EOS	The 90 degree extended position detent or physical retention must be overcome. Alternate means must be provided to effect release. The movement of the payload interface to the cargo bay can be accomplished electrically or pheumatically, however, a manual means must be provided as both a backup and an override.
9.	Secure for Earth Return	EOS	All mechanisms must be passified and physical restraints engaged.

2.7.2 PROCEDURES APPLICABILITY

Three distinct types of commonality analyses will be reported in this paragraph. The first commonality is between EOS payload deployment and EOS payload retraction and stowage. The majority of EOS flights will perform both deployment and retraction on the same mission. A second commonality analysis was also conducted for both the manipulator and the pivot mechanism approaches. Some operational advantages were uncovered for each approach. The third commonality analysis to be reported is the applicability of the procedure(s) to the specific payload elements identified in the matrices. The combined deployment/retraction and stowage procedure developed as part of the first commonality analysis was used for this task.

A. EOS Payload Deployment/Retraction & Stowage Commonality

Both scheduled and unscheduled activities were investigated for examples where the deployment and retraction of EOS payload is required as part of the same mission. The following briefly shows some of the substantiating examples that drove the combination of the two interfacing activity procedures.

1. Scheduled Activities
   a. Module Exchange

      Examples (1) MSS cargo module exchange
      (2) MSS power module exchange
      (3) OPD propellant module exchange

   b. Element Replacement

      Examples (1) TDRS replacement
      (2) Space based tug replacement

   c. Routine Service

      Examples (1) Detached RAM resupply
      (2) Tug resupply

   d. Multiple Elements

      Example (1) Deploy MSS module and retrieve a satellite

2. Unscheduled Activities

   a. Rescue

      Examples (1) EOS rescue
      (2) MSS rescue

   b. Maintenance

      Examples (1) Detached RAM
      (2) Space tug

The examples identified create the need for a common deployment and retraction procedure. However, there are many additional examples where only a deployment or a retraction activity is required. Therefore, a common procedure must include the following five separate operational options:

1. Deploy payload only
2. Retract and stow payload only
3. Deploy one payload, then retract and stow a second payload
4. Retract and stow one payload, then deploy a second payload
5. Retract a payload (service) then redeploy the same payload

All options except (4) can be performed with either a manipulator or a pivot mechanism. Option (4) would not be practical with the current design concepts of the pivot mechanism. Options 3 and 4 cover two separate payloads while option 5 is for a single payload.

Figure 2.7-3 shows the procedural steps for each of the operational options. A procedure flow diagram was prepared for both the manipulator approach and the pivot mechanism approach.

Manipulator Approach (Refer to Figure 2.7-3)

The first three steps are basic to either a deployment or retraction activity. At step 4, either a deployment path (4D) or a retraction path can be followed (4R). Steps A1 through A6 represent a side path for either deployment or retraction where a payload adapter is required and the payload is to be placed at the external airlock. Steps 5D through 8D cover the preparation of the payload for removal from the cargo bay. Steps 5R through 8R cover the operations associated with attaching the manipulator to the payload. Steps B1 through B7 include the operations required during service at an external airlock for the following: (1) Prior to initial deployment, (2) Prior to redeployment, or (3) Prior to retraction and stowage in the cargo bay. If no service is required at the external airlock, a direct path can be taken from step 8 to step 9. Steps 9D through 12D cover the operations for both the deployment and the redeployment options. A recycle path from step 12D to step 4D is provided to include the deployment of subsequent payloads. Steps 9R through 12R cover the positioning of a retrieval in the cargo bay. A recycle path back to step 4R is provided for the retraction of subsequent payloads. Steps A7 through A12 cover the operations with the

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removal of the payload adapter from the external airlock and the stowage in the cargo bay. These steps are companion to A1 through A6 and only exist if an adapter is required. The remaining two steps (13 & 14) are the reverse steps 1 & 3, and cover the manipulator stowage and deactivation which is common to either deployment or retraction.

Figure 2.7-4 illustrates the five major operational options represented by the basic procedure. Each of the numbered circles corresponds to an operational block of the procedure. This figure illustrates how the procedure can be used for each option that the various payloads may require. The options 1 through 5 will be used in subsequent matrices to show applicability to the EOS payloads as a result of the third phase of the commonality analyses.

Pivot Mechanism Approach (Refer to Figure 2.7-3)

This procedure is structured in a format similar to the manipulator approach previously discussed. The operational blocks with the letter "D" are for deployment with the "R" designator for retraction and stowage. Steps A1, A2, and A3 are provided for the case where manned ingress is required as part of the service prior to either deployment or retraction with the payload pivoted out of the cargo bay.

Operational Option number 4, retract and stow one payload, then deploy a second payload, is not possible with the current pivot mechanism and cargo bay configuration. The remaining four options are applicable as follows.

Option 1 - Deploy payload only

Sequence 1, 2D, 3D, 4D, 8D, A1, A2, A3a, 9D, 10D, 11D

Option 2 - Retract and stow payload only

Sequence 1, 2R, 3R, 4R, 5R, 6R, 7R, 8R, A1, A2, A3b, 9R, 10R

Option 3 - Deploy one payload, then retract and stow a second payload

Sequence 1, 2D, 3D, 4D, 8D, A1, A2, A3a, 9D, 10D, 2R, 3R, 4R, 5R, 6R, 7R, 8R, A1, A2, A3b, 9R, 10R

Option 5 - Retract a payload (service), then redeploy same payload

Sequence 1, 2R, 3R, 4R, 5R, 6R, 7R, 8R, A1, A2, A3a, 9D, 10D, 11D

B. Manipulator and Pivot Mechanism Approach Commonality

The manipulator approach has an apparent operational advantage associated with the deployment and/or retrieval of multiple payload on the same mission. No current requirement for this multiple payload option has been identified. This study is constructed to considered pairs of orbital elements; therefore, no penetration was conducted to derive a requirement. The pivot mechanism could be augmented with a special device to permit multiple payload deployment; however, the retraction and stowage

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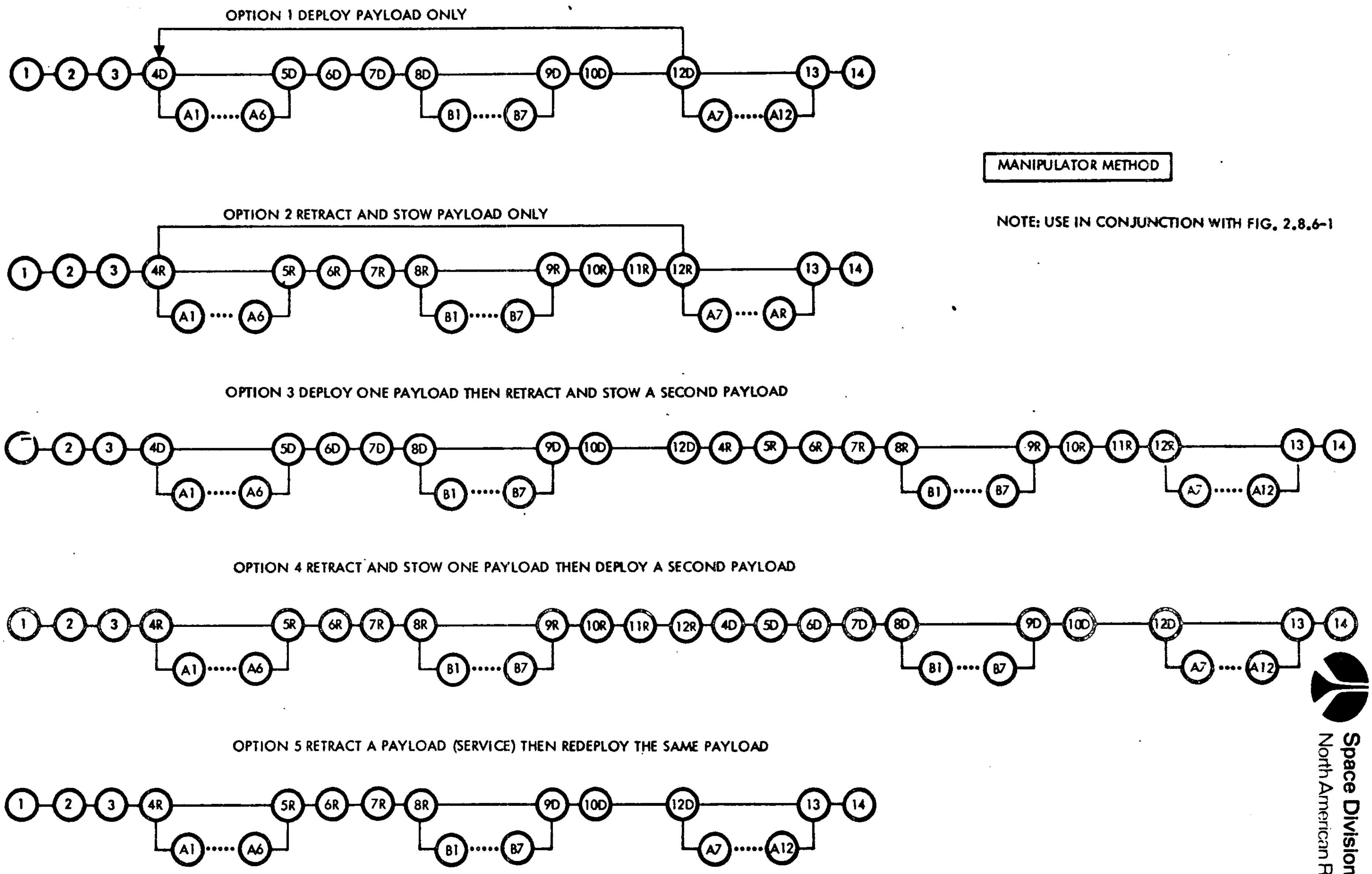

Figure 2.7-4. EOS Payload Deployment/Retraction and Stowage Operational Mode Options

case would be the most difficult design case.

The pivot mechanism has an apparent operational advantage for the case where crew ingress and/or checkout of a payload must be conducted with the payload out of the cargo bay. The interface remains intact throughout the transfer of the payload from the cargo bay to the 90° deployment position. The manipulator approach requires a complete separation and reconfiguration of the interface at an external airlock.

The pivot mechanism does not readily permit the operational option of retracting and stowing one payload prior to deployment of a second payload during the same mission. This apparent operational disadvantage may not be significant as no known requirement for this option has been uncovered during this study.

The following commonality exists between selected operational steps of the manipulator and pivot mechanism procedures.

Table 2.7-1. Commonality Comparison

Common Function (Refer to Figure 2.7-3)	Manipulator Operation	Pivot Mech Operation
Illuminate cargo bay	2	1
Transmit payload conditioning commands	5R	3R
Verify payload retrieval condition	6R	4R
Prepare for crew ingress	B4	A1
Ingress and perform service	B5	A2
Condition payload for deployment	B6a	A3a
Condition payload for earth return	B6b	A3b
Verify payload operational status	12D	10D

Table 2.7-1 shows that only a small degree of commonality exists between the two procedural methods at the detail function level.

C. Operational Procedure Applicability

The five separate operational options combined with both manipulator and pivot mechanism approaches combine for a total of 10 possible procedures for each payload element. The matrix of Figure 2.7-5 shows the applicability of each of the 10 procedure alternates to the payload elements. The matrix has two distinct parts with the abscissas displaying manipulator applicability and the ordinate displaying the pivot mechanism applicability. A summation of both ordinate and abscissa for identical coded blocks will indicate how many of the procedure alternates are possible for each payload element. The returnable tug for example has all five manipulator procedure possibilities and four pivot mechanism procedure possibilities for a total of nine.

		SPACE PROGRAM ELEMENTS																
		(PIVOT MECH) EOS PROC. #7-2	TUG		RAM				SATELLITE			EO RESUP. MODS	LOW EO MSS ***	CPS		RNS CLS ***	OLS ***	OPD ***
			RTN	SPACE BASED	ATT. EOS *	DET. EOS	ATT. MSS	DET. MSS	EOS DELIV.	EOS + 3RD ST DELIV.	RETR, RESUP.			OIS	CLS			
	EOS (MANIPULATOR) PROC. #7-1	NA	1,2,3, 4,5	1,2,3, 4,5	1,2,5	1,2,5	1,2,3,4	1,2,5	1,2,3, 4,5	1	1,2,5	1,2,3, 4,5	1,2		NA **	1,2	1,2	1,2
TUG	RETURNABLE	1,2,3,5								NA								
TUG	SPACE BASED	1,2,3,5		NA			NA	NA		NA	NA	NA	NA	NA	NA	NA	NA	NA
RAM	ATT. EOS *	1,2,5																
RAM	DET. EOS	1,2,5																
RAM	ATT. MSS	1,2,3		NA									NA					
RAM	DET. MSS	1,2,5		NA									NA					
SATEL	EOS DELIV.	1,2,3,5																
SATEL	EOS + 3RD ST	1	NA	NA														
SATEL	RETR, RESUP.	1,2,3,5		NA														
	EO RESUP. MODS	1,2,3,5		NA								NA	NA		NA	NA		NA
	LOW EO MSS	1,2		NA			NA	NA				NA	NA					
CPS	OIS			NA											NA	NA	NA	NA
CPS	CLS	NA **		NA								NA		NA	NA		NA	NA
	RNS-CLS	1,2		NA								NA		NA		NA	NA	NA
	OLS	1,2		NA										NA	NA	NA	NA	
	OPD	1,2		NA								NA		NA	NA	NA		NA

LEGEND

Operational Mode Options

- 1 Deploy payload only
- 2 Retract and stow payload only
- 3 Deploy one payload, then retract and stow a second payload
- 4 Retract and stow one payload, then deploy a second payload
- 5 Retract a payload (service), then redeploy same payload
- NA Not Applicable

NOTES:

- * Refer to Attached Element Operations (2.12)
- ** 33-ft dia not compatible with EOS cargo bay
- *** Refer to Orbital Assembly (2.2) for all modules except initial

Figure 2.7-5. Operational Procedures Applicability - Interface Activity: EOS Payload Deployment

2.8 EOS PAYLOAD RETRACTION AND STOWAGE

This section presents the operational procedures for EOS Payload Retraction and Stowage, and includes one procedure for each alternate approach identified in Volume II of this report. Also presented and discussed is the applicability of these procedures to each element pair included in the in-depth analysis portion of the Orbital Operations Study.

2.8.1 OPERATIONAL PROCEDURES

Two operational procedures were developed for EOS Payload Retraction and Stowage, one for each of the conceptual approaches. Procedure number 8-1 applies to the EOS equipped with a manipulator. Procedure number 8-2 is applicable to the EOS with a pivoting mechanism in the cargo bay.

Assumptions

The following three major assumptions were used in developing the operational procedures. The third assumption applies to the manipulator concept only:

a. A cooperative payload state is achievable. The commands (whether from the ground or the EOS) required to ready the payload in a mode/condition for retrieval were assumed to exist and function. Non-cooperative payloads were considered beyond the scope of this procedure.

b. Solar illumination not available or inadequate. The procedure was developed with contingencies of artificial light being planned to handle the situation when either insufficient solar illumination existed or the procedures was required during the dark part of an orbit.

c. Second manipulator arm for backup only. The EOS models utilized in the development of this procedure had manipulator concepts with two arms. All procedural steps were designed capable of being accomplished with a single failure. Each manipulator arm was considered to be a potential single failure. Therefore, the assumption was developed that the second manipulator arm was considered for backup only.

Initial Conditions

The following initial conditions apply to both procedures:

a. Communications and data links have been established between the EOS and any program element that is being retrieved.

b. The final phase of rendezvous are completed. The procedure is subsequent to rendezvous of the EOS to the system delivering the payload or after specific payload retrieval position (altitude, inclination) has been acquired.

c. The EOS cargo bay doors are open to permit active thermal control via door mounted radiators.

Final Conditions

The following two major final conditions apply to both procedures:

a. Payload secured in cargo bay. Once the payload has been retrieved and stowed, the EOS will provide retention devices. The EOS will verify that the payload is secured and ready for transfer.

b. Monitoring/service umbilicals connected to provide the support necessary to service the payload and determine its status prior to final disposition (earth return or possible redeployment), the service lines and umbilicals necessary to accomplish this will have to be connected and secured.

Description of Procedures

The procedures for EOS payload retraction and stowage were written in the same manner as the Payload Deployment procedures. There are two procedures: one utilizing manipulation (8-1), the other a pivot mechanism (8-2). The following two paragraphs describe the unique features of each procedure approach.

a. Procedure No. 8-1 (Manipulator Approach)

This procedure contains 35 operations. The flow diagram, Figure 2.8-1 , contains three by-passes that are utilized if the mission does not require manning of the payload. Also referenced were two interfacing activities (Attached Element Operations 2.12, and Separation 2.3). The Attached Element Operations were referenced for those operations that would be utilized if crew ingress of a payload is required. The Separation procedure is referenced to cover the operations involved with the removal of an adapter located on the cockpit airlock. The remarks/rationale for each operation of the procedure are described in the following paragraphs.

b. Procedure No. 8-2 (Pivot Mechanism Approach)

The pivot mechanism approach was developed in essentially the same manner as the manipulator approach. The operations with reading the EOS for retrieval, the payload and then effecting the retrieval It also covers the possible operations associated with crew ingress if servicing and maintenance are required prior to positioning the payload in the EOS cargo bay. The flow diagram also contains a by-pass that is used if no crew ingress is required by the mission. A description of the rationale/remarks for each of the 14 operations of the logic flow are contained in the pages following the block flow diagram, Figure 2.8-2.

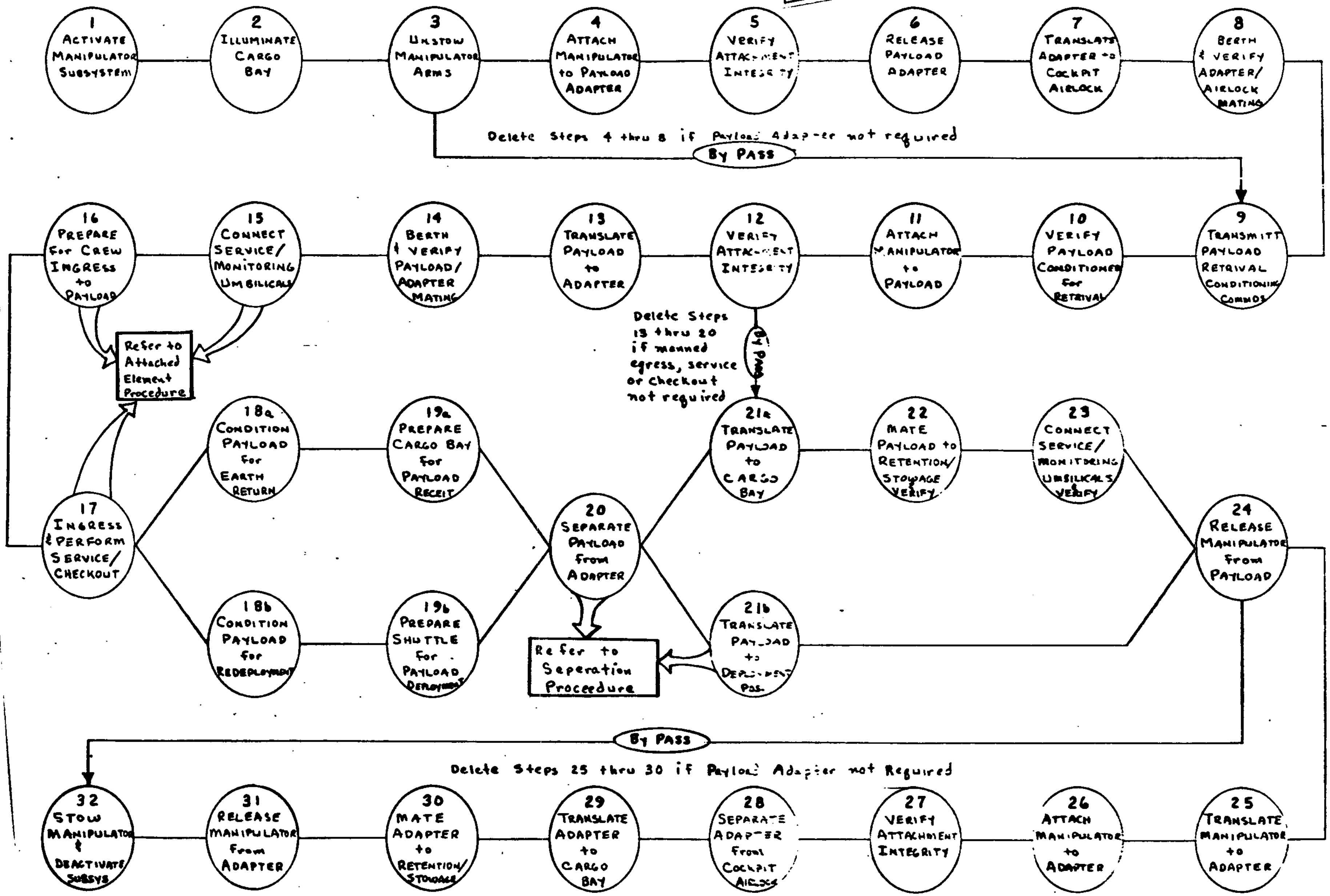

Figure 2.8-1. Description of Procedure No. 8-1, EOS Payload Retraction and Stowage

OPERATIONAL PROCEDURE NO. 8-1

TITLE: EOS PAYLOAD RETRACTION AND STOWAGE - MANIPULATOR

ELEMENT INTERFACES: EOS ORBITER, WITH MANIP. (ACTIVE)/PAYLOAD (PASSIVE)

Operation		Performed by:	Rationale
1	Activate manipulator system	EOS	A manipulator control center in the crew compartment must be brought to an operational status from either a powered down or a standby mode to determine the operational status at the manipulator. Dependent upon the type of payload and degree of automation either a manual or preprogrammed mode may be selected. The manipulator arm and its effector end are in a stowed position to prevent damage to the manipulator and/or the payloads. Therefore, this activation does not include physical movement of the arm. However, TV, floodlight and force feedback sensors will provide verification of arm activation.
2	Illuminate cargo bay	EOS	This is a precursor to subsequent activities and required to allow TV coverage of the cargo bay activities. The shuttle can maneuver to a sunlight orientation or cargo bay floodlights may be employed.
3	Unstow manipulator arm	EOS	The manipulator arms and effector ends have been stowed in a position to prevent damage to the manipulator and/or the payloads. Therefore, this restraint

OPERATIONAL PROCEDURE NO. 8-1

Operation		Performed by:	Rationale
			must be released prior to operational use of the manipulator. Captive latches can be released via a hardwire signal from the control center. However, a manual force override is required for contingency to prevent a single failure from discontinuation of the retrieval operation. The physical movement of the shoulder, wrist, extension, and effector end can now be verified. TV coverage via cargo bay and direct visual can be employed.
4	Attach manipulator to payload adapter	EOS	Certain payloads may require an adapter to provide either reach or interface compatibilities between the EOS airlock and the payload. The adapter is stowed in the cargo bay with its manipulator attachment points visible by either cargo bay TV or direct from the crew compartment. This alternative viewing is required as a backup to the manipulator arm-mounted TV. The effector end is physically engaged with either of the redundant attachment point.
5	Verify attachment integrity	EOS	Whenever the manipulator will be used to move an object in order to prevent damage from a faulty or incomplete attachment this physical junction will have to be verified. The manipulator arm applies the simulated normal ops

OPERATIONAL PROCEDURE NO. 8-1

	Operation	Performed by:	Rationale
			forces to the interface prior to release of the retention mechanism. Visual and touch sensor feedback to the control center are required to verify the integrity of the interface connection.
6	Release payload adapter	EOS	The adapter must now be placed on the cockpit airlock. Captive latches can be released via a hardwire signal from the control center. However, a manual release must be provided for contingency. If the force requirement for pullaway (must exceed that of step 5 and the launch forces) exceeds practical manipulator design, an alternate procedure must be employed either using the redundant manipulator arm or EVA.
7	Translate adapter to cockpit airlock	EOS	After release, the adapter is translated to a position in direct alignment with the airlock. If a cooperative arm mode is utilized, arm #2 can enhance the operation by providing illumination and TV coverage. In addition, the mating interfaces can be inspected and capture latches armed. In the single arm mode the inspection and latch arming (if required) would be sequenced prior to step 4.

OPERATIONAL PROCEDURE NO. 8-1

Operation		Performed by:	Rationale
8	Berth and verify adapter/airlock mounting	EOS	The mating velocity is imparted to the adapter via the manipulator and physical contact acquired. Verification of the mating is required prior to release of the manipulator arm. A force is applied to test the interface with TV and touch sensor feedback sent to the control center for verification. Dependent upon the design concept, additional rigidizing of the interface may be required. This rigidizing can be accomplished externally with the manipulator or internally. Failure to release the manipulator can result in mission discontinuation, therefore alternative procedures must be employed.
9	Transmit payload retrieval conditioning commands	EOS	Single or multiple commands must be transmitted to the various payloads to initiate the following types of payload activities: (a) inhinit spin, nutation, or tumble; (b) enable/disable attitude control; (c) inhibit appendages such as antenna booms, solar arrays, etc.; (d) retract appendages; (e) close airlock doors and sensor protective shutters; (f) vent hazardous fluids and gases.
10	Verify payload conditioned for retrieval	EOS	To avoid damage to either the payload or the EOS, during the final retrieval activities, the shuttle will be required to selectively inhibit engine firings

OPERATIONAL PROCEDURE NO. 8-1

Operation		Performed by:	Rationale
			and hold the venting of effluents. The verification of the payload response to the conditioning commands can be accomplished by direct visual from the crew compartment and/or TV coverage of the payload via the manipulator arm.
11	Attach manipulator to payload	EOS	Attachment is required to complete the mating sequence. The effector end is extended to engage one of the redundant attachment points. Illumination and TV coverage can be supplied by the manipulator. However, the shuttle and payload can be positioned to enable sun illumination and direct visual as a contingency mode. A second manipulator arm also can be employed as a backup.
12	Verify attachment integrity	EOS	Whenever the manipulator will be used to move an object in order to prevent damage from a faulty or incomplete attachment this physical function will have to be verified. After engagement of the effector end with the payload attachment point, the manipulator provides forces equal to the subsequent translation maneuver's magnitude to verify attachement. The forces are applied in a directi n that will not lead to shuttle impact if the attachment is not fully secured. Visual and touch sensor feedback is provided to the control center.

OPERATIONAL PROCEDURE NO. 8-1

Operation		Performed by:	Rationale
13	Translate payload to adapter	EOS	The payload is translated within close proximity to the EOS to enable the berthing port to be aligned with the airlock. If either of the two berthing interfaces require cocking of capsule latches, the cocking will be accomplished by the manipulator at step 10. The latch cocking, if required can also be accomplished via the redundant manipulator arm at this step.
14	Berth and verify payload/adapter mating	EOS	The mating must be verified prior to the connection of umbilicals and the start of servicing and crew ingress. The mating velocity is imparted to the payload via the manipulator and physical contact acquired. Verification of the mating is required prior to release of the manipulator arm. A force is applied to test the interface with TV and touch sensor feedback to the control center. Dependent upon the design concept, additional rigidizing of the interface may be required.
15	Connect service/monitoring umbilicals	EOS	The connection of umbilicals will be accomplished either shirtsleeve or IVA via the cockpit airlock. The shirtsleeve case will require the adapter to be pressurized and equalized before the airlock external hatch is opened.

OPERATIONAL PROCEDURE NO. 8-1

	Operation	Performed by:	Rationale
16	Prepare for crew ingress to payload	EOS	The operational activities associated with this step are detailed in the Attached Element Operations procedure. Briefly the following types of activities are required: (a) sense payload atmosphere (toxic, humidity, temperature, pressure, etc.); (b) dump, purge, pressurize, equalize pressure; (c) open hatches, verify latches, rigidize; (d) connect IVA umbilicals and communication/instrumentation lines.
17	Ingress and perform service/checkout	EOS	The operational activities associated with this step are detailed in the Attached Element Operations procedure
18a	Condition payload for earth return	EOS	Scientific sensors and subsystem equipment will require protective packaging and tie-down to eliminate damage or a hazard during the reentry and landing. Manual retraction of external appendages and passification of equipment are required.
18b	Condition payload for redeployment	EOS	Subsequent to the service and checkout activities, those equipment items passified or put into standby or deactivated modes will require reconfiguration to operational status. The EOS will be required to perform orbital maneuvers to verify correct response of attitude control, solar array orientation, antenna positioning, and scientific sensor orientation.

OPERATIONAL PROCEDURE NO. 8-1

Operation		Performed by:	Rationale
19a	Prepare cargo bay for payload receipt	EOS	Illumination of the cargo bay may be accomplished by shuttle maneuvers or floodlights mounted in the bay. Retention devices may be required as well as special cradles or pallets. These various payload retention devices can be fixed mounted or adjustable. For the adjustable cases the manipulator is a potential backup for failure of the erection mechanism. The design concept selected for capture may require manual cocking of latches with the manipulator.
19b	Prepare EOS for payload deployment	EOS	Selected subsystem and scientific sensor equipment are sensitive to contamination. Therefore the shuttle will be required to selectively inhibit engine firing and manage the venting of cabin effluents. The shuttle will be required to conduct orbital maneuvers to enable closed loop verification of orientation devices and attitude control.
20	Separate payload from adapter	EOS	This operational activity is detailed in the separation procedure. Failure of the release mechanism is a mission continuation hazard. For the payloads that do not require an adapter and are berthed to the airlock, failure of the release mechanism is a safety critical problem that can potentially prevent reentry. Alternate means of accomplishing the release must be provided.

OPERATIONAL PROCEDURE NO. 8-1

	Operation	Performed by:	Rationale
21a	Translate payload to cargo bay	EOS	The manipulator positions the payload close to the cargo bay in direct all alignment with the retention/stowage mechanism.
21b	Translate payload to deployment position	EOS	The deployment position for specific payloads is a function of: (1) external appendages, (2) sensitivity to solar orientation for arrays, sensors and thermal control, (3)minimize propulsive impingement on either the payload or the shuttle, and (4) antenna view angles.
22	Mate payload to retention/ stowage mechanism and verify	EOS	A mating velocity is imparted to the payload via the manipulator and physical contact acquired. The verification of the interface is by application of force from the manipulator with TV and touch sensor feedback sent to the control center. Illumination and TV coverage from the cargo bay may be required as a backup.
23	Connect service/monitoring umbilicals and verify	EOS	Payload status must be provided to give warning of a potentially hazardous condition. The payload may require vent lines to remove residual fluids and gases. Either the manipulator or a special device may be used to connect the umbilicals.

OPERATIONAL PROCEDURE NO. 8-1

	Operation	Performed by:	Rationale
24	Release manipulator from the payload	EOS	The failure to release the manipulator arm from a payload either in the cargo bay or separted from the shuttle is a critical condition that requires alternate means to accomplish physical separation. The release of the effector end is not accomplished until a force test has been conducted to verify the integrity of the retention/stowage mating.
25	Translate manipulator to payload adapter	EOS	The payload adapter must be removed from the cockpit airlock and returned to the cargo bay or in the case of the MSS, placed on the station core module.
26	Attach manipulator to payload adapter	EOS	The adapter must be returned to the cargo bay for stowage. Any external rigidizing must be removed prior to engaging the effector end of the manipulation to either of the redundant attachment points.
27	Verify attachement integrity	EOS	Force is applied via the manipulator with TV and touch sensor feedback sent to the control center.
28	Release adapter from cockpit airlock	EOS	Automatic release of capture mechanism is possible, however manual backup is required due to the criticality of a release failure.

OPERATIONAL PROCEDURE NO. 8-1

	Operation	Performed by:	Rationale	Functional Reqmt.
29	Translate adapter to cargo bay	EOS	The manipulator arm provides the translation positioning the adapter in line with its retention/stowage mechanism. Cargo bay illumination and TV coverage required as a backup.	2
30	Mate adapter to retention/ stowage mechanism	EOS	The mating velocity is imparted via the manipulator. If captive latches need cocking, the activity is performed prior to step 26 or by the redundant manipulator arm	
31	Release manipulator from payload adapter	EOS	Release of the effector end is accomplished only after verification of attachment integrity. Redundant means of release must be provided.	
32	Stow manipulator and deactivate subsystem	EOS	The manipulator arms are physically restrained in the cargo bay to prevent damage and eliminate a hazard to the payload(s). The control center conducts a normal shutdown sequence after verification of stowage.	

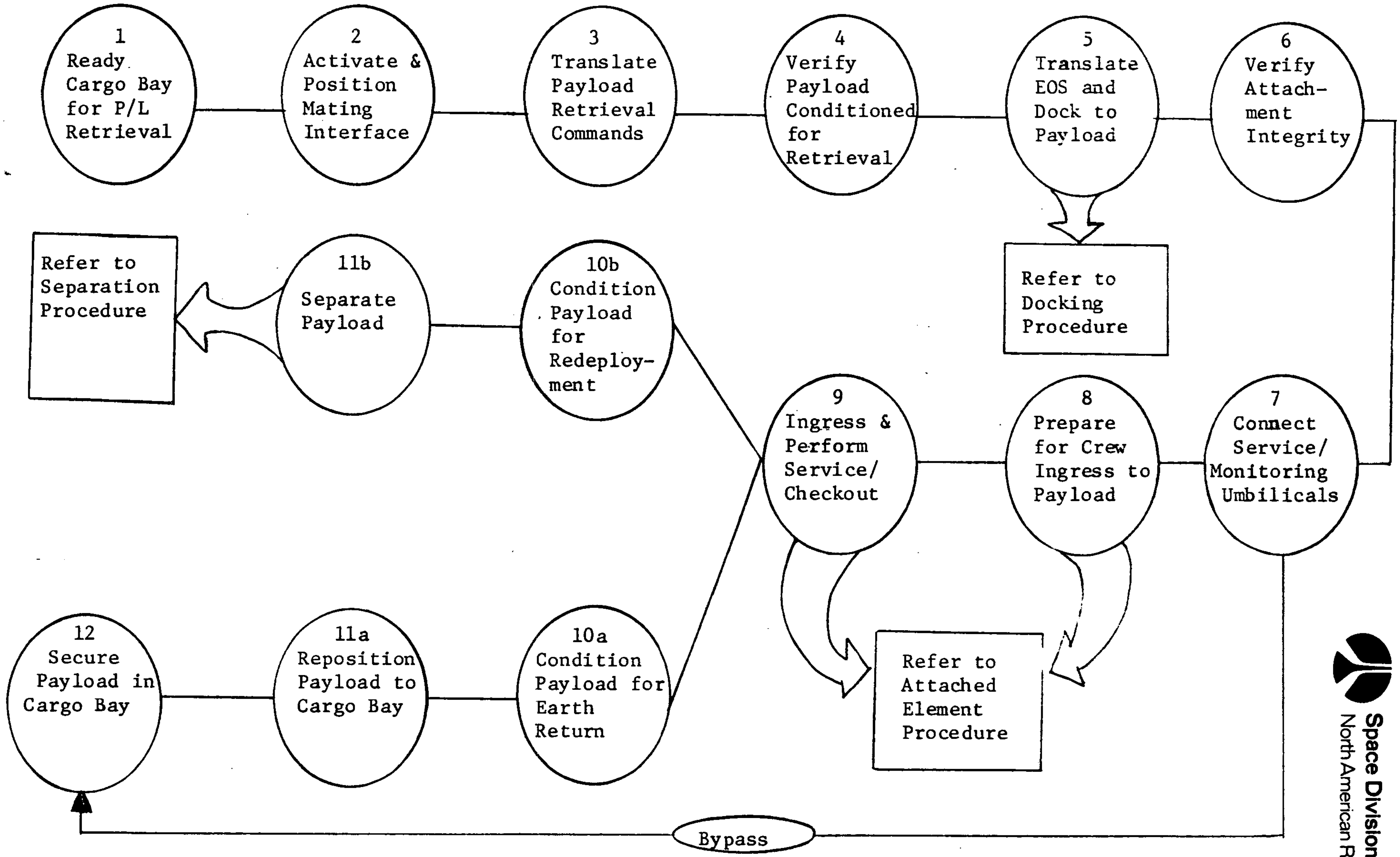

Figure 2.8-2. Summary of Procedure No. 8-2
EOS Payload Retraction & Stowage
(Pivot Mechanism)

OPERATIONAL PROCEDURE NO. 8-2

TITLE: EOS PAYLOAD RETRACTION AND STOWAGE - PIVOT MECHANISM

ELEMENT INTERFACES: EOS ORBITER (ACTIVE)/PAYLOAD (PASSIVE)

	Operation	Performed by:	Rationale
0	Initial Conditions	EOS	EOS has established communication link with payload and rendezvous has occurred. The cargo bay doors are open.
1	Ready cargo bay for payload retrieval	EOS	The retrieval of one payload can be accomplished prior to delivery of a second payload already in the cargo bay. In addition, a second payload may have been retrieved and secured in the cargo bay. In either of the two cases, a reconfiguration of the loaded payload and the retraction/stowage mechanisms may be required to free the payload mating interface. The loaded payload may be pivoted out of the aft end or slid on rails to the aft portion of the cargo bay.
2	Activate and position mating interface	EOS	Current reference design concepts employ a mating interface that is collapsible and restrained in the cargo bay when inactive and repositioned 90 degrees to extend outside the cargo bay for docking with payloads. Activation of this mating interface is dependent upon the design concept selected for the alignment during docking. Laser radar, TV cameras and illumination equipment

Space Division
North American Rockwell

OPERATIONAL PROCEDURE NO. 8-2

	Operation	Performed by:	Rationale
			(if installed) will require activation and verification. The 90-degree docking position will require some locking devices and verification that the proper position has been reached and rigidized.
3	Transmit payload retrieval conditioning commands	EOS	Single or multiple commands must be transmitted to the various payloads to initiate the following types of payload activities: (a) inhibit spin, nutation, or tumble; (b) enable/disable attitude control; (c) inhibit appendages such as antenna booms, solar array, etc.; (d) retract appendages; (e) close airlock doors and sensor protective shutters; (f) vent hazardous fluids and gases.
4	Verify payload conditioned for retrieval	EOS	During the final retrieval activities the shuttle will be required to selectively inhibit engine firings and hold the venting of effluents. The verification of the payload response to the conditioning commands can be accomplished by direct visual from the crew compartment and/or TV coverage of the payload via the mating interface.
5	Translate EOS and dock to payload	EOS	The detailed steps and the alternatives for the docking activity are delineated in a separate procedure entitled "Docking". Briefly, this sequence

OPERATIONAL PROCEDURE NO. 8-2

	Operation	Performed by:	Rationale
			includes the following: (a) target acquisition and alignment; (b) closing; (c) capture; (d) impact attenuation and relative velocity damping; and (e) rigidization.
6	Verify attachment integrity	EOS	This verification is via remote sensors that indicate the state of the capture and rigidizing mechanisms. Visual verification can be provided; however the design solutions are complex. Visual inspection can be performed shirtsleeve after hatch opening which should preclude the need for external visual verification.
7	Connect service/monitoring umbilicals	EOS	This activity can be accomplished automatically after the docking using remote coupling mechanisms or manually after the EOS mating interface hatch has been opened. For the manual case, shirtsleeve or IVA may be employed. The umbilicals will include electrical, communication/ data fluid, and gas dependent upon the type of payload.
8	Prepare for crew ingress to payload	EOS	The operational activities associated with this step are detailed in the Attached Element Operations procedure. Briefly, the following types of activities are included: (a) sense payload atmosphere; (b) dump, purge, pressurize, and equalize payload pressure; (c) open

OPERATIONAL PROCEDURE NO. 8-2

Operation		Performed by:	Rationale
			hatches and inspect interface (rigidize if necessary); (d) connect umbilicals
9	Ingress and perform service/ checkout	EOS	The operational activities associated with this step are many and varied. Refer to Attached Elements Operations Procedure for details.
10a	Condition payload for earth return	EOS	Scientific sensors and subsystem equipment will require protective packaging and tie-down to eliminate damage or a hazard during entry and landing. Manual retraction of appendages, manual closing of external ports and protective covers may also be required. Some scientific and subsystem equipment may require passification.
10b	Condition payload for redeployment	EOS	Subsequent to the service and checkout activities, those equipment items passified will require reconfiguration to operational status. The EOS will be required to perform orbital maneuvers to verify correct responses of attitude control, solar array orientation, antenna positioning, and sensor orientation.
11a	Reposition payload to cargo bay	EOS	The pivotal mechanism that positioned the mating interface from the cargo bay to its current 90-degree mating state must be resequenced. Failure to accomplish this retraction can result

OPERATIONAL PROCEDURE NO. 8-2

	Operation	Performed by:	Rationale
			in a mission continuation failure, therefore redundant means must be provided for both release and positioning. The mechanism shall be capable of this activity while the attitude control is enabled and correcting attitude.
11b	Separate payload	EOS	This operational step is detailed in the separation procedure that covers the various means of accomplishment with either or both EOS and payload providing the release thrust. Failure to release the payload is a mission continuation failure that requires alternate means of accomplishment.
12	Secure payload in cargo bay and verify	EOS	Special attachement hard points must be provided to take out the landing loads and restrain the payload. Verification can be accomplished via TV and/or capture mechanism sensors.

2.8.2 PROCEDURES APPLICABILITY

Three distinct types of commonality analyses will be reported in this paragraph. The first commonality is between EOS payload deployment and EOS payload retraction and stowage. The majority of EOS flights will perform both deployment and retraction on the same mission. A second commonality analysis was also conducted for both the manipulator and the pivot mechanism approaches. Some operational advantages were uncovered for each approach. The third commonality analysis to be reported is the applicability of the procedure(s) to the specific payload elements identified in the matrices. The combined deployment/retraction and stowage procedure developed as part of the first commonality analysis was used for this task.

A. EOS Payload Deployment/Retraction and Stowage Commonality

Both scheduled and unscheduled activities were investigated for examples where the deployment and retraction of EOS payload is required as part of the same mission. The following briefly shows some of the substantiating examples that drove the combination of the two interfacing activity procedures:

1. Scheduled Activities

   a. Module Exchange

      Examples (1) MSS cargo module exchange
      (2) MSS power module exchange
      (3) OPD propellant module exchange

   b. Element Replacement

      Examples (1) TDRS replacement
      (2) Space based tug replacement

   c. Routine Service

      Examples (1) Detached RAM resupply
      (2) Tug resupply

   d. Multiple Elements

      Example (1) Deploy MSS module and retrieve a satellite

2. Unscheduled Activities

   a. Rescue

      Examples (1) EOS rescue
      (2) MSS rescue

b. Maintenance

Examples (1) Detached RAM
(2) Space tug

The examples identified create the need for a common deployment and retraction procedure. However, there are many additional examples where only a deployment or a retraction activity is required. Therefore, a common procedure must include the following five separate operational options:

1. Deploy payload only
2. Retract and stow payload only
3. Deploy one payload, then retract and stow a second payload
4. Retract and stow one payload, then deploy a second payload
5. Retract a payload (service) then redeploy the same payload

All options except (4) can be performed with either a manipulator or a pivot mechanism. Option (4) would not be practical with the current design concepts of the pivot mechanism. Options 3 and 4 cover two separate payloads while Option 5 is for a single payload.

Figure 2.8-3 shows the procedural steps for each of the operational options. A procedure flow diagram was prepared for both the manipulator approach and the pivot mechanism approach.

Manipulator Approach (refer to Figure 2.8-3)

The first three steps are basic to either a deployment or retraction activity. At Step 4, either a deployment path (4D) or a retraction path can be followed (4R). Steps A1 through A6 represent a side path for either deployment or retraction where a payload adapter is required and the payload is to be placed at the external airlock. Steps 5D through 8D cover the preparation of the payload for removal from the cargo bay. Steps 5R through 8R cover the operations associated with attaching the manipulator to the payload. Steps B1 through B7 include the operations required during service at an external airlock for the following: (1) Prior to initial deployment, (2) Prior to redeployment, or (3) Prior to retraction and stowage in the cargo bay. If no service is required at the external airlock, a direct path can be taken from Step 8 to Step 9. Steps 9D through 12D cover the operations for both the deployment and the redeployment options. A recycle path from step 12D to Step 4D is provided to include the deployment of subsequent payloads. Steps 9R through 12R covers the positioning of a retrieval in the cargo bay. A recycle path back to Step 4R is provided for the retraction of subsequent payloads. Steps A7 through A12 covers the operations with the removal of the payload adapter from the external airlock and the stowage in the cargo bay. These steps are companion to A1 through

A6 and only exist if an adapter is required. The remaining two steps (13 and 14) are the reverse of Steps 1 and 3, and cover the manipulator stowage and deactivation which is common to either deployment or retraction.

Figure 2.8-4 illustrates the five major operational options represented by the basic procedure. Each of the numbered circles corresponds to an operational block of the procedure. This figure illustrates how the procedure can be used for each option that the various payloads may require. The Options 1 through 5 will be used in subsequent matrices to show applicability to the EOS payloads as a result of the third phase of the commonality analyses.

Pivot Mechanism Approach (refer to Figure 2.8-3)

This procedure is structured in a format similar to the manipulator approach previously discussed. The operational blocks with the letter "D" are for deployment with the "R" designator for retraction and stowage. Steps A1, A2, and A3 are provided for the case where manned ingress is required as part of the service prior to either deployment or retraction with the payload pivoted out of the cargo bay.

Operational Option Number 4, retract and stow one payload, then deploy a second payload, is not possible with the current pivot mechanism and cargo bay configuration. The remaining four options are applicable as follows:

Option 1 - Deploy payload only

Sequence 1, 2D, 3D, 4D, 8D, A1, A2, A3a, 9D, 10D, 11D

Option 2 - Retract and stow payload only

Sequence 1, 2R, 3R, 4R, 5R, 6R, 7R, 8R, A1, A2, A3b, 9R, 10R

Option 3 - Deploy one payload, then retract and stow a second payload

Sequence 1, 2D, 3D, 4D, 8D, A1, A2, A3a, 9D, 10D, 2R, 3R, 4R, 5R, 6R, 7R, 8R, A1, A2, A3b, 9R, 10R

Option 5 - Retract a payload (service), then redeploy same payload

Sequence 1, 2R, 3R, 4R, 5R, 6R, 7R, 8R, A1, A2, A3a, 9D, 10D, 11D

Same as Figure 2.7-3

Figure 2.8-3. EOS Payload Deployment/Retraction and Stowage Operational Procedures Alternatives

Same as Figure 2.7-4

Figure 2.8-4. EOS Payload Deployment/Retraction and Stowage Operational Mode Options

B. Manipulator and Pivot Mechanism Approach Commonality

The manipulator approach has an apparent operational advantage associated with the deployment and/or retrieval of multiple payload on the same mission. No current requirement for this multiple payload options has been identified. This study is constructed to consider pairs of orbital elements; therefore, no penetration was conducted to derive a requirement. The pivot mechanism could be augmented with a special device to permit multiple payload deployment; however, the retraction and stowage case would be the most difficult design case.

The pivot mechanism has an apparent operational advantage for the case where crew ingress and/or checkout of a payload must be conducted with the payload out of the cargo bay. The interface remains intact throughout the transfer of the payload from the cargo bay to the 90-degree deployment position. The manipulator approach requires a complete separation and reconfiguration of the interface at an external airlock.

The pivot mechanism does not readily permit the operational option of retracting and stowing one payload prior to deployment of a second payload during the same mission. This apparent operational disadvantage may not be significant as no known requirement for this option has been uncovered during this study.

The following commonality exists between selected operational steps of the manipulator and pivot mechanism procedures:

Table 2.8-1. Operational Commonality

Common Function (Refer to Figure 2.8-3)	Manipulator Operation	Pivot Mech Operation
Illuminate cargo bay	2	1
Transmit payload conditioning commands	5R	3R
Verify payload retrieval condition	6R	4R
Prepare for crew ingress	B4	A1
Ingress and perform service	B5	A2
Condition payload for deployment	B6a	A3a
Condition payload for earth return	B6b	A3b
Verify payload operational status	12D	10D

Table 2.8-1 shows that only a small degree of commonality exists between the two procedural methods at the detail function level.

C. Operational Procedure Applicability

The five separate operational options combined with both manipulator and pivot mechanism approaches combine for a total of ten possible procedure alternates to the payload elements. The matrix presented in Figure 2.8-5 has two distinct parts with the abscissas displaying manipulator applicability. A summation of both ordinate and abscissas for identical coded blocks will indicate how many of the procedure alternates are possible for each payload element. The returnable tug for example has all five manipulator procedure possibilities and four pivot mechanism procedures possibilities for a total of nine.

		SPACE PROGRAM ELEMENTS																
		(PIVOT MECH) EOS PROC. #8-2	TUG		RAM				SATELLITE			EO RESUP. MODS	LOW EO MSS ***	CPS		RNS CLS ***	OLS ***	OPD ***
			RTN	SPACE BASED	ATT. EOS *	DET. EOS	ATT. MSS	DET. MSS	EOS DELIV.	EOS + 3RD ST DELIV.	RETR, RESUP.			OIS	CLS			
	EOS (MANIPULATOR) PROC. #8-1	NA	1,2,3, 4,5	1,2,3, 4,5	1,2,5	1,2,5	1,2,3,4	1,2,5	1,2,3 4,5	1	1,2,5	1,2,3, 4,5	1,2		NA **	1,2	1,2	1,2
TUG	RETURNABLE	1,2,3,5								NA								
	SPACE BASED	1,2,3,5		NA			NA	NA		NA	NA	NA	NA	NA	NA	NA	NA	NA
RAM	ATT. EOS *	1,2,5																
	DET. EOS	1,2,5																
	ATT. MSS	1,2,3		NA									NA					
	DET. MSS	1,2,5		NA									NA					
SATEL	EOS DELIV.	1,2,3,5																
	EOS + 3RD ST	1	NA	NA														
	RETR, RESUP.	1,2,3,5		NA														
	EO RESUP. MODS	1,2,3,5		NA								NA	NA		NA	NA		NA
	LOW EO MSS	1,2		NA			NA	NA				NA	NA					
CPS	OIS			NA											NA	NA	NA	NA
	CLS	NA **		NA								NA		NA	NA		NA	NA
	RNS-CLS	1,2		NA								NA		NA		NA	NA	NA
	OLS	1,2		NA										NA	NA	NA	NA	
	OPD	1,2		NA								NA		NA	NA	NA		NA

LEGEND

Operational Mode Options

1 Deploy payload only
2 Retract and stow payload only
3 Deploy one payload, then retract and stow a second payload
4 Retract and stow one payload, then deploy a second payload
5 Retract a payload (service), then redeploy same payload
NA Not Applicable

NOTES:

* Refer to Attached Element Operations (2.12)
** 33-ft dia not compatible with EOS cargo bay
*** Refer to Orbital Assembly (2.2) for all modules except initial

Figure 2.8-5. Operational Procedures Applicability - Interface Activity: EOS Payload Retraction and Stowage

2.9 COMMUNICATIONS

This section presents the operational procedures for communications, and includes one procedure for each alternate approach identified in Volume II of this report. Also presented and discussed is the applicability of these procedures to each element pair included in the in-depth analysis section of the Orbital Operations Study.

2.9.1 OPERATIONAL PROCEDURES

Three sets of operational procedures were developed, one for each alternate approach. Each set contains sub-sets for the different types of communications activity, i.e., data transfer, tracking and ranging and command and control. Modifications are also noted to account for unscheduled, urgent and non-urgent operations in the ground-to-element interface (either direct ground via the Ground Network or by TDRS). Although the three approaches appear as alternates, it is likely that each alternate link will be used during any elements mission. This drives the requirement for element-to-element links to be compatible with Ground Network and/or TDRS links. It should also be noted that the Ground Network or TDRS communications links will require a handover procedure from one station to the next when the contact carries on beyond the element containment in the field of view of a single station. Handover accounts for the major differences between the procedures. Element-to-element links can be continuous, as necessary, since it is assumed that the two elements are always in line of sight of each other. The other delta - the processing and routing of data - differs only in respect to the location of the data processing. It is likely that one of the space elements in the element-to-element interface will process the data and either display it on board or store it for future transmission to ground for subsequent routing to user. Such a case would occur in the case of a space station and RAM. The space station would collect data from the RAM, process it and either display it on board or store it and then transmit to ground at the appropriate time. It is important to note that communications is not an activity in itself. It is a support to almost every other interfacing activity. Initial and final conditions are therefore completely dependent on the interface activity being supported.

Details of the assumptions, initial and final conditions are included with each of the operational procedures contained in this section.

OPERATIONAL PROCEDURE NO. 9.1

Communications--Element-to-Ground (Direct)

Assumptions

Ground stations will be used for the ground terminal in accordance with NASA model (Reference DS-504). This establishes the frequency bands of operation (S-band), the ranging system (PRN ranging) and the location of usable ground stations. The major impact, other than the frequency compatibility, is the need for a cooperative transponder on the space element for the ranging function. A live wake-up receiver is needed to support the initiation of any operational procedure for unmanned space elements. This could be either on S or VHF frequencies.

The procedures are generic. They can be used for any combination of elements, either manned or unmanned. When unmanned elements are used, commands are initiated either from ground or by an automated, pre-programmed element sequencing system. Manned elements take advantage of the availability of man to initiate commands and control the operations.

Initial Conditions

Space element is in quiescent state and the unmanned elements contain a live wake-up receiver alert and available to receive command signals. It is in a predictable orbit that is programmed in the ground station scheduled operations. Since communications is a supporting activity, the time and duration of the operation depends on the activity being supported.

Final Conditions

After completion of communications support, the orbital element terminal equipment is de-activated and returned to a quiescent mode; i.e., a live wake-up receiver is available. This allows conservation of space element power and leaves the ground and/or TDRS station available for other operations.

Description

Considerations of the Space Element operations will be limited to those necessary for orbital operations only. No operations concerned with the element ascent or descent will be considered. During orbital operations, the Element/ground direct interface activity is used to provide for transmission to ground of TLM digital data, TV data and voice and the reception at the Space Element of digital command data and voice. Tracking and ranging are also provided and are performed at the ground station either by ground direction or by Element request. Tracking data is derived at the ground by utilizing antenna pointing angles from the ground station 85-foot antennas. Range and range rate data is provided by the transmission from the ground station of an appropriate PRN range code, its reception at the Element and subsequent turn-around transmission of its code back to ground. By comparative means range is derived at the ground station from the correlation of the PRN code and the measurement of round trip time. Range rate can be obtained either by successive measurements or by doppler measurement.

Establishment of the links, transfer of appropriate data and tracking and ranging of the space element require certain operational procedures. These procedures involve signal acquisition, transmission and reception of data signals and/or performance of the tracking and ranging function. Performance of these operations must be scheduled to satisfy the time requirements of each mission. Tracking and ranging needs to be performed on a regular basis (one to three times per orbit) to establish accurate orbital parameters. Certain missions may require knowledge of state vectors at specific times. Status telemetry may be necessary on an almost continuous basis. Voice and experiment telemetry are random requirements, but may require operation for a period of more than one orbit on as continuous a basis as possible. Contact time per orbit depends on the orbital altitude, orbital inclination and the location of ground stations. NASA reference ground model defines the use of Goldstone, Madrid, Canberra, Rosman and Fairbanks. All of these are 85-foot antenna stations. Use of these ground stations, with their attendant narrow beam antenna patterns (85 feet = 0.3 degree), dictates efficient planning to optimize contact time. Two types of operation are possible. Figure 2.9-1 illustrates the types of operation and the flow that is described below. One type of operation is that associated with the situation where the ground station is dedicated on a full-time basis to the space element mission. In this case, all operations will be prescheduled and each ground network station will acquire and perform previously scheduled functions whenever the element is in its view.

Space element operational procedures are associated with equipment monitor and control to provide the proper data transfer. If the ground station is not dedicated to the particular space element mission, but is used on an as required basis, two types of operation result. One would be similar to the dedicated type mission, utilizing a prearranged contact schedule. The only difference from dedicated is that the ground stations must be ready to acquire signal at the prearranged time and the element must ensure the availability of a singal at this time. It is also possible that contacts need to be made at unscheduled times, initiated by either the space element or ground. In this case, if the space element wishes to establish contact, there are two choices dependent on the urgency of the situation. One is to alert the ground during the last scheduled contact prior to the unscheduled operation. If there is a gap, and the ground must be contacted, other than S-band must be used. If there is a gap, and ground must be contacted, other than S-band must be used, since the S-band link is constrained by the field of view of the ground system antenna. Alert signals or voice could be used via TDRS or direct to ground (voice only). VHF TDRS and ground antenna systems have a wide enough field of view to receive the space element signal whenever it is in line of sight of the station. After being alerted, normal acquisition and contact can be implemented. Ground to element unscheduled contact is simpler since the S-band space element terminal utilizes a semi-directive antenna that can be illuminated from ground whenever necessary. Both type operations require that continuous monitoring of the link frequency be implemented by ensuring a live receiver at the proper frequency and the existence of some type of alert indication to the system operators. A typical set of operational sequence for the element to ground is included.

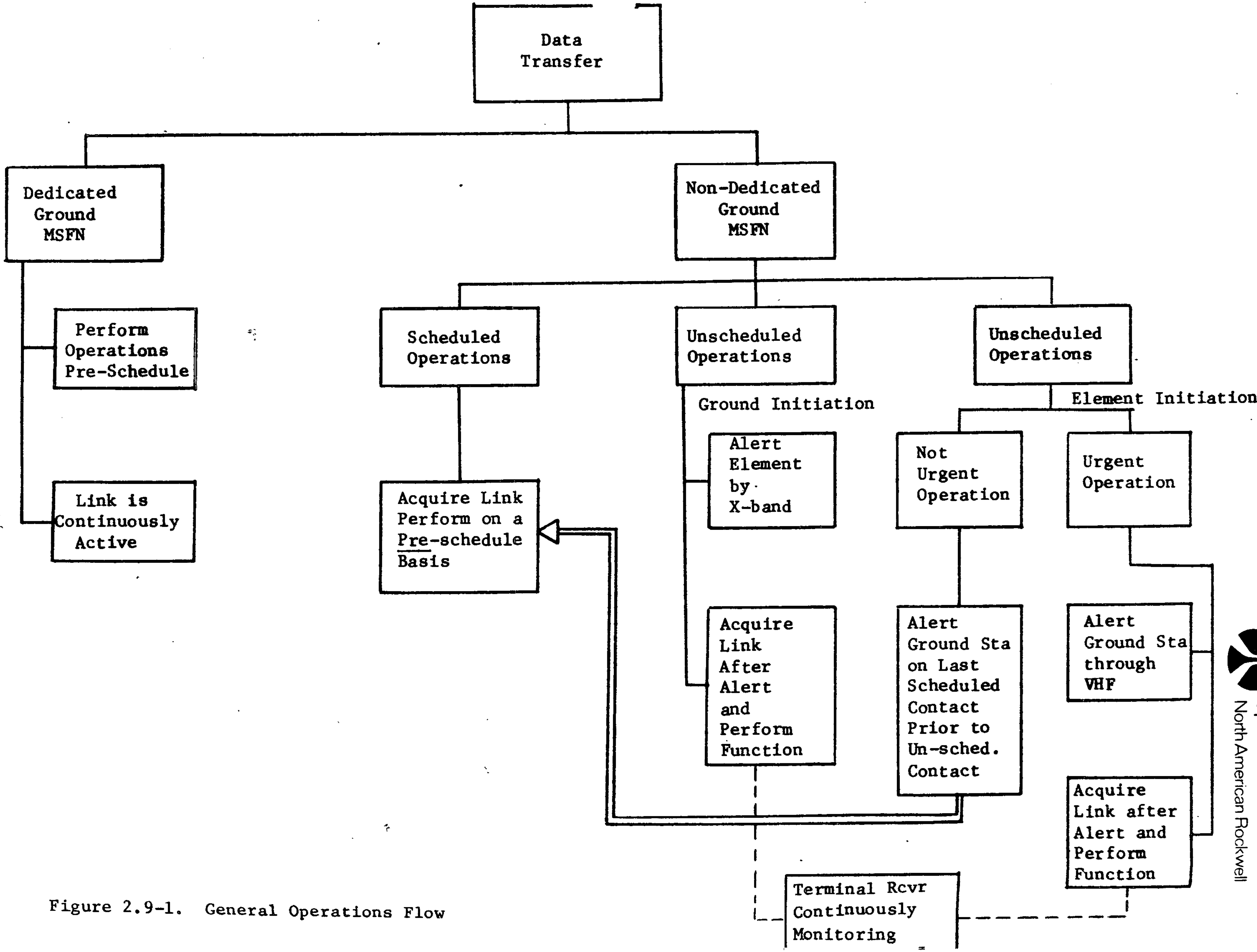

Figure 2.9-1. General Operations Flow

OPERATIONAL PROCEDURE NO. 9-1

TITLE: COMMUNICATIONS--ELEMENT TO GROUND--DIRECT

ELEMENT INTERFACES: EARTH ORBITAL SHUTTLE--GROUND

	Operation	Performed by:	Rationale
	FOR PRESCHEDULED SITUATION--DATA TRANSFER		
1.	Transmit signal, activate S-band receiver	Space Element	Provides signal for ground acquisition
2.	Orient antenna to prescheduled orbital position	Ground Station	To ensure contact ASAP after element entry into field-of-view of ground antenna
3.	Activate receiver, acquire signal and put antenna in auto-track mode	Ground Station	
4.	After acquisition, transmit readiness signal to space element	Ground Station	Ensure optimum data transfer--minimum data loss
5.	Activate proper modulator, route data to modulator, start transmission	Space Element	Initiates data transfer
6.	Receive signal, route to destination	Ground Station	For end use, either listen, display or record and route
7.	Check accuracy or quality of signal, send verification or rejection to space element	Ground Station	To ensure accurate signal transfer
8.	Continue data transmission	Space Element	After verification

OPERATIONAL PROCEDURE NO. 9-1

Operation		Performed by:	Rationale
9.	Alert next ground station to orient antenna for space element acquisition	Ground Mission Control Center	To allow acquisition of signal as soon as space element comes into antenna field-of-view
10.	Next sequence of operations same as steps 2 through 8	Ground and Space Element	Continues data transfer for length of time required
11.	Send end of message signal to ground when applicable	Space Element	Terminate data transfer when completed
12.	Terminate link operations	Ground	To allow ground station to implement other links
13.	Stop all transmissions but leave receiver live	Space Element	In readiness for next scheduled operation or a ground alert for contact. Reduces power drain.
	UNSCHEDULED OPERATIONS--NOT URGENT		
1.A	Before end of last transmission, send request for data transfer at next station or on next pass	Space Element to Station Ground	Need for transmission not previously scheduled--not an urgent requirement
1.B	Schedule acquisition and data transfer operation for next station or on next pass	Ground	To ensure readiness to handle requirement
1.C to 8.A	Perform operations 1 through 8 same as Prescheduled Situation	Ground and Space Element	These operations are the same once contact has been established

OPERATIONAL PROCEDURE NO. 9-1

Operation		Performed by:	Rationale
11.A to 13.A	Terminate contact in same manner as steps 11 through 13 of Prescheduled Situation	Ground and Space Element	No difference between unscheduled and prescheduled operations for these steps
	UNSCHEDULED OPERATIONS--URGENT		
1.A	Activate alert transmission	Space Element	To request unscheduled operation--can use VHF (136-144 MHz) through TDRS--or VHF (225-400 MHz)* direct to ground--these are non-directive antenna systems(1).
1.B	Ground receives alert alarm and acknowledges contact	Ground Station or TDRS Ground Station	Ground stations must be continuously monitoring space element frequency(2).
1.C	Transmit request for audience	Space Element	
1.D	Verify contact, transmit readiness signal to receive request	Ground Station	Ensure readiness and link establishment

*If Available

(1) Need availability of link other than "S" band since space element must be in "FOV" of MSFN "S" band antenna.

(2) Either on VHF or "S" band.

OPERATIONAL PROCEDURE NO. 9-1

	Operation	Performed by:	Rationale
1.E	Transmit request or data	Space Element	
1.F	Activate "S" band system, orient antenna to intercept and acquire space element	Ground Station	"S" band link is needed if data is either TV or needs data rate transfer >10 Kbps (1)
	Perform operations same as remainder of steps 4 and over from Prescheduled Operation as applicable	Ground and Space Element	
	COMMAND AND CONTROL OF ELEMENT		
1.	Element control center initiates command request to mission control center	Element Control Center	To activate a specific element operation. All control must go through MCC
2.	Alerts specific ground station	MCC	To schedule and initiate antenna orientation for acquisition of element
3.	Receives request, orients antenna and sends readiness signal to MCC	Ground Station	Use "S" band--high gain antenna and system (2)
4.	MCC issues commands to ground station	MCC	

(1) Orientation and auto-track procedures same as prescheduled steps.

(2) Same steps as prescheduled data transfer for orientation and auto-track or must computer track until element signal is available for auto-track.

OPERATIONAL PROCEDURE NO. 9-1

	Operation	Performed by:	Rationale
5.	Receives command, verifies link acquisition with element, sends command	Ground Station	Ensures element can receive command prior to transmission
6.	Receives command data, decodes, processs, holds and returns verification	Element	To ensure proper command reception
7.	Transmit command execute signal	Ground Station	
8.	Monitor command operation, translate to digital format and transmit	Element	To send verification of command completion to Ground Control
9.	Receives command monitor data and verifies completion of command	Ground Station to MCC	Ensures activity has been accomplished in accordance with plan
10.	Terminates contact with element as applicable	Ground Station	To release Ground Station for other operations (1)

(1) If the contact time is not long enough for the series of commands, it may be necessary to schedule more than one ground station to complete the transmission. The same sequence of events are used to perform the command transfer with subsequent ground stations. Handover from one to another can be accomplished when the element is in view of both stations at the same time. If this is not true, a gap may need to be tolerated before the next ground station acquires signal lock. Steps 9 through 13 of Prescheduled data transfer would be used for this handover.

OPERATIONAL PROCEDURE NO. 9-1

	Operation	Performed by:	Rationale
	UNSCHEDULED OPERATIONS (URGENT OR NON-URGENT) GROUND INITIATED--DATA TRANSFER		
1.	"S" band receiver is live in listening mode	Element	To be available for alert signals--element S-band antennas are semi-directive and can receive any signal transmitted from ground on assigned frequency
2.	Element control center requests data transfer to element	Element Control Center	To inititate unscheduled operations
3.	Mission control center receives request, checks element orbital parameters, requests proper ground station to point "S-band" antenna at computed position and become ready for data transmission	Mission Control Center	Mission control center has computer file on predicted orbital parameters and chooses ground station that is in view of space element
4.	Receives request, orients antenna to point at predicted orbit and tracks by computer commands, acknowledges request and confirms readiness to MCC	Ground Station	Computer controls antenna until signal from element is acquired tracking starts when element comes in view over horizon
5.	Issues command to element to activate proper demodulators and to transmit a beacon signal	MCC and Ground Station	To alert element to need for contact and to provide signal so ground station can auto-track

OPERATIONAL PROCEDURE NO. 9-1

	Operation	Performed by:	Rationale
6.	Receives command, activates demodulator, activates transmitter, transmits verification and readiness signal	Element	To ensure proper equipment is activated for data reception
7.	Receives signals including verification and readiness and advises element control center	Ground Station and MCC	
8.	Starts data transmission on command or receipt from element control center	MCC and Ground Station	(1)
9.	Simultaneously, puts "S band" antenna in auto-track mode	Ground Station	Begins after acquisition of element signal
10.	Receives data, routes to proper location	Space Element	For processing, recording, or display
11.	Send end of message signal when applicable and terminate transmission	Ground Station	To verify completion and release Ground Station for other operations
12.	Turn off transmitter, leave receiver live	Space Element	To delete unnecessary power consumption and release frequency

(1) If ground request is for data from the space element, procedure is to go through operational sequence to command proper data transmission and then perform data transfer as per data transfer operational sequence.

OPERATIONAL PROCEDURE NO. 9-1

Operation		Performed by:	Rationale
	PRESCHEDULED OR UNSCHEDULED TRACKING AND RANGING		
1.	Transponder is active--receiver listening and transmitter is transmitting signal	Space Element	Either by prescheduled operation or by prior ground command to activate transponder--to provide signal for auto-tracking and path for ranging.
2.	Orient "S band" antenna to predicted orbital position	Ground Station	To be ready for space element contact
3.	Puts "S band" antenna in auto-track mode	Ground Station	After space element comes in antenna field-of-view and element signal is acquired
4.	Transmit PRN ranging code to space element	Ground Station	To initiate ranging operation
5.	Extract antenna pointing angles (A_Z/E_L) from antenna gimbal servo error signals (auto-track processor)	Ground Station	For calculation of Space Element state vectors
6.	Receive PRN range code route through transponder transmitter and transmits signal		
7.	Receives turn-around range code	Ground Station	
8.	Perform correlation function	Ground Station	To compute range by measurement of round trip time

OPERATIONAL PROCEDURE NO. 9-1

	Operation	Performed by:	Rationale
9.	Extract doppler frequency shift from T-A signal	Ground Station	To compute range-rate
10.	Route tracking data, range rate, range data to computer	Ground Station	For calculation of orbital parameters and element state vectors
11.	Perform calculations, route resulting data for transmission, display and/or recording	Ground Station	To provide data to element for navigation, to control or for position monitoring
12.	Deactivate ranging function alert space element to completion	Ground Station	To provide availability of link for other possible data
13.	Turn-ranging transponder transmitter off	Space Element	To conserve power and keep frequency spectrum clear

OPERATIONAL PROCEDURE NO. 9.2

Communications--Element to TDRS

Assumptions

In accordance with NASA Model (DS-504), the TDRSS will be a system of two satellites at 15°W and 145°W in an equatorial orbit. Each satellite will contain the capability to support communications user spacecraft links on Ku band (2 each) and VHF (20 each). VHF is usable for voice and low data rates ($\leq$10 Kbps) while Ku band is usable for data rates up to 50 Mbps per channel. Details are noted in functional requirements. Operations must consider the need for a VHF order wire to alert TDRS and to be alerted by TDRS. This requires the need for a live VHF wake-up receiver to support the initiation of unscheduled operations with TDRS.

Initial Conditions

The space element in a quiescent state and contains a live VHF wake-up receiver alert and available to receive command signals. It is in a predictable orbit that is programmed in the ground control center so that TDRS may point to the proper position. Since communications is a supporting activity, the time and duration of the operation depends on the activity being supported.

Final Conditions

After completion of communications support, the terminal equipment is de-activated and returned to a quiescent state, i.e., a live VHF wake-up receiver is available. This allows conservation of the space element power and leaves the TDRS channel available for other operations.

Description

Orbital operations for the element to TDRS link involve all the same activities as the element to ground direct link. Since the TDRS is used as a communications relay for the element to ground link these element operations are impacted by TDRS characteristics. The primary data link from element to TDRS is in Ku band. VHF is used for voice, low data rate transfer and command signals. Ku band operation requires high gain, directive antennas on the orbital element, capable of auto-tracking the TDRS. Ranging can be performed by ground via the TDRS. Tracking for position determination is performed by successive measurements by a single TDRS or by utilizing two TDRS's. Reference DS-504 gives tracking uncertainties between 2 to 6 meters for range and 0.05 to 0.6 meters (10 second to 1 second integration times) for range-rate for basic equipment.

TDRS characteristics that impact the space element are included in Table 2.9-1. Unless otherwise stated these characteristics are derived from the NASA reference model (Reference DS-504). Some characteristics were not included in this reference but from the NASA RFP for the TDRS (Reference DS-503) and are identified in Table 2.9-1.

As noted in the characteristics, only two return link channels are available for high data rate transfer. Thus, high data rate channel use must be scheduled in advance either by pre-mission planning or by request via the TDRS VHF channels. All data transfer contacts must be processed through ground TDRS control. Upon request, either advance pre-scheduled or new schedule, the TDRS control can command TDRS to point its Ku band antenna to the predicted orbital position and acquire the user signal. User element Ku-band antenna system must in the meantime be commanded to point at the TDRS.

Twenty low data rate return channels are available at each TDRS by user elements. Pre-scheduling is probably necessary for these links but not as critical as for high data rate transfer. VHF antennas do not require pointing and thus signal acquisition is simpler. Data rates are, of course, limited to 10 Kbps. A single voice channel can also be supported.

The operational sequences will portray those operations unique to the element to TDRS interfacing activity. Only those activities required during element orbital operations will be covered. These include element command and control from ground via TDRS, tracking and ranging through TDRS and the transfer of data either digital or analog-to-ground via TDRS.

Table 2.9-1. TDRS Characteristics

User Rate	Forward Link Ground to TDRS to Element			Return Link Element to TDRS to Ground		
	Data Rate	Frequency MHz	Channels	Data Rate	Frequency MH_z	Channels
Low	100 1000 bps (Ø)	VHF* 126 - 130	2 - (Ø)	100 bps 10 Kbps	VHF* 136 - 144	20 - 10 Kbps +1 Voice
High	100 1000 bps (Ø) Analog Data to TV	Ku* 13.4 - 14.2 GHz	1 - (Ø)	1 Mbps (Ø)	Ku* 14.4 - 15.35 GHz	2 - 50 Mbps* --- Color TV

(Ø) From TDRS RFP of May 11, 1971. Reference DS-503.

* From NASA Model Reference DS-504.

OPERATIONAL PROCEDURE NO. 9-2

TITLE: COMMUNICATIONS

ELEMENT INTERFACES: ELEMENT TO GROUND VIA TDRS

	Operation	Performed by:	Rationale
	COMMAND AND CONTROL OF ELEMENT		
1.	Element control center initiates command request to TDRS ground station	Element	To activate a specific element operation
2.	Command transmitted	From TDRS Ground Station to TDRS	Ground to TDRS link is on Ku band
3.	Signal received/frequency translated and signal transmitted	TDRS	Ground to TDRS is Ku band/translation to either another Ku frequency or VHF (1)
4.	Receive command data, decode, process, hold and return	Element	To ensure proper command reception
5.	Receive command verification, decode and compare to command transmission	Ground from TDRS from Element	TDRS again acts as a relay by frequency translating signal from element to ground Ku band frequency

(1) Most commands can be transmitted over the VHF TDRS to element channel. No antenna orientation is necessary at VHF. If commands are to be transferred via Ku band, the element Ku band antenna and the TDRS Ku band antenna must be oriented to point at each other and to auto-track on signals from each terminal. Acquisition of target must be verified prior to command transmission. Both Ku band antenna (element and TDRS) must therefore be commanded (or prescheduled) for the proper pointing direction. TDRS to element command may be accomplished via VHF. Ground to TDRS is performed over the normal Ku link.

OPERATIONAL PROCEDURE NO. 9-2

	Operation	Performed by:	Rationale
6.	Transmit command; execute signal	Ground to Element via TDRS	TDRS again accomplishes frequency translation to transmit to space element
7.	Receives command executes command by releasing and routing command signal to terminal point	Element	Actual command accomplishment
8.	Monitor command operation, translate to digital format and transmit	Element to TDRS to Ground	To send verification of command completion to ground control
9.	Receive command monitor data and verify completion of command	Ground from element via TDRS	TDRS again performs relay function
10.	Terminate all transmission to element as necessary	Ground to Element via TDRS	Or continues with sequence of further commands as required(1)

(1) If command link needs to be maintained for a period of time that requires contact with two TDRS's for continuity, a handover procedure will need to be followed. This would include orientation of both element and TDRS antennas to acquire each other and then continuance with second TDRS in same manner as steps for TDRS No. 1. If the element has two Ku band tracking antennas, it may be possible to orient the second antenna to the new pointing position and obtain handover with no interruption. According to orbital altitudes, there may be short periods where both TDRS's are occulted. Figure 2.9-2 illustrates this possibility.

OPERATIONAL PROCEDURE NO. 9-2

	Operation	Performed by:	Rationale
	TRACKING AND RANGING OF SPACE ELEMENT		
1.	Request for tracking and ranging to be performed	Element Control Center (Ground)	To determine element ephemerides
2.	Initiate tracking and ranging activity	TDRS Control	
3.	Transmits commands to TDRS to orient antenna to predicted element position	TDRS Control	Element control provides previously computed and updated orbital data
4.	Orients antenna to element predicted point	TDRS	Ku band TDRS antenna Beamwidth = 1 degree at 3 db points (1)
5.	Command transmitted to orient element antenna to point at TDRS	TDRS Control via TDRS	Command follows same procedure* as steps under command/control operational sequence (2)

(1) The TDRS antenna is continuously controlled by ground program either computer directed or by signal quality loop.

* See steps 2 through 9 of Command and Control of Element.

(2) Verification of command then execute may be unnecessary. Operation will be confirmed by acquisition of signal. Command to element for antenna orientation may be accomplished over the TDRS/Element VHF link or may be a preprogrammed scheduled operation.

OPERATIONAL PROCEDURE NO. 9-2

	Operation	Performed by:	Rationale
6.	Orient antenna and transmit signal	Element	Signal transmission is necessary to provide link acquisition
7.	Confirm link acquisition, command TDRS antenna to auto-track element	TDRS Control	Element antenna must also be placed on auto-track
8.	Transmit PRN ranging code from range code generator	TDRS Ground Station	
9.	Receive PRN code, translate frequency, transmit on Ku element frequency	TDRS	Ranging signal is repeated through TDRS. Delay time through TDRS is known--previously calibrated
10.	Receive range code route through transponder transmitter	Element	Provides turn-around ranging signal to ground processing
11.	Receive turn-around ranging signal, translates frequency, retransmits on Ku ground frequency	TDRS	Turn-around ranging signal is repeated through TDRS to ground. Delay time through TDRS is known--previously calibrated.

OPERATIONAL PROCEDURE NO. 9-2

	Operation	Performed by:	Rationale
12.	Receives turn-around range signal, processes, computes range, range rate numbers	TDRS Ground Station	Range rate computed from doppler shift extracted from carrier or by successive range measurements.(1), (2)
13.	Route tracking and ranging data to computer center	TDRS Control Center	To perform calculation of orbital parameters and element ephemerides
14.	Calculate ephemerides, format and transmit data to required terminal points	TDRS Control Center	To either mission control for element control or to element through TDRS for update of navigation parameters

(1) The processing of range and range rate must consider the delay times in the TDRS repeater operation (both ways) and any time jitter associated with this operation. TDRS position and movement in relation to the ground station must also be accounted for to accomplish accurate measurements.

(2) It is likely that range and range rate measurements should be made via both TDRS's when the element is in view of both. Figure 2.9-3 shows that a single TDRS range measurement would take more than 30 minutes to reach position uncertainties of less than 1 kilometer. With simultaneous tracking by two TDRS's, these uncertainties can be reduced to less than 100 meters within 5 minutes. Simultaneous operation to two TDRS's, however, adds considerable complexity to the element Ku band system. A requirement for two Ku band systems with separately pointed antennas is imposed on the element. The narrow beamwidths of these antennas and the 130 degre separation of TDRS's causes this requirement. Further studies should be made to determine the feasibility of TDRS tracking.

OPERATIONAL PROCEDURE NO. 9-2

	Operation	Performed by:	Rationale
15.	Continue tracking and ranging function as applicable	TDRS Control TDRS Element	Continue for period that ensures accuracy required for specific operation(1)
16.	When applicable discontinue tracking and ranging and issue command deactivate this loop	TDRS Ground Control	Perform command functions similar to normal commands and release equipment for other uses
	PRESCHEDULED OPERATION		
1.	At prescheduled time, transmit commands to orient TDRS-element Ku antennas to proper pointing angles	TDRS control	To put both TDRS and element in readiness for Ku band contact utilizes predicted orbital parameters
2.	TDRS and element receive command, orient antennas and sends verification signals	TDRS and Element	Element can verify either over Ku band or VHF link. Ground control must continue to command antenna orientation by computer program until link is established and auto-track initiated
3.	Transmit command to element to activate proper terminal equipment and start transmission	TDRS Ground Control	Command can be processed through TDRS to element. Antennas are in auto-track mode
4.	Receives command, activates equipment, starts transmission	Element from TDRS	Activation of sensors, recorders, modulators, etc., according to type of data transfer

(1) It TDRS handover is necessary, it is described under data transfer and command operations.

OPERATIONAL PROCEDURE NO. 9-2

	Operation	Performed by:	Rationale
5.	Receives signals, translates frequency, transmits to ground	TDRS	
6.	Receives signals, confirms quality, routes to element control center	TDRS Ground	Ensures quality of signal
7.	Data transfer continues as long as necessary	Element to TDRS to Ground	If transfer continues until out of view of TDRS No. 1, handover to No. 2 TDRS necessary
8.	Perform handover maneuver to TDRS No. 2 if necessary	TDRS Ground	TDRS ground control initiates commands similar to steps No. 1-6 for TDRS No. 2 link(1)
9.	Issue commands to terminate link, when applicable	TDRS Ground Control	Involves same command sequences to both TDRS and element as steps 1 through 4 but results in deactivation of link by shutting down element terminal and TDRS--element operation

(1) Prescheduled handover is performed by commands to the second TDRS while the first TDRS is still in view of the element. If the element has two Ku band systems and antennas, the second antenna may be oriented to the second TDRS and the link acquired and data transfer continued without interruption. If the element has only one antenna, it must be command via TDRS to reorient its Ku antenna and repeat any data transfer missed during the interruption until re-acquisition and confirmation of link operation. After acquisition and confirmation, data transfer may continue as applicable. Similar operational procedures will need to be initiated for elements at low altitudes when the data transfer continues for more than one orbit. Loss of view of both TDRS's may occur for a short period. Reorientation, signal acquisition, configuration and continuation of data transfer. Figure 2.9-2 illustrates typical viewing situations of element to TDRS for both two-TDRS view period and loss of contact time.

OPERATIONAL PROCEDURE NO. 9-2

	Operation	Performed by:	Rationale
10.	Receives command, stops transmission, turns off all Ku equipment	Element	To save power consumption, Ku band system can be awakened via VHF or S-band direct from ground
11.	Receives command, release Ku band system to operate with other elements	TDRS	To provide TDRS availability to other users

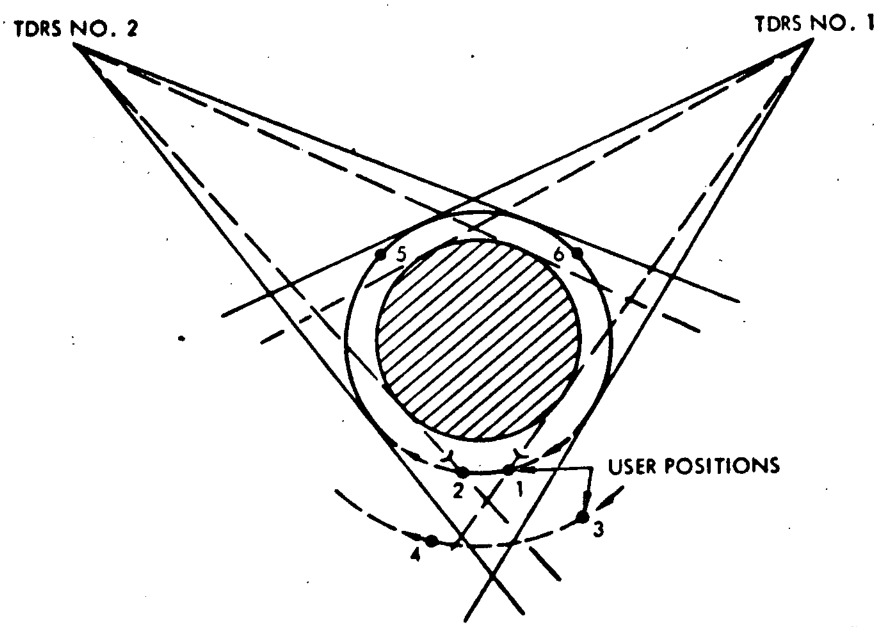

Figure 2.9-2. Acquisition/Handover of MDR Users

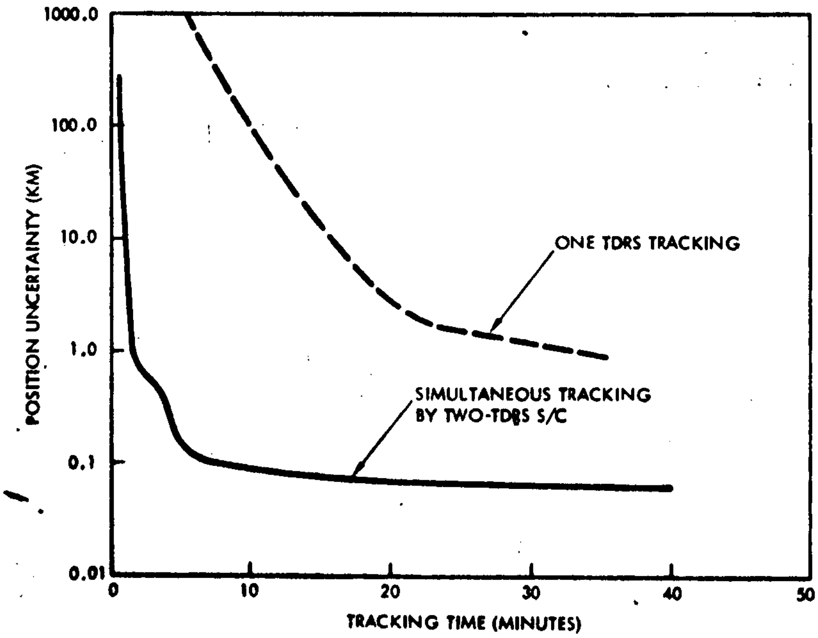

Figure 2.9-3. User Spacecraft Tracking Accuracies

Communications--Element to TDRS--Unscheduled Operations

As pointed out in the element-to-ground operations, there may be a requirement for unscheduled-urgent or non-urgent operations. These could be either element or ground initiated. Since the TDRS operation must be controlled and scheduled by TDRS Ground Control, these special requirements must be requested through TDRS Ground Control. A space element urgent request can be made through the TDRS via the VHF element/TDRS link or, if available, via element/ground network link. Non-urgent, element initiated requests can be scheduled at the end of a prior transmission or in the same manner as above. Ground initiated requests from the Element Control Center wiuld be given directly to TDRS Ground Control. All operations after request acceptance, would be implemented in the same manner as listed for the scheduled operations.

OPERATIONAL PROCEDURE NO. 9-3

Communications--Element-to-Element

Assumptions

Since most elements will operate with ground and/or TDRS during their operations, the same frequency and modulation type links are assumed to be utilized during element-to-element communications operations. This establishes Ku, S and VHF bands as the communication link frequencies. It is generally assumed that the controlling element is a manned element. It is possible, however, that both units could be un-manned. In this case, the controlling element would require an automated system-sequence timer or computer operated timing--to initiate and control the operations.

Initial Conditions

All communications equipment is in a quiescent state with controlled element containing a live wake-up receiver that is alert and ready to receive any command signals from the controlling element.

Final Conditions

The communications equipment is de-activated and placed in quiescent state as described under initial conditions.

Description

During orbital operations, element-to-element operation involves the transfer of data between elements, command, tracking and ranging of the controlled element (probably unmanned) by a controlling element (probably manned). Data transfer will vary according to the mission ranging from low rate telemetry data (up to 10 Kbps) to digital experimental data (up to 50 Mbps) or analog TV of 2.9 MHz baseband. Operations of the unmanned element will be controlled by the manned element to perform mission activities. This command and control provided by the communications link digital command transmission will initiate all experimental tasks and orbital maneuvers of the element. Efficient and accurate accomplishment of these activities necessitates the accurate knowledge of the controlled element orbital parameters and ephemerides. This, in turn, requires that the controlling element must know its position accurately, if it performs the ranging and tracking of the detailed element directly. An alternate method would be to establish position information at the controlled element. Figure 2.9-4 illustrates the links established for the communications element-to-element interface activity. Tracking of the controlled element requires a tracking antenna system on the controlling element. Ranging requires that the PRN range system be implemented on both ends. Turn-around transponding capability is necessary in the controlled element. The controlling element needs the capability to transmit the PRN signal, receive the turned-around signal from the target vehicle and compute the range and range rate of the target vehicle. All of these operations need to be performed at a time consistent with mission support. Tracking and ranging are needed as required consistent with the mission. The controlled vehicle must continuously monitor the command and control frequency to be ready for mission performance. Certain activities will probably be automatically performed and timelines prescheduled. All other activities will be performed at the initiation and direction of the controlling element. Operational sequence for element-to-element operations will be classified as follows:

I. Controlling to Controlled Element

A. Transmission of command data and/or computer data

B. Ranging and/or tracking

II. Controlling Element to Controlled Element

Transmission of digital and analog data

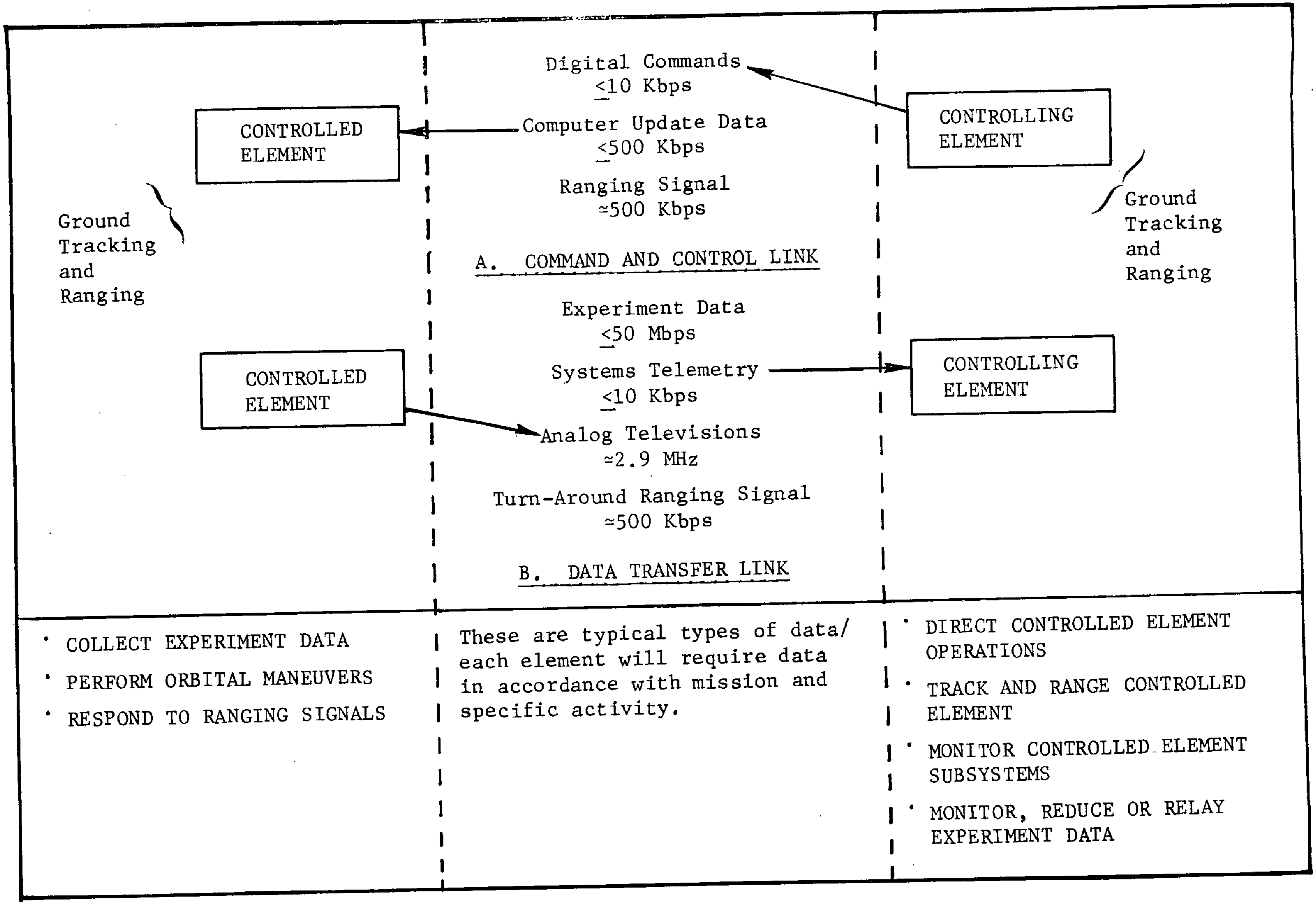

Figure 2.9-4. Communication Link Interface

OPERATIONAL PROCEDURE NO. 9-3

TITLE: COMMUNICATIONS

ELEMENT INTERFACES: ELEMENT-TO-ELEMENT

	Operation	Performed by:	Rationale
	TRANSMISSION OF COMMAND DATA		
1.	Activate command transmitter, send command signal for activation of command processing	Control-ling Element	To prepare controlled vehicle for reception of commands
2.	Activate command processing equipment send readiness signal	Control-led Element	
3.	Send command data	Control-ling Element	To control specific activities
4.	Receive command data, decode, process, hold and return verifi-cation of commands	Control-led Element	
5.	Receive command verification, decode and compare to command transmission	Control-ling Element	To ensure correctness of received command
6.	Transmit command to initiate verified commands	Control-ling Element	
7.	Receives initiate command, releases and route command data to terminal point	Control-led Element	

OPERATIONAL PROCEDURE NO. 9-3

Operation		Performed by:	Rationale
8.	Monitor command operation, translate to digital format and transmit	Controlled Element	To send verification of command completion to ground control
9.	Receive command monitor data and verify completion of command	Control-ling Element	Ensure proper completion of command
10.	When applicable, transmit de-activate signal	Control-ling Element	To put controlled element in standby condition
11.	Receives de-activate signal, puts communication terminal in standby condition (receiver on-ready for activation signal)	Controlled Element	To reduce power requirements
12.	Terminate all transmission to controlled element	Control-ling Element	
	PERFORMANCE OF TRACKING AND RANGING		
1.	Establish tracking and ranging link by sending command to (controlled element) activate transponder transmitter	Control-ling Element	To ensure availability of ranging transponder and signal for tracking
2.	Receive command, activate transponder	Controlled Element	

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OPERATIONAL PROCEDURE NO. 9-3

Operation		Performed by:	Rationale
3.	Transmit PRN range code	Controlling Element	
4.	Receive PRN code, route to transponder transmitter and transmit	Controlled Element	To provide signal to controlling element for processing and range calculation
5.	Receives turned-around PRN ranging code and routes to range computer	Controlling Element	
6.	Performs range and range rate calculation	Controlling Element	
7.	Switch tracking antenna to auto-track mode	Controlling Element	Utilizes signal being transmitted by controlled element for auto-track operation and processing
8.	Extract tracking information from auto-track error signals	Controlling Element	To determine controlling element direction in relation to controlled element
9.	Compute ephemerides of controlling element by utilizing this information (range, range rate and tracking data) and controlling element ephemeris data	Controlling Element	To obtain accurate ephemeris data

OPERATIONAL PROCEDURE NO. 9-3

	Operation	Performed by:	Rationale
10.	Utilize data for required operations	Controlling Element	For pointing of sensors, maneuvering of controlled element, information, etc.
11.	Continue ranging and tracking for as long as necessary	Controlling Element	To ensure timely and accurate ephemeris data
12.	Terminate tracking and ranging as applicable	Controlling Element	
13.	De-activate ranging transmitter and range code generator	Controlling Element	To release tracking and ranging function for other element operations
14.	Transmit command to de-activate ranging transponder transmitter	Controlling Element	
15.	Receive command, de-activate transponder transmitter	Controlling Element	To reduce power consumption, and de-activate unnecessary systems
	TRANSFER OF DATA (ANALOG OR DIGITAL) FROM CONTROLLED ELEMENT		
1.	Activate command transmitter, send command signal for activation of command processing	Controlling Element	To prepare controlled vehicle for reception of commands

OPERATIONAL PROCEDURE NO. 9-4

	Operation	Performed by:	Rationale
2.	Activate command processing equipment send readiness signal	Controlled Element	
3.	Send command to start data transfer	Controlling Element	Command includes proper address and code to activate required data route and mode specific to the particular requirement(1)
4.	Receive command data, decode, process, hold and return verification of commands	Controlled Element	To ensure correctness of received command
5.	Receive and check command verification	Controlling Element	
6.	Transmit initiation of data transfer command	Controlling Element	
7.	Receive command, activates activity, starts transmission of data	Controlled Element	Initiates the required data transfer

(1) According to the type of activity and the necessary data transfer--i.e., digital--bandwith--voice to television--specific combinations of communication equipment need to be activated. Specific modulation modes, frequency bands and antennae are needed for each case. Data could either be a real time transfer of experimental data or the dump of data from a tape recorder.

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OPERATIONAL PROCEDURE NO. 9-4

	Operation	Performed by:	Rationale
8.	Receive data and route to applicable terminal use	Controlling Element	Data is routed to displays and/or recorder for real time utilization or recording for later data reduction and/or transmission to ground
9.	Monitor data and perform necessary operations on data	Controlling Element	Ensure adequacy of data, use for other control activities, etc.
10.	When applicable, transmit de-activate signal	Controlling Element	
11.	Receive de-activate signal, puts communication terminal in standby condition	Controlled Element	Receiver is on, ready for activation signal

2.9.2 PROCEDURES APPLICABILITY

Communications is a supporting activity to other orbital operations activities. Examination of the element pair matrix (Figure 2.9-5) indicates that only element-to-element orbital pairs are included. For these pairs, the alternate approach for element-to-element communications is the only applicable operational procedure. There is, however, the requirement in most cases to communicate with ground, for data transfer and/or monitor and control of the orbiting element. Thus, most orbiting elements will need to interface with ground utilizing either a direct to ground link or the link through TDRS to ground. Under certain circumstances, the element-to-ground link might also be used for element-to-element communications. This would occur if the orbital elements were out of communications line of sight with each other. The communications link would probably not be a direct relay, but rather an element-to-ground transmission, a deciphering by ground control, a ground control decision, and then finally a ground-to-element transmission. The basic area for examination of commonality is the communication frequency band or bands to be utilized for element-to-element interface that will account for compatibility with the element-to-ground frequency bands. As discussed in the functional requirements section (Volume II), this involves an iteration of requirements to ensure the proper choice of parameters to fulfill all the requirements with equipment commonality and complexity considerations.

		SPACE PROGRAM ELEMENTS																
		EOS	TUG		RAM				SATELLITE			EO RESUP. MODS	LOW EO MSS	CPS		RNS CLS	OLS	OPD
			RTN	SPACE BASED	ATT. EOS	DET. EOS	ATT. MSS	DET. MSS	EOS DELIV.	EOS + 3RD ST DELIV.	RETR, RESUP.			OIS	CLS			
	EOS	3	3	3	3	3	NA	3	3	3	3	NA	3		3	3	3	3
TUG	RETURNABLE	NA								NA								
	SPACE BASED	NA		3			NA	3		NA	3	NA	3	3	3	3	3	3
RAM	ATT. EOS	NA																
	DET. EOS	NA																
	ATT. MSS	NA		NA									NA					
	DET. MSS	NA		NA									3					
SATEL	EOS DELIV.	NA																
	EOS + 3RD ST	NA	NA	NA														
	RETR, RESUP.	NA		NA														
	EO RESUP. MODS	NA		NA								NA	NA		NA	NA		NA
	LOW EO MSS	NA		NA			NA	NA				NA	NA					
CPS	OIS			NA											3	3	3	3
	CLS	NA		NA								NA		NA	3		3	3
	RNS-CLS	NA		NA								NA		NA		NA	3	3
	OLS	NA		NA										NA	NA	NA	NA	
	OPD	NA		NA								NA		NA	NA	NA		NA

NOTE:

The communications links are bi-directional in every case, necessitating the completion of the upper half of the matrix only. The Operational Procedures 2.9-1 and 2.9-2 utilize ground and TDRS and are not shown on this chart as interfacing elements. Therefore, Procedure 2.9-3 is the only element-to-element operational procedure applicable on this matrix. Procedures 2.9-1 and 2.9-2 are, however, applicable for use with every orbiting element.

NA - Not Applicable

Figure 2.9-5. Operational Procedures Applicability - Interface Activity: Communications

2.10 RENDEZVOUS

This section presents the operational procedures for rendezvous, and includes one procedure for each alternate approach identified in Volume II of this report. Also presented and discussed is the applicability of these procedures to each element pair included in the in-depth analysis portion of the Orbital Operations Study.

2.10.1 OPERATIONAL PROCEDURES

The sequences of events which occur when rendezvous is conducted via the independent approach (with either the passive or active element in command), the ground control or space control approach (three procedures in all) are presented in this subsection. One procedure can be utilized for either ground or space control rendezvous by utilizing the term controller to indicate either the space control element or the ground control system element. Procedure 10-3 introduction indicates in greater detail the proper application and differences. These procedures, while for a specific approach, are general to the extent that they can be applied to any applicable element pair as identified in subsection 2.10.2 and are applicable to any particular flight plan. No specific flight plan or definitive number of impulse maneuvers are assumed necessary to achieve rendezvous. All the operations preceding and following any delta-V maneuver are defined. Most rendezvous procedures do need at least three delta-V maneuvers including the terminal phase initiation (TPI) maneuver to establish the active rendezvous element on a terminal intercept trajectory with a target point in space or a passive rendezvous (target) element. The actual number of impulse delta-V maneuvers required during any particular rendezvous is dependent on the orbital phasing, orbital transfer, and plane change maneuvers required.

Figure 2.10-1 indicates the basic procedure flow and the differences between the two major alternate approaches, i.e., Independent and Separate Control (Space or Ground).

Terms used in this diagram are explained below:

1. Rendezvous Control Center (RCC). The RCC is a manned center which is in command and control of all rendezvous operations. The RCC may be located on the ground or on-board an earth orbiting space element.

2. Controlling Element or Controller. The controlling element or controller is the home of the RCC for the rendezvous approach and procedure in question. The controlling element or controller must always be manned and may be located on:

   (a) the ground (ground control approach)
   (b) a space element not one of the rendezvous elements (space control approach)
   (c) one of the rendezvous elements (independent approach).

3. Active Element. The active element is the rendezvous element which under the direction of the RCC performs the impulse delta-V maneuvers required to effect rendezvous. The active element may be manned or unmanned. The active element if unmanned must be fully automated so that it can be operated by remote commands from the RCC via a communications link.

4. Passive Element. The passive element is the rendezvous element which serves as the target element for the active element. The passive element may be manned or unmanned.

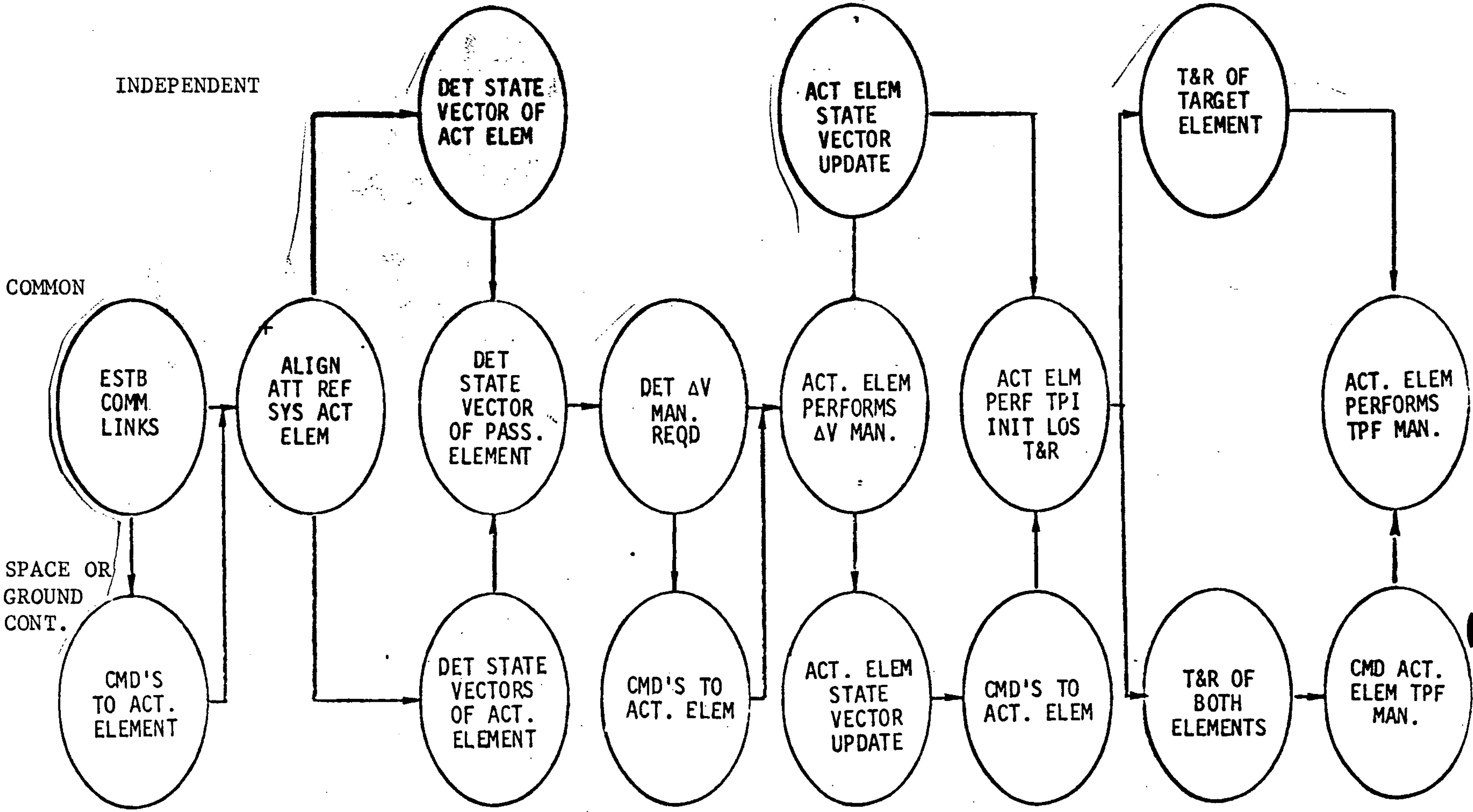

Figure 2.10-1. Comparison of Rendezvous Procedures

The initial rendezvous activity as indicated in Figure 2.10-1 consists of establishing the initial orbital parameters and ephemerides of the rendezvous elements and calculating the delta-V impulse maneuvers required to effect the necessary phasing changes and orbital transfers so that rendezvous will occur within a desired time period, usually dictated by favorable lighting conditions during terminal rendezvous. The velocity change calculation is generally determined through the use of an algorithm that may include the prediction of the future state of each element. Associated with each delta-V maneuver is a series of functions which must be performed by the active element and/or ground or space-based flight support elements. These functions involve: (1) configuring the active element for the maneuver, (2) establishing the required active element flight attitude, (3) performing the delta-V maneuver, (4) performing post-burn verification, (5) configuring the active element for orbital coasting operations, (6) determining the new state-vector and orbital parameters to determine the success of the delta-V maneuver, and (7) computing the time, magnitude, and direction of the next required delta-V maneuver. The sequence of events which follow the initial rendezvous activity start with the TPI maneuver, which puts the active element into a trajectory which will intercept the target.

The terminal phase finalization (TPF) maneuvers are planned to occur on a particular elevation angle such that the velocity changes are primarily along the line-of-sight to the passive element. The TPF maneuvers then consist of a series of braking burns required to satisfy a braking gate criteria wherein the allowable relative closing velocity between the target and the active element is limited to a value which varies with closing distance.

The operations required to effect a rendezvous between two orbiting bodies can be conducted by any of the three rendezvous alternate approaches. If the independent rendezvous approach is employed, the space navigation operations and computations required are conducted on-board one of the rendezvous elements with no up-dates required from the ground or other orbital element. This approach does require that the controlling rendezvous element have apriori knowledge of the other rendezvous elements ephemerides.

Presented for each of the procedures are operations required together with: (1) a rationale explaining the reason each operation is required, (2) which element (active, passive, or controlling) performs each operation, and (3) the functional requirements identified in Volume II which are associated with each operation.

General Assumptions

1. The controlling element whether ground or space-based has the necessary navigation and/or tracking and ranging equipment to determine the orbital parameters and state-vectors of the rendezvous elements.

2. Communications links with voice and digital data transfer capability are available between elements as well as between the space or ground control elements and the rendezvous elements.

3. The RCC has the computational capability, given the necessary input data, to compute the rendezvous element ephemerides and the delta-V maneuvers (time, magnitude, and direction) required of the active element to effect rendezvous.

4. The active element is capable of executing all required delta-V maneuvers.

5. All earth orbit rendezvous are affected by the active element/passive element approach which evolved from the Gemini Program and was used on all Apollo flights. This, however, does not preclude the passive element from having just previously made delta-V maneuvers to acquire its present orbit.

6. Near continuous communications are possible between the RCC and all rendezvous elements through use of TDRS whenever the elements are not within line-of-sight.

7. The active element must be equipped with some type of attitude reference and attitude control system and be capable of either manually or automatically orienting itself in inertial space.

8. Alignment of attitude reference systems is performed either manually or automatically,based either on on-board navigation or update from the RCC.

General Initial Conditions

Initial conditions common to all rendezvous approaches and procedures are as follows:

1. All space elements participating in rendezvous operations are in some initial earth orbit, i.e., boost to orbit procedures are not considered.

2. All participating rendezvous elements are free to perform rendezvous operations without first engaging in separation or other type activities, i.e., no other interfacing activity procedures are covered in this section.

General Final Conditions

Final conditions common to all rendezvous approaches and procedures are:

1. The active and passive elements are in close proximity in essentially identical earth orbits with zero range-rate between the two.

2. At the point that rendezvous operations cease either stationkeeping or mating operations commence.

Operational Procedure No. 10-1. Rendezvous-Independent, Passive Element in Control

Assumptions (Also see General Assumptions)

1. The passive element which in this case is also the controlling element is manned and has all of the controlling element capabilities defined under general assumptions.

2. The passive element is capable of maintaining and changing its flight attitude.

3. The passive element has both navigation and tracking and ranging equipment so that it can, with the aid of TDRS or ground network, autonomously compute both its own and the active elements orbital parameters and state-vectors.

4. The active element is either manned or fully automated and is capable of receiving, performing, and transmitting verification of commands from the controlling element.

Initial Conditions (See General Initial Conditions)

Final Conditions (See General Final Conditions)

Description

The sequence of operations for the independent rendezvous approach, with the passive element in control, is presented in Procedure 10-1. In this rendezvous approach the passive (controlling) element first establishes and verifies that all required communications links (i.e., voice, data transfer, and tracking and ranging) are operational. If the active element is unmanned and in a quiescent state, the passive element commands activation of all active element subsystems and then commands alignment of the active elements attitude reference system. The passive element then aligns its own attitude reference system and determines its own orbital parameters and state-vector. The active element orbital parameters and state-vectors are determined using either on-board navigation equipment or by direct tracking and ranging from the controlling vehicle. The controlling (passive) element then initiates the rendezvous computer program(s) and, based on the now known rendezvous element position data, computes the element ephemerides and the delta-V maneuvers required of the active element to effect rendezvous. The controlling (passive) element then commands the active element to execute the pre-maneuver operations including attitude orientation, the required delta-V maneuver(s), and verification culminating in the terminal phase initiation (TPI) maneuver. The controlling (passive) element then orients itself and the active element to the flight attitudes preferred during terminal rendezvous and commands the active element to activate any required rendezvous aids such as beacon lights, targets, etc. The passive (controlling) element (and the active element, if manned) determines (short-range tracking and ranging aids) and displays the range, range-rate, bearings, and bearing angle rates between the rendezvousing elements. The passive (controlling) element then commands the active element to execute the terminal phase finalization (TPF) braking maneuvers resulting in rendezvous.

OPERATIONAL PROCEDURE NO. 10-1

TITLE: RENDEZVOUS-INDEPENDENT APPROACH, PASSIVE ELEMENT IN CONTROL

ELEMENT INTERFACES: Modular Space Station (Passive and Controller)/Tug (Active)

	Operation	Performed by:	Rationale
1	Establish and verify communications links	Controller (passive)	Data transfer including command and control signals will be required during subsequent operations.
2	Command activation of all active element subsystems	Controller (passive)	If the active element is initially in quiescent storage its subsystems must be activated via RF command(s) prior to initiating rendezvous operations.
3	Command alignment of active elements attitude reference system	Controller (passive)	Required to minimize fuel consumption due to attitude errors during the rendezvous delta-V maneuvers.
4	Align attitude reference system of active element	Active	See above.
5	Align attitude reference system of passive element	Passive (controller)	This operation is required to minimize errors in the computation of orbital parameters and state vectors made in subsequent operations.
6	Determine passive elements orbital parameters and state vector	Controller (passive)	Required as initial and periodic input to the rendezvous computer program(s). Also required prior to the determination of the orbital parameters and state vector of the active element which are determined by and relative to the passive element.

OPERATIONAL PROCEDURE NO. 10-1

	Operation	Performed by:	Rationale
7	Command active elements G&N subsystem to determine its state vector and orbital parameters and transmit data to rendezvous control center (RCC)	Controller (passive)	These data are utilized in the determination of the active elements orbital parameters and state vector.
8	Active element performs navigation sightings and relays position and velocity data to RCC	Active	See above.
9	Perform tracking and ranging of active element	Controller (passive)	Required in the determination of the active elements orbital parameters and state vector.
10	Determine active elements orbital parameters and state vector	Controller (passive)	Required as initial and periodic input to the rendezvous computer program(s).
11	Initiate rendezvous navigation program(s)	Controller (passive)	Required to compute the ephemerides of the rendezvousing elements and to calculate the required active element delta-V maneuvers necessary to effect rendezvous.
12	Command active element to configure for delta-V maneuvers	Controller (passive)	Required to prevent damage to extended solar panels, etc., while maneuvering.
13	Configure active element for delta-V maneuvers	Active	See above.
14	Command active element, assume desired attitude	Controller (passive)	Active element must be positioned per RF command(s) from the rendezvous control center (RCC) so that its thrust vector will be in the desired direction during the coming impulsive maneuver, as determined in Operation 11.

	Operation	Performed by:	Rationale
15	Maneuver active element to desired flight attitude for delta-V maneuver and maintain throughout the maneuver	Active	See above.
16	Command active element execute delta-V maneuver	Controller (passive)	Required to effect the desired change(s) in the active elements orbital parameters as part of the rendezvous procedures.
17	Execute required delta-V maneuvers	Active	See above.*
18	Determine active elements orbital parameters and state vector**	Controller (passive)	Required to verify the success of the foregoing delta-V maneuver.
19	Command active element perform post-maneuver procedures	Controller (passive)	Required to initiate post-maneuver procedures following each delta-V maneuver.
20	Perform maneuver verification	Active	Required to ensure proper operation after each delta-V maneuver.
21	Command active element configure for orbital coast	Controller (passive)	Required to configure the element for orbital coasting operation.
22	Configure active element for coast	Active	See above.

* Depending on the rendezvous procedures employed, different numbers of delta-V maneuvers (i.e., repetition of Operations No. 7 through 22) are required to effect various phasing and orbital changes. The final delta-V maneuver in this series is the TPI maneuver which initiates the terminal rendezvous sequence.

** This operation repeats Operations 7 through 10.

OPERATIONAL PROCEDURE NO. 10-1

	Operation	Performed by:	Rationale
23	Command active element attitude change	Controller (passive)	Following the TPI maneuver the RCC sends the RF commands required to put the active element into the flight attitude required during the terminal rendezvous operations.
24	Active element maneuvers to and maintains the required attitude for terminal rendezvous	Active	This attitude is dictated by the retro-grade delta-V maneuvers required and to properly orient any docking aids such as targets, beacon lights, etc.
25	Passive element maneuvers to required attitude for terminal	Passive (Controller)	This attitude required to permit both visual and instrument tracking of the active element as it approaches along the anticipated line-of-sight.
26	Command active element activate rendezvous aids	Controller (passive)	An RF command is required to signal to active element to activate any required rendezvous aids.
27	Active element activates rendez-vous aids	Active	Rendezvous aids such as lights, targets, etc., may be required during terminal rendezvous operations.
28	Determine and display in the RCC the range, range-rate, bearings, and bearing-rates between rendezvousing elements	Controller (passive)	During the terminal phases of rendez-vous, safety considerations require that manned elements and the controller be capable of determining and displaying, on a continuous basis, the relative position of the rendezvousing elements.
29	Determine and command the active element to execute TPF delta-V maneuvers	Controller (passive)	The RCC is required to compute the TPF delta-V maneuvers and initiate RF commands to the active element to cause it to perform the required braking maneuvers.

	Operation	Performed by:	Rationale
30	Active element executes TPF delta-V maneuvers	Active	Upon receipt of the proper RF commands the active element performs the impulsive TPF braking maneuvers calculated and commanded by the RCC. These maneuvers are required to satisfy the established rendezvous braking gate criteria.
31	Complete rendezvous, and deactivate rendezvous aids	Controller (passive) and Active	When the rendezvousing elements have closed to within the prescribed distance, rendezvous is completed. The RCC issues the necessary RF commands, which are then executed by the active vehicle, to deactivate any rendezvous aids such as beacon lights.

Operational Procedure No. 10-2

Rendezvous-Independent, Active Element in Control

Assumptions (Also see General Assumptions)

1. The active element which in this case is also the controlling element is manned and has all of the controlling element capabilities defined under general assumptions.

2. The passive element, which is either manned or unmanned, is capable of maintaining and changing its flight attitude.

3. The active (controlling) element has both navigation and tracking and ranging equipment so that it can, with the aid of TDRS or ground network autonomously compute both its own and the passive elements orbital parameters and state vectors.

Initial Conditions (See General Initial Conditions)

Final Conditions (See General Final Conditions)

Description

The sequence of operations for the Independent Rendezvous approach with the active element in control is presented in Procedure 10-2. In this rendezvous approach the active (controlling) element first establishes and verifies that all required communications links (i.e., voice, data transfer, and tracking and ranging) are operational. The active element then either manually or automatically aligns its attitude reference system and based on its on-board navigation equipment determines its own orbital parameters and state vector. Next the orbital parameters and state vector of the passive element are determined. This is accomplished either by the passive element itself, if it possesses the necessary navigation equipment, or by tracking the passive element from the active element and determining its position with reference to the active element. The active (controlling) element then initiates the rendezvous computer program(s) and based on the now known rendezvous element position data computes the element ephemerides and the delta-V impulsive maneuvers required of the active element to effect rendezvous. The active (controlling) element then configures itself for orbital maneuvers, orients itself to the flight attitude required for its first delta-V maneuver and executes the maneuver. Following the maneuver the active element redetermines its orbital parameters and state vector to verify the success of the foregoing maneuver, performs maneuver verification and configures for orbital coasting operations. These maneuver sequences are repeated for each of the required rendezvous delta-V maneuvers culminating in the TPI maneuver. The active (controlling) element then orients itself and commands the passive element to orient to the flight attitude preferred for terminal rendezvous operations. Next the passive (target) element is commanded to activate any required rendezvous aids such as beacon lights or targets. The active (controlling) element and the passive element (if manned) then determine (through optical tracking and ranging) and display the range, range-rate, bearing angles, and bearing angle rates between the rendezvous elements. The active (controlling) element executes the required TPF braking maneuvers resulting in final rendezvous position.

OPERATIONAL PROCEDURE NO. 10-2

TITLE: RENDEZVOUS-INDEPENDENT APPROACH, ACTIVE ELEMENT IN CONTROL

ELEMENT INTERFACES: EOS Orbiter (Active and Controller)/RAM (Passive)

	Operation	Performed by:	Rationale
1	Establish and verify communications links	Controller (Active)	Data transfer including command and control signals will be required during subsequent operations.
2	Align attitude reference system	Active (Controller)	Required to minimize fuel consumption due to attitude errors during the rendezvous delta-V maneuvers.
3	Determine orbital parameters and state vector	Controller (Active)	Required as initial and periodic input to the rendezvous computer program(s).
4	Determine passive vehicle orbital parameters and state vector*	Passive or Controller (Active)	Required as initial and periodic input to the rendezvous computer program(s).
5	Initiate rendezvous navigation program(s)	Controller (Active)	Required to compute the ephemerides of the rendezvous elements and to calculate the required active element delta-V maneuvers necessary to effect rendezvous.
6.	Configure for delta-V maneuver	Active (Controller)	Required to prevent damage to extended solar panels, etc., while performing impulsive delta-V maneuvers.

*These data are determined either: (1) automatically on command by the passive vehicle or (2) determined relative to the active vehicle by the active vehicle and/or TDRS or ground network RF tracking and ranging equipment. Detailed procedures relating to tracking and ranging both element-to-element or via TDRS or ground stations are presented in the communications area.

OPERATIONAL PROCEDURE NO. 10-2

	Operation	Performed by:	Rationale
7	Maneuver to desired flight attitude for - delta-V maneuver and maintain throughout the maneuver	Active (Controller)	Required so that the subsequent impulsive maneuver will be conducted in the direction calculated in Operation 4.
8	Execute required delta-V maneuver(s)*	Active (Controller)	Required to effect the desired change(s) in the active elements orbital parameters as part of the rendezvous procedures.
9	Determine orbital parameters and state vector**	Controller (Active)	Required to verify the success of the foregoing delta-V maneuver.
10	Perform maneuver verification	Active (Controller)	Required to proper operation after each delta-V maneuver.
11	Configure for coast	Active (Controller)	Required to configure the element for orbital coasting operations.
12	Command passive element activate attitude control system	Controller (Active)	If the passive element has been in an inactive state its attitude control system must be activated prior to terminal rendezvous operations so that the element is able to reorient and maintain a desirable flight attitude.

*Depending on the rendezvous procedure employed different numbers of delta-V maneuvers, i.e., repetition of Operations No. 3 through 11 are required to effect various phasing and orbital changes. The final delta-V maneuver in this series is the TPI maneuver which initiates the terminal rendezvous sequence.

**This operation repeats Operation No. 3.

OPERATIONAL PROCEDURE NO. 10-2

	Operation	Performed by:	Rationale
13	Command passive element attitude change	Controller (Active)	It is desirable to orient the passive element to a flight attitude preferred during terminal rendezvous operations.
14	Maneuver to preferred attitude for terminal rendezvous	Passive	This attitude is preferred to properly orient any docking aids such as targets, beacon lights, etc.
15	Command passive element activate rendezvous aids	Controller (Active)	Controller initiated command is required to signal the passive element to activate any required rendezvous aids.
16	Passive element activates rendezvous aids	Passive	Rendezvous aids such as lights, targets, etc., may be required during terminal rendezvous operations.
17	Determine and display range, range-rate, and bearing to target	Controller (Active) and Passive (if manned)	During the terminal phases of rendezvous safety considerations require that manned elements and controller be capable of determining and displaying, on a continuous basis, the relative position of the rendezvousing elements.
18	Perform TPF delta-V maneuvers	Active (Controller)	These maneuvers are required to satisfy the established braking gate criteria.
19	Complete rendezvous and deactivate rendezvous aids	Controller (Active) and Passive	When the rendezvousing elements have closed to within the prescribed distance rendezvous is completed and any special rendezvous aids such as beacon lights are deactivated.

Operational Procedure No. 10-3

Rendezvous-Ground Control or Rendezvous-Space Control

Assumptions (Also see General Assumptions)

1. The RCC (Rendezvous Control Center) is located either on a third (manned) space element or at a ground control center location. In both cases, the command and control of both rendezvous elements is accomplished through a communications link. The space link is direct as long as the rendezvous elements are in LOS of the control element and through the TDRSS if not in LOS. The ground link is accomplished either through ground net stations or through the TDRSS.

2. Tracking and ranging is accomplished from either space or ground in a similar manner.

3. Both the active and passive elements are equipped with some type of attitude reference and attitude control subsystems and are capable (if unmanned) of orienting themselves in inertial space by a remote command via an RF communication link.

4. Both the active and passive elements, if initially unmanned and in a quiescent state, can be activated by command via an RF communication link.

Initial Conditions (See General Initial Conditions)

Final Conditions (See General Final Conditions)

Description/Summary of Procedure

The sequence of operations for the Ground or Space Control approach to rendezvous is presented in Procedure 10-3. The only difference between the two approaches is in the fact that the Space Control Element must first determine its own state-vectors and orbital parameters prior to any such determination of the rendezvous elements. In examining the procedures, "controller" describes either the Space Control element or the Ground Control element.

In this rendezvous approach the ground located RCC initiates continuous tracking of the active and passive elements and then establishes and verifies all required communications links. If the rendezvous elements are unmanned and in a quiescent state, the RCC activates all of the subsystems of both elements. The RCC then commands alignment of the active element's attitude reference system. The active element responds either manually or automatically and verifies by transmitting subsystem status data to the RCC. The RCC then determines the active and passive elements orbital parameters and state-vectors. This is determined by one of the following methods: (1) ground tracking data only, (2) a combination of ground tracking and rendezvous element space navigation (if the elements have this capability), or (3) on a combination of these methods and element-to-element tracking and ranging.

After obtaining the necessary rendezvous element position data, the RCC initiates rendezvous navigation program(s) and computes the active and passive element ephemerides and the active element delta-V impulse maneuvers required to effect rendezvous. The active element is then commanded to configure for delta-V maneuvers, orient itself to the required flight attitude and execute the maneuver at the proper time. Following each delta-V maneuver the active element is commanded to conduct maneuver verification and to reconfigure for orbital coasting operations. The orbital parameters and state-vector of the active element are then determined to verify the success of the delta-V maneuver and to aid in computing the magnitude and direction of the next delta-V maneuver. This cycle of operations is repeated for each of the required delta-V maneuvers culminating in the TPI maneuver. At this point the RCC commands the passive element to assume the flight attitude preferred for terminal rendezvous operations and to activate any required rendezvous aids. Next the active element is commanded to initiate optical (visual) tracking and ranging of the passive (target) element and to relay range, range-rate, bearing angles, and bearing angle rate data to the RCC. These data are transmitted to and displayed in real time at the RCC and on-board all manned rendezvous elemtnts. The active element is commanded to assume the attitude required for terminal rendezvous operations and to execute the TPF braking burns which culminate in rendezvous. When the two elements have achieved rendezvous the RCC commands deactivation of any required rendezvous aids and initiates either stationkeeping or mating operations.

OPERATIONAL PROCEDURE NO. 10-3

TITLE: RENDEZVOUS-GROUND CONTROL OR RENDEZVOUS-SPACE CONTROL

ELEMENT INTERFACES: EOS Orbiter (Active)/RAM (Passive) or MSS (Controller)/Tug (Active)/RAM (Passive)

	Operation	Performed by:	Rationale
1	Initiate and maintain tracking of active and passive rendezvous elements	Controller	Necessary to determine the orbital parameters, state vectors, and ephemerides of the rendezvousing elements.
2	Establish and verify communications links	Controller	Data transfer including command and control signals will be required during subsequent operations.
3	Command activation of all active and passive element subsystems	Controller	If the active and passive rendezvousing elements are currently in a quiescent state they must be activated by commands over a communication link from the RCC prior to initiating rendezvous operations.
4	Command alignment of active elements attitude reference system	Controller	Required to minimize fuel consumption due to attitude errors during the rendezvous delta-V maneuvers.
5	Align attitude reference system of active element	Active	See above.
6	Determine active and passive elements, orbital parameters and state vector	Controller	Required as initial and periodic input to the rendezvous computer program(s).
7	Initiate rendezvous navigation program(s)	Controller	Required to compute the ephemerides of the rendezvousing elements and to calculate the required active element delta-V maneuvers necessary to effect rendezvous.

OPERATIONAL PROCEDURE NO. 10-3

	Operation	Performed by:	Rationale
8	Command active element to configure for delta-V maneuvers	Controller	Required to prevent damage to extended solar panels, etc., while performing delta-V maneuvers.
9	Configure active element for delta-V maneuvers	Active	See above.
10	Command active element assume desired attitude	Controller	Active element must be positioned by command from the rendezvous control center (RCC) so that its thrust vector will be in the desired direction during the coming impulsive maneuver, as determined in Operation 7.
11	Maneuver active element to desired flight attitude for delta-V maneuver and maintain throughout the maneuver	Active	See above.
12	Command active element execute delta-V maneuver	Controller	Required to effect the desired change(s) in the active elements orbital parameters as part of the rendezvous procedures.
13	Execute required delta-V maneuver*	Active	See above.

*Depending on the rendezvous procedure employed different numbers of delta-V maneuvers, i.e., repetition of Operations No. 6 through 18, are required to effect various phasing and orbital changes. The final delta-V maneuver in this series is the TPI maneuver which initiates the terminal rendezvous sequence.

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OPERATIONAL PROCEDURE NO. 10-3

	Operation	Performed by:	Rationale	Functional Reqmt.
14	Determine active elements orbital parameters and state vector (6)	Controller	Required to verify the success of the foregoing delta-V maneuver.	1,7
15	Command active element perform post-maneuver procedures	Controller	May be required to initiate post-maneuver procedures following each delta-V maneuver.	
16	Perform maneuver verification	Active	Required to ensure proper maneuvers after each delta-V maneuver.	1,7
17	Command active element configure for orbital coast	Controller	It may be required to signal the active element to configure for orbital coast.	6
18	Configure active element for orbital coast	Active	Between impulsive maneuvers it may be required to extend solar panels, etc.	4,5
19	Command passive element activate attitude control system	Controller	If the passive element has been in an inactive state, its attitude control system must be activated prior to terminal rendezvous operations so that the element is able to reorient and maintain a desirable flight attitude.	4,6
20	Command passive element attitude change	Controller	It is desirable to orient the passive element to a flight attitude preferred during terminal rendezvous operations.	5,6
21	Passive element maneuvers to preferred attitude for terminal rendezvous	Passive	This attitude is preferred to properly orient any docking aids such as targets, beacon lights, etc.	5
22	Command passive element activate rendezvous aids	Controller	A controller initiated command is required to signal the passive element to activate any required rendezvous aids.	6

OPERATIONAL PROCEDURE NO. 10-3

Operation		Performed by:	Rationale
23	Passive element activates rendezvous aids	Passive	Rendezvous aids such as lights, targets, etc., may be required during terminal rendezvous operations.
24	Command active element initiate tracking and ranging of passive element	Controller	A controller-initiated command is required to signal the active element to track the passive element.
25	Active element performs tracking and ranging of passive element and transmits data to the RCC	Active	These data are desirable if not required, in addition to controller tracking data in the determination of range, range-rate, bearing angles, and bearing angle rates to target.
26	Determine and display range, range-rate, bearing, and change of bearing rates to target	Controller, Active and Passive (if manned)	To provide the visibility necessary to safely direct and control the terminal rendezvous operations, the relative position, velocity, bearing, and bearing-rates between the active and passive rendezvousing elements must be displayed in real time both at the RCC and on-board manned rendezvousing elements.
27	Command active element attitude change	Controller	Following the TPI maneuver the RCC sends the commands required to put the active element into the flight attitude required during the terminal rendezvousing operations.
28	Active element maneuvers to and maintains the required attitude for terminal rendezvous	Active	This attitude is dictated by the retrograde delta-V maneuvers required.

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OPERATIONAL PROCEDURE NO. 10-3

	Operation	Performed by:	Rationale
29	Determine and command the active element to execute TPF delta-V maneuvers	Controller	The RCC is required to compute the TPF delta-V maneuvers and initiate commands to the active element to cause it to perform the required braking maneuvers.
30	Perform TPF delta-V maneuvers	Active	From safety considerations the range, range-rate, bearing and bearing rates, between rendezvousing elements must be closely controlled during the terminal rendezvous operations. This is achieved by a series of braking maneubers which are executed by the active element to properly satisfy the established braking gate criteria.
31	Complete rendezvous and deactivate rendezvous aids	Controller and Passive	When the rendezvousing elements have closed to within the prescribed distance rendezvous is completed and rendezvous aids such as beacon lights may be deactivated by commands from the RCC over a communications link.

2.10.2 PROCEDURES APPLICABILITY

Figure 2.10-2 presents a definition of the procedures applicability and relates to the following discussion. As in stationkeeping, two elements predominate as the active rendezvous elements. One is the EOS orbiter; the other is the space-based tug. In all EOS independent rendezvous operations with unmanned elements, the EOS is the control element. In a few cases where the passive elements are manned (such as with the OLS, OPD or MSS), control may be taken over by the passive element. In most independent cases, the EOS would be the active element. In some types of rendezvous activities with detached RAM's, a second EOS, or a space-based tug; the EOS could become the target element and the other element, the active. Procedure 10-2 would apply to every EOS rendezvous pair where the EOS is the active element. Procedure 10-1 would apply only when the passive element is manned. When a third element is used for control, either a third space element or ground control, Procedure 10-3 would apply. It could apply to every EOS rendezvous case.

A similar utilization of procedures is true for the operations where the space-based tug is the active rendezvous element. Procedures 10-2 (independent, active element in control) and 10-3 (separate control) apply in every case involving the tug. In some cases, when the passive element is manned, Procedure 10-1 (for passive element in control) is applicable. A few other cases involving the CPS, RNS and detached RAM cover the other rendezvous operations possible. In all these cases, except for the MSS detached RAM, the three procedures may be applied according to the mission. When the detached RAM is rendezvousing with the MSS, it will always be the active element but never be in control. Either the MSS, as the passive element, would be in control or control would be from a separate element, possibly ground. Thus, Procedures 10-1 or 10-3 would be applicable to this case. The same logic would hold for MSS detached RAM and the space-based tug if the tug is manned. If the tug and RAM are unmanned, only Procedure 10-3 would be applicable.

PASSIVE (TARGET) \ ACTIVE		SPACE PROGRAM ELEMENTS																
		EOS	TUG		RAM				SATELLITE			EO RESUP. MODS	LOW EO MSS	CPS		RNS CLS	OLS	OPD
			RTN	SPACE BASED	ATT. EOS	DET. EOS	ATT. MSS	DET. MSS	EOS DELIV.	EOS + 3RD ST DELIV.	RETR, RESUP.			OIS	CLS			
	EOS	1,2	NA	$1,2^M,3$	NA	NA	NA	NA	NA	NA	NA	NA	NA		$1,2^M,3$	$1,2^M,3$	NA	NA
TUG	RETURNABLE	2,3								NA								
TUG	SPACE BASED	$1^M,2,3$		$1,2^M,3$			NA	NA		NA	NA	NA	NA	NA	NA	NA	NA	NA
RAM	ATT. EOS	NA																
RAM	DET. EOS	2,3																
RAM	ATT. MSS	NA		NA									NA					
RAM	DET. MSS	2,3		$1^M,2,3$									NA					
SATEL	EOS DELIV.	NA																
SATEL	EOS + 3RD ST	NA	NA	NA														
SATEL	RETR, RESUP.	2,3		$2^M,3$														
	EO RESUP. MODS	NA		NA								NA	NA		NA	NA		NA
	LOW EO MSS	1,2,3		$1,2^M,3$			NA	$1,2^M,3$				NA	NA					
CPS	OIS			2,3											NA	NA	NA	NA
CPS	CLS	$1^M,2,3$		2,3								NA		NA	$1^M,2^M,3$		NA	NA
	RNS-CLS	$1^M,2,3$		$1^M,2,3$								NA		NA		NA	NA	NA
	OLS	$1^M2,3$		$1^M,2,3$										NA	NA	NA	NA	
	OPD	2		2,3								NA		NA	$1^M,2^M,3$	$1^M,2^M,3$		NA

NOTE:

Superscript "M" indicates application of that procedure number only if the control element is manned.

Either the active or passive element may be in control.

NA - Not Applicable

Figure 2.10-2. Operational Procedures Applicability—Interface Activity: Rendezvous

2.11 STATIONKEEPING

This section presents the operational procedures for stationkeeping, and includes one procedure for each alternate approach identified in Volume II of this report. Also presented and discussed is the applicability of these procedures to each element pair included in the in-depth analysis portion of the Orbital Operations Study.

2.11.1 OPERATIONAL PROCEDURES

Stationkeeping is defined as the act of maintaining two space elements in a particular spatial relationship with each other and possibly with relation to certain absolute state vectors. This could be a situation where one element - the target element - performs all the maneuvers to maintain attitude and state vectors as controlled by another element, or where both stationkeeping elements perform attitude and state vector maintenance maneuvers. In these operational procedures, both elements have been indicated as maneuverable elements. There may be -ases where only the target element need maneuver or where only the target element need maneuver or where the active element is the only maneuvering vehicle - such as inspection. There are also cases where absolute state vectors are an unnecessary requirement; only relative state vectors are necessary - again, such as inspection. The procedure, therefore, should be applied as fits the activity, and deletion of steps should be appropriately applied. Although the procedures define singular maneuvers, it is assumed that repetitions of maneuvers may be necessary to perform certain stationkeeping flight modes. This would be true for inspection modes where the inspecting element maneuvers around the target element for full inspection.

Inspection modes are relatively near separations to allow for either direct visual or television sensor type inspection. Support of these maneuvers and stationkeeping operations from approximately 50 nautical-mile separation to 1000 feet requires a more accurate ranging and range rate system than the RF system described in the operations. A laser scanning radar at 50 to 75 nautical miles to 1000 feet is capable of providing these accuracies. Utilization of a laser system does not require an active transponder on the target element. Passive corner reflectors are used to enhance the return of laser signals. Again, the operational procedures account for an active transponder on the target element. Unapplicable steps may be deleted when laser systems are used. Optical systems could supplement laser operations at very close ranges, $\lesssim$ 1000 feet.

In all such cases, the procedures account for the most complex operations. Deletion of steps and substitutions of different sensor systems may be applied as required.

Two procedures are presented. One is for autonomous operation that covers both elements unmanned, and also one element unmanned (target) and one element manned and in control (active). The other procedure covers the operation of the stationkeeping elements by a third element - either another space element or ground. In this manner, all four alternate approaches are covered by two operational procedures. In the case of the autonomous operational procedures, the difference between automated and manned is reflected only in the introduction of manned control to replace the automatic sequencing necessary in the unmanned case. Space control and ground control are basically the same. The major difference comes in the necessity to allow for interruptions, handover and link reacquisition when using ground control. Such extra operations are necessary when communication needs to be extended over a time period that exceeds a link contact with a single ground station or one TDRS. When a third space element is used for control, it is assumed that one or both stationkeeping elements are in line of sight of the control element, thus allowing continuous communications for the mission duration.

When applicable, procedural differences noted above are indicated in the steps. Individual procedure descriptions and assumptions are provided with each of the operational procedures.

OPERATIONAL PROCEDURES NO. 11-1

Stationkeeping - Autonomous, Both Elements Unmanned

Assumptions

The elements are within line of sight of each other and are separated by at least 75 miles and possibly up to the limit of line of sight, i.e., a maximum of 4000 nautical miles.

Stationkeeping is assumed to be the maintenance of a specified element-to-element orbital relation and a specified earth relationship.

The separation distance dictates the use of specific sensors. Greater than 75 miles separation needs the utilization of RF-type ranging and tracking sensors. Less than 75 miles would utilize laser devices and/or at visual contact distances (less than five miles), optical devices.

Initial Conditions

The elements have been in quiescent state for several orbits. The elements may have assumed any attitude and their orbits may have been perturbed.

The elements were left in a stationkeeping mode at the beginning of their quiescent state with known orbital parameters and state vectors.

Final Conditions

The elements are again in quiescent state in the same conditions as found initially. No attitude stabilization, attitude reference or attitude control system is active. Wakeup receivers and timer systems are activated allowing the wakeup at the prescheduled time.

Description

It is defined that one element is the controlling element. It contains all necessary sensing and computation capability and is completely autonomous from outside control. All operations for stationkeeping have been preprogrammed and on-board memory contains sufficient data to relate actual and required position and attitude data of itself and the element with which it operates. It shall be called the active element. A controlled, cooperative element, known as the target element is the target vehicle with which the active element is stationkeeping. It is cooperative from the sense that a communications and tracking and ranging link capability exists between the elements. Autonomy exists because no external controls are necessary. Both elements must however be capable of determining their own attitude. The active vehicle must be able to determine its own state vectors and orbital parameters, one mode of which may be a cooperation with the ground stations or with the TDRS network. Although not stated, the ground (either direct or via TDRS) must retain the ability to override autonomous operation and control either element. This is not part of this operational procedure.

Operational procedure logic is easily related by use of the procedure logic flow diagram, Figure 2.11-1. After the active element wakes itself up by means of a self-contained scheduled timing system, it determines its own attitude and absolute state vectors and orbital parameters. It then corrects its attitude, awakens the target element by means of an omni-directional communication link and proceeds to determine the target element position. Before proceeding any further, the active element corrects its own position to the desired position utilizing data from Step 3 and the predicted data contained in its computer memory. Knowing both its position and the target element position, it now commands the target element to determine its attitude and then performs the comparison of actual to predicted and commands the proper attitude maneuvers to correct the target element attitude. With the target element in the proper attitude, delta-velocity maneuvers for orbital makeup can be commanded by the active element and the target element placed in its desired state vectors and orbital parameters. Continuous monitoring of the operation and corrections as necessary result in stationkeeping at a specified separation distance and the performance of any desired mission. After mission completion, both elements are deactivated. The major requirements to fulfill these operations include attitude reference systems, attitude control systems, position determination systems, on-board computation capability and, of course, a communication and ranging tracking link between the elements. The detailed requirements are discussed in detail in the Functional Requirements subsection.

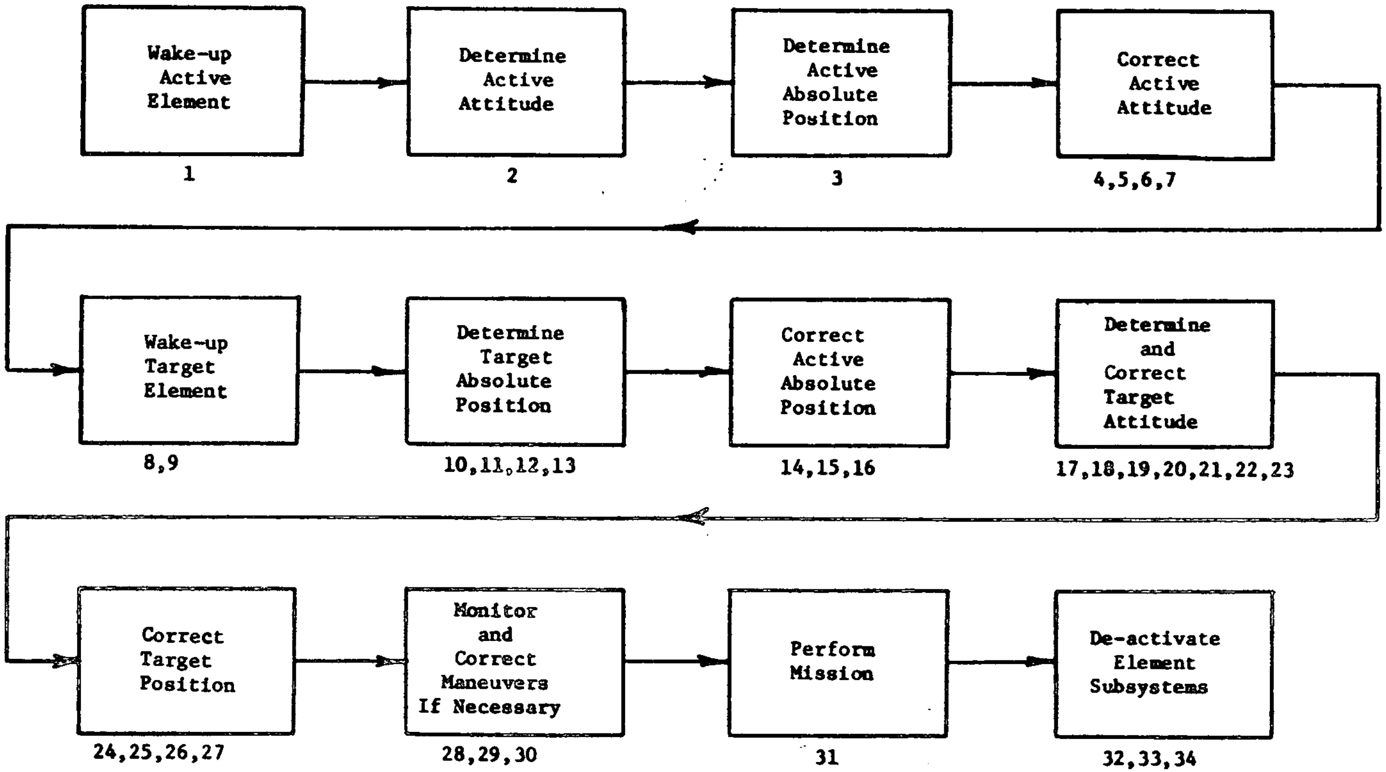

Figure 2.11-1. Procedure Logic Operational Procedure 11-1, Stationkeeping Autonomous, Both Elements Unmanned

OPERATIONAL PROCEDURE NO. 11-1

TITLE: STATIONKEEPING, AUTONOMOUS - BOTH ELEMENTS UNMANNED

ELEMENT INTERFACES: CISLUNAR SHUTTLE - ORBITAL PROPELLANT DEPOT

	Operation	Performed by:	Rationale
1	Automatic, preprogrammed timer activates attitude control subsystem on active element	Active element	Active element has been in quiescent mode.
2	Perform update of attitude reference data in subsystem	Active element	To ensure availability of link to target element by pointing of antenna systems or other viewing devices
3	Perform navigation update to state vectors and orbital parameters	Active element	To establish absolute position for reference
4	Compute proper attitude for pointing to predicted target element position	Active element	In preparation for attitude maneuvers
5	Compare actual attitude (Step 2) against proper attitude (Sept 4)	Active element	
6	Compute attitude maneuver for proper orientation	Active element	
7	Issue commands to attitude control system and perform attitude maneuver to proper orientation (as necessary)	Active element	In preparation for contact with target element

OPERATIONAL PROCEDURE NO. 11-1

	Operation	Performed by:	Rationale
8	Command activation of target element cooperative transponder	Active element	Target element must be awakened from its quiescent mode and alerted to respond to active element tracking and ranging.
9	Activates transponder and transmits signals	Active element	Target element must radiate signal to allow active element acquisition by a directive antenna
10	Acquire signal from target element, point directional antenna (if applicable)	Active element	Completes acquisition of tracking and ranging link provides readiness for tracking and ranging measurements.
11	Initiate tracking and ranging measurements	Active element	Communications operational procedures define the technique and method for performing tracking and ranging
12	Perform range, range rate and angle measurements	Active element	To determine relative state vectors and orbital parameters of target element
13	Determine target element actual state vectors and orbital parameters	Active element	Computes from relative data and knowledge of its own (active) state vectors and orbital parameter; see Step 3.
14	Compare active element position	Active element	In preparation for any translation maneuver that is necessary
15	Compute delta-V maneuvers necessary to perform any required orbit makeup	Active	

OPERATIONAL PROCEDURE NO. 11-1

	Operation	Performed by:	Rationale
16	Issue commands for delta-V maneuvers and perform maneuver (as necessary) to reach required orbital position	Active element	To ensure active element is in proper orbital position
17	Command activation of attitude reference subsystem on target element	Active element	In preparation for determination of target element attitude
18	Activate attitude reference system and determine attitude	Target element	
19	Relay information to active element	Target element	Active element needs element orientation to command any necessary new orientation or element interrelationship. Directional antenna pointing could be one example.
20	Compare target element attitude data with predicted	Active element	In preparation for computation and command of target element orientation maneuvers
21	Compute attitude maneuver of target element for proper orientation	Active element	
22	Command target element attitude control system to perform maneuvers	Active element	

	Operation	Performed by:	Rationale
23	Performs maneuvers to assume proper attitude orientation with active element referenced against local coordinates	Target element	
24	Compare target element actual position information with desired position.	Active element	In preparation for computation of maneuvers for target element
25	As applicable, compute orbit makeup delta velocity requirements	Active element	
26	Command target element to perform makeup delta-V maneuvers	Active element	To align relative positions to specified mission stationkeeping requirements
27	Perform makeup delta-V maneuvers	Target element	Target element performs maneuvers by direct command from active element
28	Monitor makeup maneuver of target element provides corrective commands as necessary. Same as Steps 24 through 27	Active element	To ensure proper maneuvers are being performed
29	Cease maneuver and reach new steady-state condition	Target element	Places target element in proper relative and absolute position
30	Monitor new target state-vectors and orbital parameters and correct as necessary	Active element	Ensures proper state vectors and orbital parameters

OPERATIONAL PROCEDURE NO. 11-1

	Operation	Performed by:	Rationale
31	Perform any necessary operation/ mission	Target element	
32	Command deactivation of target element subsystems except for wakeup receiver	Active element	To conserve power and leave target element alert for next mission
33	Deactivate subsystems and leave wakeup receiver live, leaving target element in quiescent state	Target element	
34	Deactivate active element sub-systems except for programmed timer and wakeup receiver	Active element	To conserve power and leave active element in quiescent state awaiting next timer wakeup

OPERATIONAL PROCEDURE NO. 11-2

Stationkeeping - Ground Control, Both Elements Unmanned

Assumptions

The elements are within line of sight of each other and are separated by at least 75 miles and possibly up to the limit of line of sight, i.e., to a maximum of 4000 nautical miles.

Both elements - the active and the target - have some type of attitude reference and attitude control system with built-in capability to hold a specified attitude orientation.

Both elements - the active and the target - have a wakeup receiver capable of receiving wakeup command signals from any direction regardless of attitude.

The active element has the capability to make range and range rate measurements of a cooperative element and process the information for defining relative range and range rate with accurate time identification.

The active element also contains a transponder compatible with either ground network stations or TDRS to provide a cooperative terminal for range and range rate measurements.

Initial Conditions

The elements have been in quiescent state for several orbits. The elements may have assumed any attitude and their orbits may have been perturbed.

The elements were left in a stationkeeping mode at the beginning of their quiescent state with known state vectors.

Final Conditions

The elements are again in quiescent state in the same conditions as found initially. No attitude stabilization, attitude reference or attitude control system is active. Wakeup receivers are active and alert to receive wakeup commands.

Description

Stationkeeping for two elements by ground control involves essentially the same operations by the active and target elements as for the autonomous alternate approach. The exceptions relate to the shift of control, data processing and computation from the active element to the controlling element (either space or ground). Ground performs all command and control operations instead of the functions being automatically performed internally by computer or a sequence timer.

One of the major points identified in the procedure is the necessity to utilize one element as a relay for all commands to the second element. This is especially true for the ground control when using ground network stations. By always looking at one element, the problem of slewing the narrow beam antenna back and forth between elements is avoided. Item 11 of the functional requirements defines the problem in detail.

Operational procedure logic is displayed in Figure 2.11-2. Ground control operates through either ground stations or TDRS to acquire contact with the active element. Ground requests attitude data from the active element and utilizes these data to compute corrective attitude maneuvers. These corrective maneuvers are performed after command from ground. Range and range rate and tracking measurements are then performed on the active element. The active element awakens the target element by command relayed from ground. After the active element determines the range, range rate and tracking data of the target element and has determined the safety for its own maneuvers, ground computes and commands the appropriate delta-V maneuvers for the active element. After performing the active element delta-V maneuvers properly monitored by ground, ground requests the target element attitude via the active element. After obtaining these data, ground again issues commands through the active element to the target element to orient to the proper attitude. The target element is now in proper attitude to perform orbital makeup maneuvers. These are commanded via the active element and performed by the target element. After completion of the stationkeeping mission, ground commands deactivation of both elements, first the target element, then the active element.

If the word ground or ground control were replaced with space control element, the operational procedure could be used for the space control case. It is assumed that the procedure following is usable for both cases of separate control (space or ground) by this word replacement. Another alternative, in the case of space control, could be the direct control of both stationkeeping elements from the space element.

If this alternative were used, the steps using the active element as a relay would be changed to reflect direct control by the space control element. This could also be the case for elements closer than 400 nautical miles when using the TDRS as the link. The procedure shown is the most complex and capable of covering all situations.

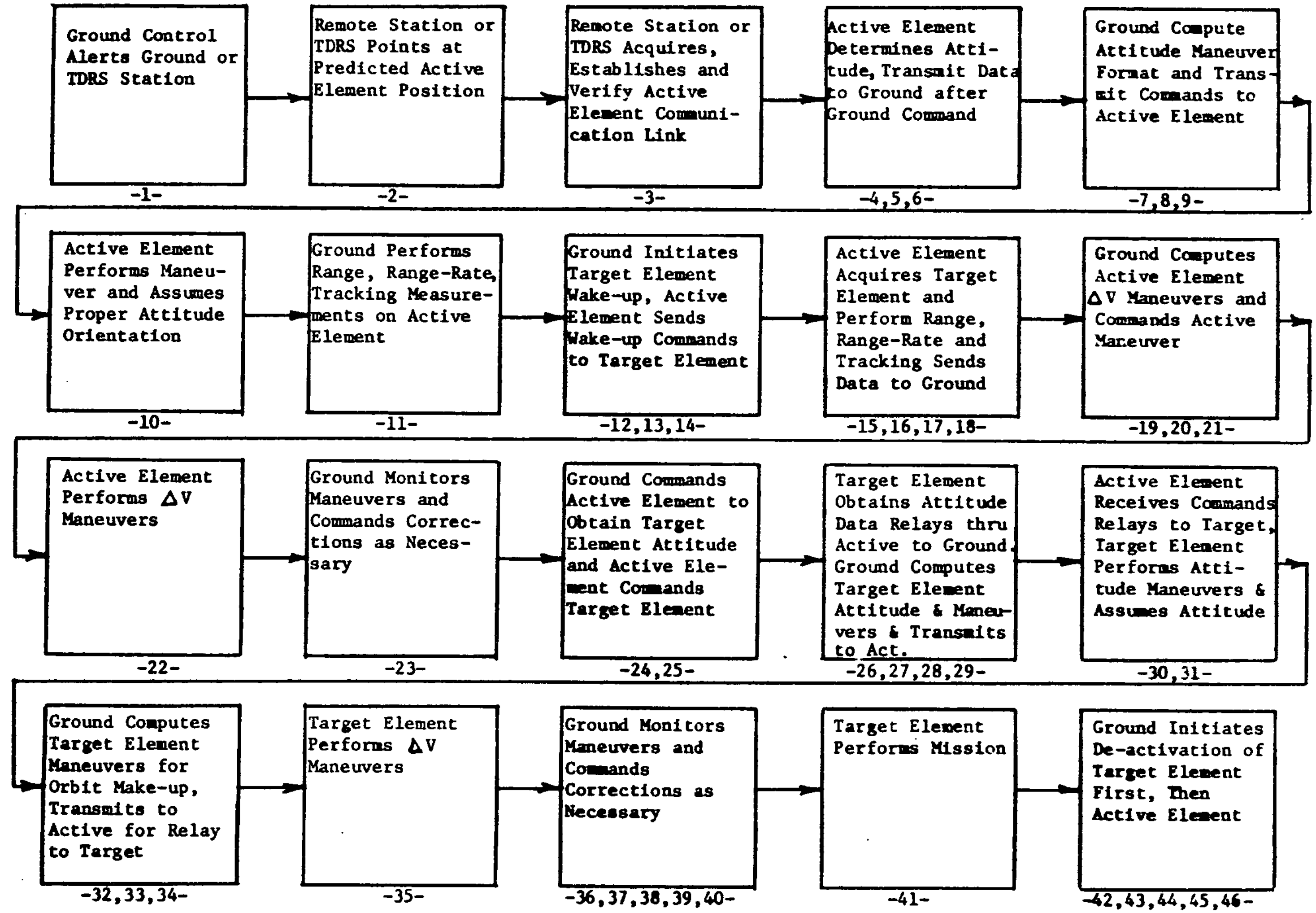

Figure 2.11-2. Procedure Logic Operational Procedure 11-3, Stationkeeping Ground Control, Both Elements Unmanned

OPERATIONAL PROCEDURE NO. 11-2

TITLE: STATIONKEEPING, GROUND CONTROLLED - BOTH ELEMENTS UNMANNED

ELEMENT INTERFACES: CISLUNAR SHUTTLE - ORBITAL PROPELLANT DEPOT

	Operation	Performed by:	Rationale
1	Control alerts proper remote station (or TDRS control) to contact with active element	Ground control	In preparation for activation of ground remote station contact with active element
2	Remote station points directional antenna at predicted orbital parameters for active element	Ground station	To make ready for communication link when active vehicle comes into LOS view
3	Acquire, establish and verify communication link with active element	Ground station	To ensure quality link with active element
4	Ground transmit commands to activate active element subsystems	Ground station	To awaken attitude reference subsystem and transponders as necessary
5	Active element activates attitude reference subsystem and determines its own attitude	Active element	In preparation for attitude sensitive operations
6	Format attitude data, transmit to ground	Active element	To provide data for computation of attitude and subsequent computation of attitude correction maneuvers by ground control

OPERATIONAL PROCEDURE NO. 11-2

	Operation	Performed by:	Rationale
7	Compute attitude of active vehicle, compare actual to required	Ground control	
8	Compute attitude maneuver for proper orientation	Ground	
9	Format and transmit attitude maneuver commands to active vehicle	Ground	In preparation for contact with target element
10	Perform attitude maneuver and assume proper orientation	Active element	
11	Perform range, range rate and angle measurements on active element	Ground station	To obtain data for computation of state vectors and orbital parameters of active element
12	Transmit command to active element to acquire target element communication link and determine target element position	Ground station	In preparation for contact between active and target elements and subsequent determination of relative and absolute positions
13	Command activation of target element transponder	Active element	Target element must be awakened from its quiescent mode and alerted to respond to active element tracking and ranging

OPERATIONAL PROCEDURE NO. 11-2

Operation		Performed by:	Rationale
14	Activates cooperative transponder and transmit signal	Target element	Target element must radiate signal to allow active element acquisition by a directive antenna
15	Acquire signal from target element, point directional antenna (if applicable)	Active element	Completes acquisition of tracking and ranging link, provides readiness for tracking and ranging measurements
16	Perform range, range rate on target element	Active element	To provide data for computation of relative and absolute position of target element
17	Relay target/active element range, range rate and relative data to ground	Active element	To supply data to ground control for computation purposes
18	Computes relative and absolute position of target element	Ground station	To locate target element position prior to any further element maneuvers
19	Compare active element position with predicted (desired)	Ground	To derive data for delta-V orbit makeup maneuvers
20	Compute delta-V maneuvers necessary to perform any required orbit makeup of active element	Ground	
21	Transmit commands for active delta-V maneuvers to reach required orbital position	Ground	To ensure active element is in proper orbital position

OPERATIONAL PROCEDURE NO. 11-2

Operation		Performed by:	Rationale
22	Perform delta-V maneuvers in accordance with command and reach new steady-state orbit	Active element	
23	Monitor delta-V maneuvers and command corrections as necessary	Ground	To ensure proper performance of delta-V maneuvers
24	Transmit command to active element to obtain target element attitude data	Ground	In preparation for determination of target element attitude. Uses active element as relay to avoid interchange of ground station antenna between elements.
25	Command target element to activate attitude reference system and obtain attitude data	Active element	To relay commands from ground to target element
26	Obtain attitude data and transmit to active element	Passive element	Necessity for target element orientation data to allow computation of any necessary new orientation for element interrelationship. Directional antenna pointing could be one example.
27	Receive attitude data and transmit to ground	Active element	
28	Compute target element attitude, compare to desired and compute any necessary attitude maneuvers to reach desired attitude.	Ground	In preparation for computation and command of target element orientation maneuvers
29	Format attitude maneuver data and transmit to active element	Ground station	For relay to target element

OPERATIONAL PROCEDURE NO. 11-2

	Operation	Performed by:	Rationale
30	Receive attitude maneuver data and transmit maneuver command to target element	Active element	
31	Receive command, perform attitude maneuvers to assume proper attitude orientation with active element referenced against local coordinates.	Target element	To prepare target element for subsequent operations or maneuvers
32	Using data from Step 18, compare target element position to desired position and compute delta-V maneuvers to correct position (as applicable)	Ground	In preparation for computation of maneuvers for target element
33	Format delta-V maneuvers for target element correction and transmit data to active element	Ground	For relay to target element
34	Receive delta-V maneuver command data and transmit maneuver commands to target element	Active element	Acts as a relay for commands to target element
35	Perform makeup delta-V maneuvers	Target element	To maneuver target element into proper state vector
36	Monitor makeup maneuvers of target element and transmit to ground	Active element	To ensure performance of proper delta-V maneuvers and relay to ground for ground monitor

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OPERATIONAL PROCEDURE NO. 11-2

	Operation	Performed by:	Rationale
37	Compute delta-V maneuver and position data, compare to predicted and compute any corrections necessary	Ground	
38	Transmit corrective maneuvers (as applicable) to active element	Ground station	
39	Receive applicable corrective maneuvers, transmit maneuver commands to target element	Active element	
40	Perform any necessary corrective maneuvers, reaches new steady-station condition	Target element	To effect any necessary corrective maneuvers for assurance of proper state vector
41	Perform any scheduled mission or operation	Target element	
42	After mission completion, transmit target element deactivation commands to active element	Ground	To deactivate and place target element in quiescent state prior to deactivation of active element
43	Transmit commands to target element to deactivate	Active element	

OPERATIONAL PROCEDURE NO. 11-2

	Operation	Performed by:	Rationale
44	Deactivate all subsystems except wakeup receiver	Target element	To conserve consumption of power and to leave target element in alert condition ready for next operation
45	Transmit active element deactivation commands to active element	Ground	
46	Deactivate all subsystems except wakeup receiver	Active element	To conserve consumption of power and to leave target element in alert condition ready for next operation

2.11.2 PROCEDURES APPLICABILITY

Examination of the operational procedure matrix (Figure 2.11-3) shows there are two elements that interface with many other elements and are the active or controlling elements. One is the EOS that stationkeeps with all elements except MSS detached RAM's, earth orbital resupply modules and any EOS attached RAM's. For each of the EOS stationkeeping cases, where the EOS is the manned active control element, Procedure 11-1 is applicable. Procedure 11-1 covers the case of autonomous operation where the active control element is manned. Procedure 11-1 is basically for the autonomous, both elements unmanned, case. It can be applied to the manned control for the automatic, computer-controlled timing sequence control.

This single procedure is then applicable to all EOS stationkeeping cases. The other active stationkeeping element is the space-based tug. It stationkeeps with all other elements except the MSS attached RAM, the EOS plus the third-stage deliverable satellite and the EOS resupply modules. In every stationkeeping case except for those involving the EOS and the low earth orbit MSS, both of the operational procedures are applicable. Procedure 11-1 is applicable if the space-based tug is manned. The separate control - either ground or space - operational procedures can be utilized for any of the interface pairs except with EOS where both elements are manned. Application of the particular procedure is determined by the mission and availability of the controlling element. One of the unique cases is that of the RAM stationkeeping with the MSS. In this case, the MSS (being a manned element) is the control element, but becomes the target element for the RAM. The RAM has all the maneuvering capability and thus is considered the active element. The MSS maintains fixed orbit and attitude and does not perform any major maneuvers. The RAM is a detached vehicle that performs missions under the direction of the MSS while performing the stationkeeping maneuvers necessary. Other stationkeeping pairs involve all unmanned vehicles that can use either Procedure 11-1 or 11-2, as applicable.

ACTIVE (1) / TARGET		SPACE PROGRAM ELEMENTS																
		EOS	TUG		RAM				SATELLITE			EO RESUP. MODS	LOW EO MSS	CPS		RNS CLS	OLS	OPD
			RTN	SPACE BASED	ATT. EOS	DET. EOS	ATT. MSS	DET. MSS	EOS DELIV.	EOS + 3RD ST DELIV.	RETR, RESUP.			OIS	CLS			
	EOS	1	NA	1	NA	NA	NA	NA	NA	NA	NA	NA	NA		NA	NA	NA	NA
TUG	RETURNABLE	1								NA								
TUG	SPACE BASED	1		1,2			NA	NA		NA	NA	NA	NA	1,2	1,2	1,2	1,2	NA
RAM	ATT. EOS	NA																
RAM	DET. EOS	1																
RAM	ATT. MSS	NA		NA									NA					
RAM	DET. MSS	1		1,2									NA					
SATEL	EOS DELIV.	1																
SATEL	EOS + 3RD ST	1	NA	NA														
SATEL	RETR, RESUP.	1		1,2														
	EO RESUP. MODS	NA		NA								NA	NA		NA	NA		NA
	LOW EO MSS	1		1,2			NA	1_T				NA	NA					
CPS	OIS			1,2											NA	NA	NA	NA
CPS	CLS	1		1,2								NA		NA	NA		NA	NA
	RNS-CLS	1		1,2								NA		NA		NA	NA	NA
	OLS	1		1,2										NA	NA	NA	NA	
	OPD	1		1,2								NA		NA	1,2	1,2		NA

NOTES

(1) Active element is always considered in control except as noted by subscript "T", which denotes target element is in control.

NA - Not Applicable

Figure 2.11-3. Operational Procedures Applicability - Interface Activity: Stationkeeping

2.12 ATTACHED ELEMENT OPERATIONS

This section presents the operational procedures for attached element operations, and includes one procedure for each alternate approach identified in Volume II of this report. Also presented and discussed is the applicability of these procedures to each element pair included in the in-depth analysis portion of the Orbital Operations Study.

2.12.1 OPERATIONAL PROCEDURES

This section presents the operational procedures developed for accomplishing the attached element operations activity. A preliminary procedure is presented for each of the three alternate approaches; RAM operations, service and checkout, and quiescent storage. Although each of these approaches are developed for a particular element-to-element interface, the procedures are, to a certain extent, developed generically so as to relate to other applicable element-to-element pairs. It may be noted that the function requirements relating to the operational procedures are relatable numerically to the functional requirements presented in Volume II.

Presented in Figure 2.12-1 is a simplified illustration of the three operational procedures together with their interrelationships. This illustration provides an overview of each of the three operational procedures, together with their commonality relationship.

No. 12-1. Attached Element Operations - RAM Operations

Assumptions

1. The RAM is developed from the orbiter using a pivoting mechanism

2. Experiment crew rides in orbiter cabin to and from orbit

3. Tunnel between orbiter and RAM is flexible and as a result contains no controls or displays

4. There are external floodlights in the orbiter cargo bay environs

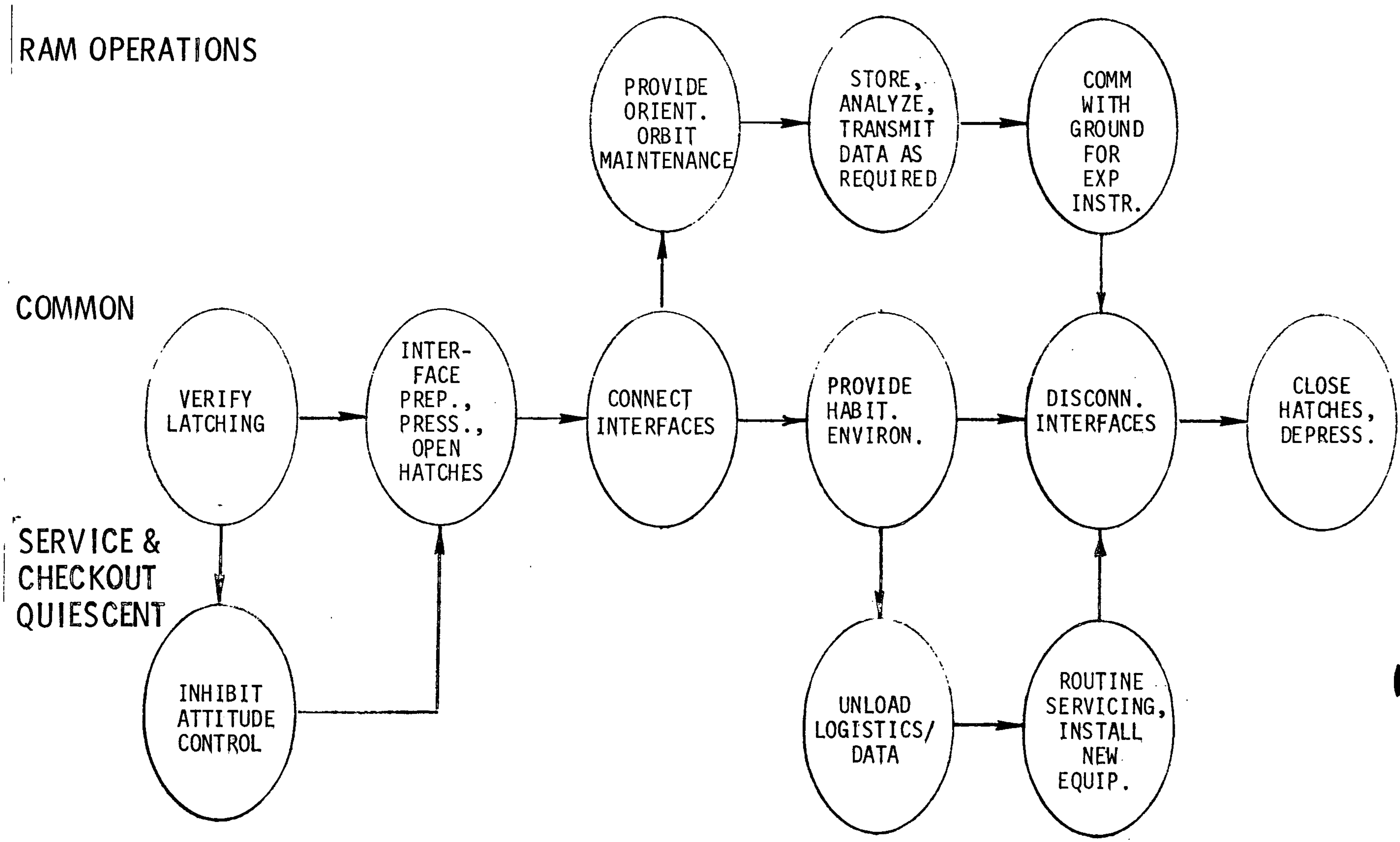

Figure 2.12-1. Attached Element Operations Procedural Comparison

5. Orbiter crew may support experiment program upon request on a non-interference basis
6. This procedure includes those class of missions known as pallets.
7. Included in RAM Operations are some unmanned satellites that are returned to the active vehicle for service in conjunction with some special experiment program.

Initial Condition

1. The Orbiter cargo bay doors are open
2. The RAM is secured in cargo bay
3. All electrical, fluid, gas, interface lines are connected between Orbiter and RAM vehicles
4. Hatches on each end of the tunnel are closed and sealed
5. Preceeding activity is Attached Element Transport and EOS Payload Deployment

Final Conditions

1. Cargo bay doors remain open
2. The RAM is secured in cargo bay
3. Subsequent activity is Attached Element Transport and EOS Payload Retraction and Stowage

Description

For purposes of accuracy and clarification, this procedure has been developed, assuming two important conditions; the experimenter crew is transported to and from orbit in the Shuttle orbiter cabin, and the RAM is deployed from the cargo bay using a pivoting extension mechanism. The operational procedures would differ significantly if the assumptions were made that the experimenter crew were transported to and from orbit in the RAM and the RAM were deployed from the cargo bay using an onboard manipulator.

Because the tunnel is flexible it has no sensors to detect atmospheric leak rate. As a result, operation #11, verification of the tunnel leak rate must be accomplished by observing the leak rate differential from the orbiter once the tunnel is pressurized. To do this of course necessitates that there is no pressure isolation between the Orbiter and the tunnel.

This procedure has a substantial supporting interface with Crew Transfer-Shirtsleeve, procedure no. 5-1. Operations 1 through 21 present basically the preparation for the RAM attached operations procedure. Operations 22 through 33 present the actual activity of RAM attached operations. These operations, being supportative of a RAM sortie program that includes several individual experiments, may be conducted in series, in parallel, may be repeated, or may be deleted depending upon the experiment program requirements. Operations 34 through 42 define the past RAM attached operation activity.

OPERATIONAL PROCEDURE NO. 12-1

TITLE: ATTACHED ELEMENT OPERATIONS - RAM OPERATIONS

ELEMENT INTERFACES: EOS ORBITER WITH PIVOTING EXTENSION (ACTIVE)/RAM (PASSIVE)

Operation		Performed by:	Rationale
1.	Monitor health and safety parameters of passive vehicle and cargo bay interior.	Active	Attention is given to parameters that signal a deterioration in health and safety and to integrate inter-related parameters to give even earlier warning if deterioration begins.
2.	Monitor and observe cargo bay environs for adequate clearance for deployment.	Active	Ensure no obstruction, loose material in path of deployment route.
3.	Inspect transfer tunnel and associated interface lines.	Active	Inspection to guarantee all interface lines will have free, unobstructed movement during deployment. Hardwire power, communications, and monitoring interface connectors, and other fluids/gases interfaces are located inside the connecting tunnel/hatch area.
4.	Activate controls/displays for deployment mechanism, pressurization.	Active	
5.	Release actuators dock and deploy passive vehicle out of cargo bay.	Active	Passive vehicle deployment is a 90-degree rotation out of the Orbiter cargo bay.

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OPERATIONAL PROCEDURE NO. 12-1

TITLE: ATTACHED ELEMENT OPERATIONS - RAM OPERATIONS

ELEMENT INTERFACES: EOS ORBITER WITH PIVOTING EXTENSION (ACTIVE)/RAM (PASSIVE)

	Operation	Performed by:	Rationale
6.	Verify deployment actuators are docked and deployment mechanism docked in place.	Active	Visual inspection by line of sight and augmentation by TV will allow viewing of all indicators.
7.	Activate and verify communications and data link to command element, activate tunnel and unmanned element lighting, confirm tunnel passageways is clear.	Active	Reference procedure No. 5-1 operations 2-5.
8.	Make initial check of unmanned element atmosphere.	Active	Initial check of atmosphere in unmanned element must be made so that shirtsleeve operations can proceed.
9.	Pressurize transfer tunnel between hatches.	Active	
10.	Equalize pressure between tunnel and active element.	Active	Any pressure difference between tunnel and airlock must be equalized prior to opening hatch.
11.	Verify tunnel leak rate.	Active	Tunnel seal must be checked prior to opening hatch.
12.	Open hatch to tunnel and perform initial inspection of tunnel and and interface lines.	Active	This operation verifies that all interface lines have deployed properly, all couplings functional.

OPERATIONAL PROCEDURE NO. 12-1

TITLE: ATTACHED ELEMENT OPERATIONS - RAM OPERATIONS

ELEMENT INTERFACES: EOS ORBITER WITH PIVOTING EXTENSION (ACTIVE)/RAM (PASSIVE)

	Operation	Performed by:	Rationale
13.	Prepare interface as required for pressurization of unmanned element.	Active/ Passive	Hardware/subsystems (i.e., monitor/ control functions) of manned and or unmanned element must be prepared for pressurization operations.
14.	Pressurize passive element	Active/ Passive	To produce a shirtsleeve environment.
15.	Isolate passive element and verify leak rate.	Active/ Passive	The passive element leak rate must be verified to be within the tolerance that can be supported.
16.	Verify the passive element atmosphere is compatible with the active element atmosphere.	Active	Prior to opening the hatch to the passive element the atmosphere in that element must be verified to be free of contamination.
17.	Equalize pressure in passive element to that of active element.	Active	The pressure between the two elements must be equalized prior to opening the final interface hatch.
18.	Open hatch to passive element	Active/ Passive	
19.	Ingress unmanned element and perform initial inspection.	Passive	Will be made prior to performing subsequent crew operations.
20.	Activate fluid interface as required.	Active/ Passive	

OPERATIONAL PROCEDURE NO. 12-1.

	Operation	Performed by:	Rationale
21.	Activate subsystems necessary for crew/habitability .	Passive	Subsystems necessary to support crew operations in unmanned element must be activated.
22.	Maintain, monitor, control, operate experiment program. Replace film, tapes, etc. Adjust update, calibrate sensors, etc.	Passive	This operation and subsequent operations through #33 are performed either in parallel or are repeated on an as needed basis. These operations constitute the experiment program operation proper. Extra vehicular activity (EVA) may be required to assist in deployment of probes, antennas, viewing covers, hatches, should the normal automatic mode not deploy properly.
23.	Maneuver orbiter to desired orientation for accomplishing initial experiment program.	Active	If RAM experiments require special orientation (solar, stellar, earth directed experiment sensors) orbiter will need to be oriented to accommodate. Influencing this orientation will be the direction, duration, field of view requirements, limit cycle, and altitude.
24.	Maneuver orbiter as required to meet requirements for subsequent experiment orientation.	Active	Because of the sequencing of experiments, and natural phenomenoa (S. Atlantic anomaly) re-orientation of the orbiter will be required.
25.	Maintain attitude pointing and attitude rate within specified limits (limit cycle)	Active	

OPERATIONAL PROCEDURE NO. 12-1

	Operation	Performed by:	Rationale
26.	Perform delta-V maneuvers to maintain orbital altitude on an as needed basis.	Active	Certain experiments may be sensitive to the change in orbit altitude due to aerodynamic drag. To correct for this, occasional delta-V thrusting of the orbiter ACPS engines may be required. The steps involved are: a) determine present orbit altitude from ground station, b) compare present altitude with that required by experiments, c) If correction is required, align G&N, system, orient orbiter, perform pre delta-V procedures, apply proper delta-V e) perform post delta-V procedures.
27.	Maintain satisfactory surrounding external environment by regulating and controlling Orbiter and RAM effluents.	Active/ Passive	During certain experiments (external viewing) there is a particular need to maintain a clean surrounding environment, free of gases and solids that may contaminate the environs. EVA may be required to clear debris from external viewing areas.
28.	Provide electrical power to RAM	Active	Power may be required to support RAM experiment and RAM subsystems. Power may be required only for peak power loads.
29.	Provide crew habitability environment control to RAM.	Active	Environment needed to support crew, sustain an atmosphere free of stagnation and contaminants and compensation for leakage.

OPERATIONAL PROCEDURE NO. 12-1

	Operation	Performed by:	Rationale
30.	Perform analysis on experiment program data.	Passive	Certain experiment program data will need to be analyzed "on site" for analysis and interpretation for assistance from the ground.
31.	Communicate with ground station, for instructions on experiment program.	Active/ Passive	Instructions may be required for open-loop experiments requiring ground evaluation and interpretation for subsequent activity.
32.	Perform routine servicing of RAM experiment packages and supporting subsystem on an as need basis.	Passive	Servicing may consist of cleaning lenses, vacuuming particles from moving parts, lubricating moving parts, replacing filters, calibrating with orbiter subsystem adjusting contsols.
33.	Monitor RAM subsystems.	Passive/ active	Safety parameters, experiment program subsystems, and RAM support subsystems will need to be monitored.
34.	Deactivate subsystem necessary for crew/habitability.	Passive	Subsequent support to crew operations in unmanned element are no longer necessary.
35.	Verify all equipment in the passive element is secured and transfer crew for passive element to active element.	Passive/ active	At this point the experiment program is complete, all subsystems have been placed on a semi-quiescent status, all data modules, tapes, probes, film, have been secured and tied down.
36.	Close hatch between passive element and tunnel.	Passive	

OPERATIONAL PROCEDURE NO. 12-1

	Operation	Performed by:	Rationale
37.	Close hatch between active element and tunnel	Active	
38.	Deactivate communication and data link to passive element, tunnel and passive element lighting	Active/ passive	
39.	Monitor and observe cargo bay environs for adequate clearnace for retraction.	Active	
40.	Unlock deployment activators and retract passive vehicle into cargo bay.	Active	
41.	Deactivate controls/displays for deployment/retraction mechanism.	Active	Controls and displays, except for safety parameters, are no longer need.
42.	Lock and secure passive element in cargo bay.	Active/ Passive	Tie-down points secure payload.

No. 12-2 Attached Element Operations - Service and Checkout

Assumptions

1. Detached elements (i.e., DRAM) once returned to the supporting element are considered "attached elements"
2. Detached RAMS are transported to and from the support element (i.e., MSS) by some propulsive element (i.e., Orbiter, RSM, Tug)
3. The RSM would provide attitude stabilization and control, delta-V translational, communications, and navigation capability
4. All detached RAM's are assumed to be unmanned during normal operations

Initial Conditions

1. Element to be serviced and checked out has been mated to the active supporting element and latching/hard docking has occured.
2. Control systems of the attached element are inactivated
3. Attached element has some of its external hatches and probes in a deployed position
4. Preceding activity is Mating

Final Conditions

1. Subsequent activity is Separation
2. There will be deployment of some external hatches and probes prior to release of the attached module

Description

This operational procedure defines those operations that pertain to basic servicing and checkout of one element while attached to another. These procedures have been developed for the case of a detached RAM returning to the Modular Space Station, however the operations are developed in a generic sense and are therefore relatable to other element pairs with some modification. In the presentation of these operations, passive refers to the detached RAM while active pertains to the modular space station.

OPERATIONAL PROCEDURE NO. 12-2

TITLE: ATTACHED ELEMENT OPERATIONS - SERVICE AND CHECKOUT

ELEMENT INTERFACES: MODULAR SPACE STATION (ACTIVE)/DETACHED RAM (PASSIVE)

Operation		Performed by:	Rationale
1.	Monitor health and safety parameters of passive vehicle.	Active	Attention is given to parameters that signal deterioration in health and safety and to integrate interrelated parameters to give even earlier warning if deterioration begins.
2.	Verify hard docked positive latching.	Active	Visual inspection by line-of-sight with augmentation by TV and sensor devices with ensure a safe latching required for all subsequent operations.
3.	Activate and verify communication and data links to unmanned element, activate tunnel and unmanned element lighting, confirm tunnel passageways is clear.	Active	Reference procedure No. 5-1, operations 2-5.
4.	Make initial check of unmanned element atmosphere.	Active	Initial check of atmosphere in unmanned element must be made so that shirtsleeve operations can proceed.
5.	Pressurize transfer tunnel between hatches.		

OPERATIONAL PROCEDURE NO. 12-2

	Operation	Performed by:	Rationale
6.	Equalize pressure between tunnel and active element.	Active	Any pressure differential between tunnel and airlock must be equalized prior to opening hatch.
7.	Verify tunnel leak rate.	Active	Tunnel seal must be checked prior to opening hatch.
8.	Open hatch to tunnel and inspect mating interface.	Active	Mating port interface must be inspected for any damage that may have occured during the docking and to verify that all latches have engaged and are locked.
9.	Conduct preparations to link active element control to passive element sensors extension mechanism, experiment hatches.	Active	Upon arrival at the active element, the passive element may have extended probes, cameras, antennas, that need to be retracted before the passive element external experiment hatch can be closed for subsequent pressurization. Preparation may involve continuity check to verify hard links, activation of a sequencer (hard dock activity) on the passive element, or an RF link.
10.	Close and seal passive element experiment hatch(s).	Active/ passive	Those hatches that provide experiment sensor deployment need to be closed.
11.	Prepare interface as required for pressurization of unmanned element.	Active/ passive	Hardware/subsystems (i.e., monitor/ control) of manned and/or unmanned element must be prepared for pressurization operations.

OPERATIONAL PROCEDURE NO. 12-2

Operation		Performed by:	Rationale
12.	Pressurize passive element	Active/ Passive	To produce a shirtsleeve environment
13.	Isolate passive element and verify leak rate.	Active/	The passive element leak rate must be verified to be within the tolerance that can be supported.
14.	Verify the passive element atmosphere is compatible with the active element atmosphere.	Active	Prior to opening the hatch to the passive element the atmosphere in that element must be verified to be free of contamination.
15.	Equalize pressure in passive element to that of active element.	Active	The pressure between the two elements must be equalized prior to opening the final interface hatch.
16.	Open hatch to passive element	Active/ Passive	
17.	Connect and activate air circulation ducts.	Active/ passive	Air circulation is required for shirtsleeve operations.
18.	Ingress unmanned/passive element and perform initial inspection.	Passive	Will be made prior to performing subsequent crew operations.
19.	Position tunnel crew restraint devices.	Active/ passive	Restraint devices must be positioned for crew stabilization during interface connection and verification operations.
20.	Connect electrical interfaces as required.	Active/ Passive	If crew tasks at unmanned element work site require electrical interfaces connected, then connections must be made.

OPERATIONAL PROCEDURE NO. 12-2

	Operation	Performed by:	Rationale
21.	Verify interface connector mate.	Active/ Passive	Connector mate integrity must be verified prior to applying power other than continuity check current.
22.	Checkout electrical interface as required.	Active/ Passive	
23.	Connect plumbed interface and verify seal integrity as required.	Active/ Passive	
24.	Activate fluid interfaces as required.	Active/ Passive	
25.	Activate subsystem necessary for crew/habitability	Passive	Subsystems necessary to support crew operations in unmanned element must be activated.
26.	Crewman traverse to passive element.	Passive	
27.	Obtain cargo transfer items	Passive	Transfer items will be restrained in storage/use location.
28.	Verify cargo transfer items are in condition for transport.	Passive	Individual cargo items will be restrained to prevent movement. Transfer time critical data packages from passive to active element for development, decoding, processing, analysis. Transfer selected data packages to active element and then to EO resupply module for down cargo delivery.

OPERATIONAL PROCEDURE NO. 12-2

Operation		Performed by:	Rationale
29.	Adjust crew restraint devices as required.	Passive	To position crewman during cargo handling.
30.	Affix cargo items to crewman cargo restraints.	Passive	To provide positive control of cargo items.
31.	Release from crew restraint devices and maneuver cargo to active element.	Passive/ active	Manual transfer will utilize crew mobility aids.
32.	Adjust crew restraint devices	Active	To position crewman during cargo handling at active element delivery site.
33.	Remove cargo items from crewman cargo restrains.	Active	Temporary work site restraints may be utilized.
34.	Position transferred items into delivery locations.		Transferred items must be positively controlled while awaiting analysis on subsequent delivery.
	NOTE: Repeat steps 27 through 34 for other types of cargo of a non-time critical nature, as required.		

OPERATIONAL PROCEDURE NO. 12-2

	Operation	Performed by:	Rationale
35.	Perform routine maintenance of passive element experiment packages and supporting subsystems.	Passive	Servicing may consist of cleaning lenses, vacuuming particles from moving parts, lubricating moving parts, coating surfaces, replacing filters and screens, adjusting and calibrating subsystems.
36.	Perform checkout of passive element support subsystems (i.e., RSM).	Passive	Checkout would consist of an integrated check of all subsystems to verify their operability within specified tolerances.
37.	Perform checkout of experiment program subsystems and equipment.	Passive	
38.	Perform maintenance and repair of subsystems and experiment program equipment as required.	Passive	Based upon the results of the proceeding checkout, there may need to be maintenance performed on these subsystems and equipment.
39.	Install new equipment for subsequent experiment program.	Passive/ Active	
40.	Perform checkout of newly installed equipment together with previously checked equipment Make necessary calibrations, adjustments, etc.	Passive/ Active	This operation is performed to ensure that integration of new equipment has not resulted in development of a problem in previously checked equipment.
41.	Replenish consumables, logistics, supplies. Repeat steps 27 through 34 as required.	Passive/ Active	Reference cargo transfer activity 4-1.

OPERATIONAL PROCEDURE NO. 12-2

Operation		Performed by:	Rationale
42.	Transfer propellants, fluids, gases through interconnect lines as required.	Passive/ Active	Reference plumbed fluid transfer activity 4-5
43.	Monitor and verify proper transfer of liquids and gases across interface and through associated plumbing.	Passive/	
44.	Perform final systems check with full up consumable capability.	Passive	
45.	Activate passive element attitude control system, with thrusters inhibited.	Passive	Thrusters are inhibited to preclude counteracting attitude maneuvers.
46.	Activate passive element guidance system and align attitude platform with active element.	Active/ Passive	
47.	Transfer crew from passive element to active element.	Active/ Passive	
48.	Deactivate subsystems necessary for crew habitability	Passive	Subsystems support to crew operations are no longer necessary.
49.	Disconnect plumbed interfaces.	Active/ Passive	Interface disconnection required prior to closing hatch.
50.	Disconnect electrical interfaces	Active/ Passive	Interface disconnection required prior to closing hatch.

OPERATIONAL PROCEDURE NO. 12-2

	Operation	Performed by:	Rationale
51.	Disconnect air circulation ducts	Active/	Interface disconnection required prior to closing hatch
52.	Verify all equipment is in airlocks and hatchways are clear	Active/ Passive	Confirmation of retrieval of all loose equipment and hatch clearance.
53.	Close hatch between passive element and tunnel	Passive/ Active	
54.	Close hatch between active element and tunnel	Active	
55.	Depressurize tunnel	Active	Confirm hatch sealing and preparation for element separation
56.	Confirm airlock and passive element sealing	Active	Leak rates must be checked to verify sealing.
57.	Deactivate crew transfer control links/subsystems of unmanned element as required.	Active	Passive element subsystems which support crew operations can be deactivated.
58.	Deactivate airlock and hatchway controls/displays.	Active	Airlock and hatchway controls/displays can be deactivated with termination of crew operations.
	NOTE: Passive element is ready and prepared for removal from the active element.		

OPERATIONAL PROCEDURE NO. 12-3

Attached Element Operations - Quiescent Storage

Assumptions

1. E. O. resupply module may contain crew in transport to and from orbit
2. While being mated to the MSS or being retracted into Orbiter cargo bay, crew is not in E.O. resupply module
3. The E.O. resupply module is dependent upon active element for subsystems support
4. E.O. resupply module will remain attached to active element for up to 120 days and act as a pantary

Initial Conditions

1. E.O. resupply module has been mated to the active element (MSS) and latching/hard docking has occured.
2. Preceding activity is mating operations

Final Conditions

1. Subsequent activity is payload retraction

Quiescent storage basically involves a condition wherein one element remains attached to another for an extended period of time and remains in a semi-active/dormant state. The passive element, in the procedure developed here, pertain to an earth orbit resupply module while the active element is the Modular Space Station. The actual period of quiescent operation occurs from operations 30 through 33.

OPERATIONAL PROCEDURE NO. 12-3

TITLE: ATTACHED ELEMENT OPERATIONS - QUIESCENT STORAGE

ELEMENT INTERFACES: E.O. RESUPPLY MODULE (PASSIVE)/MSS (ACTIVE)

	Operation	Performed by:	Rationale
1.	Monitor health and safety parameters of passive vehicle.	Active	Attention is given to parameters that signal deterioration in health and safety and to integrate interrelated parameters to give even earlier warning if deterioration begins.
2.	Verify hard docked positive latching.	Active	Visual inspection by line-of-sight with augmentation by TV and sensor devices will ensure a safe latching required for all subsequent operations.
3.	Activate and verify communication and data link to unmanned element, activity tunnel and unmanned element lighting, confirm tunnel passageway's clear.	Active	Reference procedure No. 5-1 operations 2-5.
4.	Make initial check of unmanned element atmosphere.	Active	Initial check of atmosphere in unmanned element must be made so that shirtsleeve operations can proceed.
5.	Pressurize transfer tunnel between hatches.		
6.	Equalize pressure between tunnel and active element.	Active	Any pressure differential between tunnel and airlock must be equalized prior to opening hatch.

OPERATIONAL PROCEDURE NO. 12-3

	Operation	Performed by:	Rationale
7.	Verify tunnel leak rate.	Active	Tunnel seal must be checked prior to opening hatch.
8.	Open hatch to tunnel and inspect mating interface.	Active	Mating port interface must be inspected for any damage that may have occured during the docking and to verify that all latches have engaged and are locked.
9.	Prepare interface as required for pressurization of unmanned element.	Active/ Passive	Hardware/subsystems (ie, monitor/control) of manned and/or unmanned element must be prepared for pressurization operations.
10.	Pressurize passive element.	Active/ Passive	To produce a shirtsleeve environment.
11.	Isolate passive element and verify leak rate.	Active/ Passive	The passive element leak rate must be verified to be within the tolerance that can be supported.
12.	Verify the passive element atmosphere is compatible with the active element atmosphere.	Active	Prior to opening the hatch to the passive element the atmosphere in that element must be verified to be free of contamination.
13.	Equalize pressure in passive element to that of active element.	Active	The pressure between the two elements must be equalized prior to opening the final interface hatch.
14.	Open hatch to passive element Connect and activate air circul tion ducts	Active/ Passive	Air circulation is required for shirt-sleeve operations

OPERATIONAL PROCEDURE NO. 12-3

	Operation	Performed by:	Rationale
15.	Position tunnel crew restraint devices.	Active/ Passive	Restraint devices must be positioned for crew stabilization during interfaces connection and verification operation.
16.	Connect electrical interfaces as required.	Active/ Passive	If crew tasks at unmanned element worksite requires electrical interfaces connected, then connections must be made.
17.	Verify interface connector mate.	Active/ Passive	Connector mate integrity must be verified prior to applying power other than continuing check current.
18.	Checkout electrical interface as required	Active/ Passive	
19.	Connect plumbed interface and verify seal integrity as required.	Active/ Passive	
20.	Activate fluid interfaces as required.	Active/ Passive	
21.	Activate subsystems necessary for crew/habitability	Passive	Subsystems necessary to support crew operations in unmanned element must be activated.
22.	Crewman traverse to passive element.	Passive	
23.	Obtain cargo transfer items	Passive	Transfer items will be restrined in storage/use location.

OPERATIONAL PROCEDURE NO. 12-3

	Operation	Performed by:	Rationale
24.	Verify cargo transfer items are in condition for transport.	Passive	Initial transferred cargo will be those items that are of a time critical nature. These would be film that needed special radiation shielding available only in the active element or fluids and gases that need special environmental protection.
25.	Adjust crew restraint devices as required.	Passive	To position crewman during cargo handling.
26.	Affix cargo items to crewman restraints.	Passive	To provide positive control of cargo items.
27.	Release from crew restraint devices and maneuver cargo to active element.	Passive Active	Manual transfer will utilize crew mobility aids.
28.	Adjust crew restraint devices.	Active	To position crewman during cargo handling at active element delivery site.
29.	Remove cargo items from crewman cargo restraints.	Active	Temporary worksite restraints may be utilized.
30.	Position transferred items into delivery locations.		Transferred items must be positively controlled.

OPERATIONAL PROCEDURE NO. 12-3

	Operation	Performed by:	Rationale
	NOTE: Repeat steps 23 through 30 for other types of cargo of a non-time critical nature, as required and as needed.		Cargo transfer will occur on an "a needed basis". The resupply module can serve as a pantry or storage area. As cargo is unloaded to the MSS, down cargo can be transported from the MSS to the resupply module.
31.	Periodically monitor quiescent vehicle atmosphere, subsystems.	Active/ Passive	This operation takes place concurrently with all other operations.
32.	Transfer propellant, fluids, gases through interconnect lines as required.	Passive Active	Reference plumbed fluid transfer activity 4-5.
33.	Monitor and verify proper transfer of liquids and gases across interface and through associated plumbing.	Passive/ Active	
	NOTE: At this point the E.O. resupply module has been fully unloaded and has received necessary down cargo and is ready for preparations for return to earth via the orbiter.		
34.	Transfer crew from passive element to active element	Active/ Passive	
35	Deactivate subsystems necessary for crew habitability.	Passive	Subsystems support to crew operations are no longer necessary.

OPERATIONAL PROCEDURE NO. 12-3

	Operation	Performed by:	Rationale
36.	Disconnect plumbed interface	Active/ Passive	Interface disconnection required prior to closing hatch.
37.	Disconnect electrical interface	Active/ Passive	Interface disconnection required prior to closing hatch
38.	Disconnect air circulation ducts	Active/	Interface disconnection required prior to closing hatch
39.	Verify all equipment is in airlock and hatchways are clear	Active/ Passive	Confirmation of retrieval of all loose equipment and hatch clearance.
40.	Close hatch between passive element and tunnel	Passive/ Active	
41.	Close hatch between active element and tunnel	Active	
42.	Depressurize tunnel	Active	Confirm hatch sealing and preparation for element separation
43.	Confirm airlock and passive element sealing.	Active	Leak rates must be checked to verify sealing.
44.	Deactivate crew transfer control link/subsystems of unmanned element as required.	Active	Passive element subsystems which support crew operations can be deactivated.
45.	Deactivate airlock and hatchway controls/displays	Active	Airlock and hatchway controls/displays can be deactivated with termination of crew operations.
	NOTE: Passive element is ready and prepared for removal from the active element.		

2.12.2 PROCEDURES APPLICABILITY

Figure 2.12-2 identifies the applicability of each of the three operational procedures to the element pairs which have an attached element operations interface. Those pairs that have no interface involving this activity are so indicated with a "NA". Of the 49 potential element pairs, 28 have been selected as having an attached element operations interface. These pairs are indicated in Figure 2.12-1, with a numeric defining the particular attached element operational procedure. Refering to this figure it may be seen that of the 28 attached element operations pairs, 2 are for RAM operations, 18 are defined for Service and Checkout, 4 for Quiescent Storage, and 8 for Checkout only. Four of the element pairs are represented by two procedures (service and checkout, quiescent storage) and are therefore double counted.

SUPPORTING ELEMENT \ SUPPORTED ELEMENT		SPACE PROGRAM ELEMENTS																
		EOS	TUG		RAM				SATELLITE			EO RESUP. MODS	LOW EO MSS	CPS		RNS CLS	OLS	OPD
			RTN	SPACE BASED	ATT. EOS	DET. EOS	ATT. MSS	DET. MSS	EOS DELIV.	EOS + 3RD ST DELIV.	RETR, RESUP.			OIS	CLS			
	EOS	2	NA	2	1	2	NA	NA	4	4	2	4	2		4	4	4	2
TUG	RETURNABLE	NA								NA								
	SPACE BASED	NA		2			NA	2		4	2	4	2,3	NA	2	2	NA	2,3
RAM	ATT. EOS	NA																
	DET. EOS	NA																
	ATT. MSS	NA		NA									1					
	DET. MSS	NA		NA									2					
SATEL	EOS DELIV.	NA																
	EOS + 3RD ST	NA	NA	NA														
	RETR, RESUP.	NA		NA														
	EO RESUP. MODS	NA		NA								NA	2,3		NA	NA		2,3
	LOW EO MSS	NA		NA			NA	NA				NA	NA					
CPS	OIS			NA											NA	NA	NA	NA
	CLS	NA		NA								NA		NA	NA		NA	2
	RNS-CLS	NA		NA								NA		NA		NA	NA	2
	OLS	NA		NA										NA	NA	NA	NA	
	OPD	NA		NA								NA		NA	NA	NA		NA

NA - Not Applicable

Figure 2.12-2. Operational Procedures Applicability—Interface Activity: Attached Element Operations

2.13 DETACHED ELEMENT OPERATIONS

This section presents the operational procedures for detached element operations, and includes one procedure for each alternate approach identified in Volume II of this report. Also presented and discussed is the applicability of these procedures to each element pair included in the in-depth analysis portion of the Orbital Operations Study.

2.13.1 OPERATIONAL PROCEDURES

Detached element operations involve those operational support activities provided by a controlling and/or supporting element (ground or space element) to a separated or detached element in space. In all cases a communication link provides the interface between the elements. Alternate concepts revolve around the nature of the supporting element, which may be grouped into two major categories, ground operations and control, and space operations and control. Existing space networks involve entirely direct links and interfaces between a detached space element and the ground system (MSFN). A number of elements will continue to operate under such a direct interface situation in the future. Other ground-controlled situations may involve a relay space element. Thus, detached element operations directed from the ground system through another space element acting only as a relay involve links and interfaces between the two space elements and between the relay element and the ground. When the relay element is a TDRS, similar procedures are involved, but the TDRS is given an important role in the operational functions supporting the detached element, and a new design TDRS ground station is included. The concept of space operation and control involves a direct link for space element to detached element operations.

Procedure Numbers 13-1, 13-2, 13-3, and 13-4 (below) describe the operations involved in each of the above interfacing approaches to detached element operations. In all cases the essential operations described involve the same basic functions of command and control, data transfer, monitoring and checkout, navigation tracking and ranging, and inspection. The operations differ mostly in degree, depending on the role and extent of involvement of the relay and ground in the functions and operations, the exercise of real time data transfer and processing in contrast to on-board data storage and dumping, the capability given to the space element (relay or space controlling element) for tracking, the need for handover/acquisition of detached elements, and the degree of automation provided in all elements. A combination of the ground-controlled links may be required for full support of future space programs. A combination of the direct ground-to-element procedure and the ground-to-element via TDRS procedure may be required to provide full and effective future support of detached elements, particularly as it involves rapid and high data rate transfer and near-continuous coverage. For the direct space element-to-element case, Procedure Number 13-4 illustrates a typical interface between a manned space (controlling) element (e.g., MSS) and an unmanned space (controlled) element (e.g., RAM). In such case the controlling element must be manned to provide full operational capability. When both elements are unmanned, the case becomes similar to utilization of the element as a space relay element as described in Procedure Number 13-2. In the direct space case, the MSS must have on-board data processing and display and a capability to determine its own position and ephemerides accurately in order to determine detached element position accurately.

OPERATIONAL PROCEDURE NO. 13-1

Detached Element Operations - Ground Operations and Control - Direct Ground (MSFN) to Element

Assumptions

1. All communication links are direct between the space element and the ground station (MSFN).

2. All space element operations and control (other than automated/pre-programmed operations) are directed from the ground system.

3. The space element will interface and be in view of the ground station for only a very limited portion of the orbit trajectory.

4. The space element is equipped with on-board data/command receivers, transmitters, antennas, and other equipments required for command and data transfer.

Initial Conditions

1. The space element has entered the field of view of the ground station and is in interface relationship with the ground station for subsequent operations.

2. Space element receivers are on and able to receive commands from the ground station.

Final Conditions

1. After completing all appropriate operations during the contact period available for interfacing operations, the space element continues on its orbit trajectory out of view of the ground station.

2. Space element operations during the period out of contact will be performed on the basis of preprogrammed or automated instructions introduced before launch and/or during contact periods.

3. During long periods out of contact all unnecessary powered equipment except receivers and essential mission equipment may be turned off to conserve power.

Description

1. Existing space networks involve entirely direct links and interfaces between a detached space element and the ground system (MSFN and user control center). A number of elements will continue to operate under such a direct interface situation even though a TDRSS may provide a relay capability to handle many such space elements simultaneously and almost continuously.

2. This procedure describes five operational sequences for those direct ground element interfacing links which do not involve any relay capability. These five operational sequences involve functions of command and control, data transfer, monitoring and checkout, tracking and ranging, and inspection. Since they all have features which may occur simultaneously and/or sequentially, they are all integral to one procedure.

3. Command and control operations commence with the commands to activate all equipments on the ground and in the space element, to verify and authorize command execution, to indicate readiness, to command and control or monitor operations, and at the end of a contact period to deactivate all powered equipment not required until the next contact.

4. Data transfer operations follow the initial commands for activation, verification, and execution. Operations may involve one or another of two modes of data transfer, both modes implementing the transfer only during the available contact period. In one mode the data has been collected and stored for later dumping to the ground station. In the second mode, the collected data is transferred in real time during the few minutes or so available. Previously collected data may of course be dumped while data current to the contact period may be transferred in real time. At expiration of the contact period the unnecessary equipments are deactivated.

5. Monitoring and checkout operations commence as soon as equipments are activated and operations commanded. Data obtained from the monitoring and checkout equipment and sensors will be transferred in the same manner as with data transfer, by dumping and/or real time transfer. The ground station will receive, process, display, and utilize such data or store it for later use. A computer will compare such data to a reference and cause commands to be initiated for correction of faults if required. These sequences may be repeated as often as required.

6. Navigation operations involving tracking and ranging commence as soon as equipments, including antennas, RF equipments, transponders, and receivers/transmitters, are activated and operations commanded. The ground station S-band tracking antenna is oriented toward the element, PRN ranging is carried out by both elements and range and range rate computations are performed. The ground station tracking antenna is switched to auto-track (for the entire contact period). Tracking measurements are taken periodically for several orbital passes as required and tracking errors and ephemerides are computed.

7. Inspection operations commence with activation of equipments and operations, including activation of an element black and white TV camera for video inspection of element status and operation.

8. Operational Procedure Number 13-1 shows the detailed sequence of operations for all five operational functions of command and control, data transfer, monitoring and checkout, navigation tracking and ranging, and inspection, together with the rationale for each operation, identifica-

tion of the element performing the operation, and the reference to the functional requirements supported by that operation. Figure 2.13-1 shows a block flow diagram of the operations performed in this procedure.

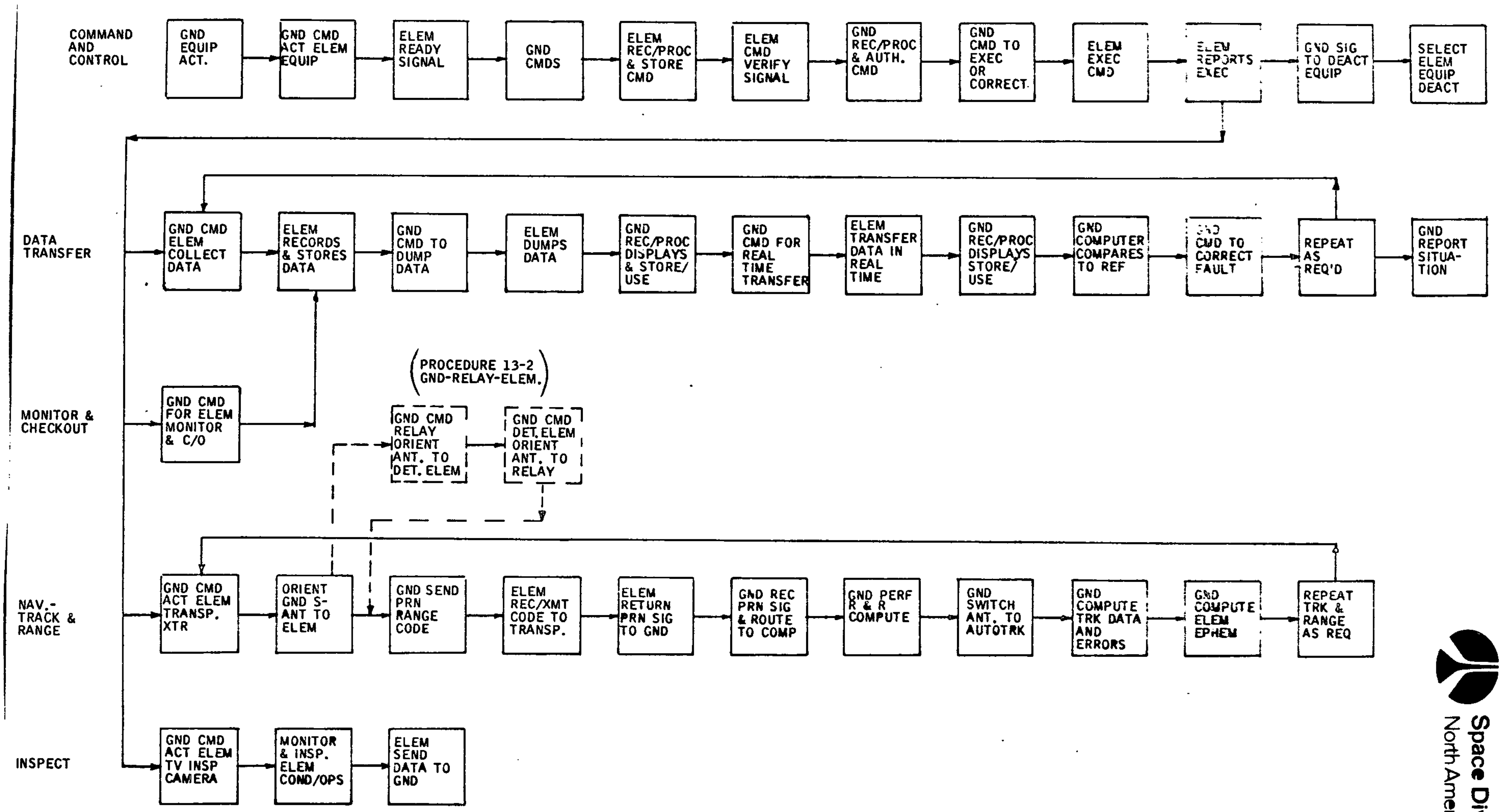

Figure 2.13-1. Procedure No. 13-1 Ground Operations and Control Direct Element to Ground

OPERATIONAL PROCEDURE NO. 13-1

TITLE: DETACHED ELEMENT OPERATIONS - GROUND OPERATIONS AND CONTROL

ELEMENT INTERFACES: Direct Ground (MSFN) to Element - A. Command & Control Operations

	Operation	Performed by:	Rationale
1	Activate Xtr/rcv/processing equipment	GS	Preparation of all equipments for element operation
2	Send command signal to activate element Xtr/rcv/processing/sensors and other equip.	GS	Preparation of element equipments for C&C and mission operations; element receiver monitors GS cmd link frequency
3	Send readiness signal	element	Indication that all element systems are ready
4	Send command	GS	Transmission of commands begins - same sequence followed for each command
5	Receive/process/store cmd	element	Command is processed, decoded and stored pending verification and authorization
6	Send command verification signal	element	Element retransmits command signal for verification & authentication
7	Receive/process/authenticate command	GS	Command is processed, compared with original

A. Command and Control Operations

OPERATIONAL PROCEDURE NO. 13-1

	Operation	Performed by:	Rationale
8	Send execute command (or correct command)	GS	Provides authority to execute command or correct command
9	Execute command	element	Commanded operation is performed
10	Monitor command operation	element	Element records operation performance
11	Send operation-executed signal/ digitized data	element	GS is informed of operation performance
12	Receive operation-executed signal/data and process/display	GS	Information on operation performance is processed and displayed
13	Send signal to deactivate communication equip. (except rcvr) as required	GS	During long periods between commands (or out of contact) all powered equip. except receivers may be turned off to conserve power
14	Communication equipment (except receivers) deactivated	element	All unnecessary equipment on standby until reactivated for use.

OPERATIONAL PROCEDURE NO. 13-1 B. DATA COLLECTION AND TRANSFER OPERATIONS

	Operation	Performed by:	Rationale
1-3	Same as for C&C	GS/ element	Preparation of both GS and element for C&C and mission operations; commands to activate selected equipments for data collection and transfer; readiness indicated
4-12	Same as for C&C; command to start data collection	GS/ element	All equipments in operation and commands received and verified; data are collected
13	Data recorded and stored	Element	Data collected while out of contact, are stored for later transfer
14	Send command to dump data	GS	Same sequence as 4-12; command to dump is sent when element is in contact (perhaps once/day)
15	Stored data are dumped	Element	Large amounts of stored data transferred
16	Dumped data are received	GS	High data rate (50 Mbps) and large quantities of data (10^{10} bits/day)
17	Dumped data processed/displayed and stored or used by ground user	GS	Data are processed and displayed for utilization and either stored for later use or used immediately by ground user
18	Send command to start real-time data transfer	GS	Same sequence as 4-12; command for real-time data transfer when elements in contact and data are time-sensitive

B. Data Collection and Transfer Operations

OPERATIONAL PROCEDURE NO. 13-1

Operation		Performed by:	Rationale
19	Real-time data are transferred	element	When in contact and ready
20	Receive real-time data	GS	Type, rate, quality vary, perhaps > 5 Mbps digital data
21	Real-time data processed/displayed and used by ground user or stored for later use	GS	After processing & display, real-time data are utilized by ground user for mission purposes as soon as received, or stored for later integration, assessment and utilization
22	Send command to deactivate data collection/transfer equip (except receivers) as required	GS	During long intervals between contacts and to conserve power
23	Element data collection/transfer equip (except rcvrs) deactivated to standby	element	As required, same as 13-14 sequence of C&C

C. Monitoring and Checkout Operations

OPERATIONAL PROCEDURE NO. 13-1

	Operation	Performed by:	Rationale
1-3	Same as for C&C	GS/ element	Preparation of both GS & element for C&C & mission operations; selected equipments activated for and checkout operations; readiness indicated
4-12	Same as for C&C; commands to start scheduled continuous/ periodic monitoring and check-out of element equipment and operations	GS/ element	Monitoring of element & experiment subsystems; status on continuous or periodic basis; periodic checkout of subsystems condition/isolate faults; requires medium rate (up to 50 kbps) telemetry, digital data, processing & display and compatible computer capability in both GS & element.
13	Monitoring and checkout data are recorded and stored	element	Same as for data transfer sequence
14	Send command to dump data	GS	"
15	Stored data are dumped	element	"
16	Dumped data are received	GS	"
17	Dumped data are processed/ displayed & stored or used by ground user	GS	"

C. Monitoring and Checkout Operations

OPERATIONAL PROCEDURE NO. 13-1

Operation		Performed by:	Rationale
18	Send command to start real-time data transfer	GS	Same as for data transfer sequence
19	Real-time data is transferred	element	"
20	Receive real-time data	GS	"
21	Real-time data processed/ displayed and used by ground user or stored for later use	GS	"
22	Computer comparison of performance data to reference data	GS	Determine existence, level & impact of error/fault on mission performance
23	Send command to correct fault	GS	Correct by command during earliest contact period, if possible
24-33	Repeat sequences 13-22 as required	GS, element	Error/fault corrected; if not corrected, determine mission loss & consequences
34	Report situation	GS	Report of situation - continue mission at degraded level or need replacement

D. Navigation Operation - Tracking and Ranging

OPERATIONAL PROCEDURE NO. 13-1

	Operation	Performed by:	Rationale
1-3	Same as for C&C	GS, element	Preparation of both GS & element for C&C and mission operations; selected equipments activated for tracking & ranging operations; readiness indicated
4-12	Same as for C&C; command to activate transponder transmitter	GS, element	Availability of ranging transponder & signal for tracking; capability to send certain types of data & simultaneously perform ranging turnaround function
13	GS S-band tracking antenna oriented toward element	GS	Tracking antenna must be oriented to predicted or known position of element during contact period of orbit; tracking can be initiated by utilizing computer orbital parameter data to drive tracking antenna
14	Send PRN ranging code	GS	To initiate ranging operation
15	Receive PRN ranging code and route to transponder transmitter	element	Provide signals for processing/ranging
16	Return PRN ranging code signal to ground station	element	To verify ranging operation & start turn-around ranging
17	Receive turn-around PRN ranging code and route to computer	GS	For range & range rate measurement and computation

OPERATIONAL PROCEDURE NO. 13-1

Operation		Performed by:	Rationale
18	Perform range and range rate computation	GS	To determine orbital parameters
19	Switch tracking antenna to auto-track mode	GS	Initiated as soon as signal from element is received; uses signal for auto-track operation and processing
20	Compute tracking data and errors from auto-track and turn-around ranging signals	GS	Determine direction, angle, etc., of element; digital encoders on antenna axes and antenna gimbal servo error signals provide antenna pointing angle data for tracking computer to compute tracking
21	Compute ephemerides of element	GS	Determination of orbital parameters & accurate ephemerides of elements; range, range rate & tracking data utilized; stored data in GS computer on element orbital characteristics
22	Continue ranging and tracking as required	GS	Ranging & tracking measurements are made during each contact period for updating orbit & ephemeride data

E. Inspection Operations

OPERATIONAL PROCEDURE NO. 13-1

Operation		Performed by:	Rationale
1-12	Same as for C&C; commands sent and received to activate equipments and operations	GS/ element	Preparation of both elements for C&C and mission operations; commands activate all appropriate equipments for operations; readiness indicated
13	Send command to activate element TV inspection camera	GS	Black and white television camera on element is activated for use in inspection of appropriate elements in line-of-sight contact for direct communication to GS (utilizes approximately 2.9 MHz baseband analog signals); visual inspection may also be possible in some cases
14	Monitor/inspect other element condition and operations	element	Other element condition and operation is monitored by element during periods of contact; data are telemetered directly to GS for evaluation and possible correction by command.

OPERATIONAL PROCEDURE NO. 13-2

Detached Element Operations - Ground Operations and Control - Ground (MSFN) to Element Via a Space Relay Element

1. All communications between the ground and the space element are by way of another space element operating only as a relay.

2. It is assumed that the detached element will always be in line-of-sight contact with the relay element. However, the two element set, being in low earth orbit, will be in line-of-sight contact with the ground station for only a limited time.

3. All detached element operations and control (other than automated/preprogrammed operations) are directed from the ground station.

4. The detached and relay elements are equipped with compatible on-board equipments (data/command receivers, transmitters, antennas, transponders/translators, etc.) for command and data transmission.

Initial Conditions

1. The detached element and relay element have entered the field of view of the ground station and are in interface relationship with the ground station for subsequent operations.

2. Detached element receivers are on and both receivers and translater/transponder on the relay are on and able to receive and relay commands from the ground station.

Final Conditions

1. After completing all appropriate operations during the contact period, the space elements continue on their orbit trajectories with both elements out of view of the ground station.

2. At loss of contact by the relay combination, detached element operations will be based on preprogrammed or automated instructions.

3. During long periods out of contact all unnecessary powered equipment except receivers and relay transponder/translator and essential mission equipment may be turned off to conserve power.

Description

1. This procedure describes five operational sequences for those ground-element interfacing links which involve an intermediate relay element. These five operational sequences involve the same functions described in Operational Procedure No. 13-1, namely command and control, data transfer, monitoring and checkout, tracking and ranging, and inspection.

The sequences of operations are quite similar as well. Since they all have features which may occur simultaneously and/or sequentially they are all integral to one procedure. Differences in functions and operations are only in degree and the extent to which the relay element is given increased capabilities for data transmission and is mechanized for relay operation at increased complexity.

2. Command and control operations commence with the commands through the relay to activate equipments in both space elements, to verify and authorize command execution, to indicate readiness, to command and control or monitor operations, and finally to deactivate all powered equipment not required while out of contact.

3. Data transfer operations follow initial commands for activation, verification and execution. Two modes of data transfer are possible during the period of contact. In one data is collected and stored for later dumping through the relay to the ground. In the second data is transferred in real time through the relay to the ground during the period of contact. At expiration of the period of contact the unnecessary equipments are deactivated.

4. Monitoring and checkout operations commence as soon as equipments, sensors, and controls are activated and operations commanded. Data obtained will be transferred in the same manner as with data transfer, by dumping and/or real time transfer. The ground station receives, processes, displays, and utilizes such data or stores it for later use. A computer will compare such data to a reference and cause commands to be initiated for corrections of faults if required. These sequences may be repeated as often as required.

5. Navigation operations involving tracking and ranging commence as soon as equipments, including antennas, RF equipments, transponders and receivers/transmitters, are activated and operations commanded. The ground station commands the relay and detached elements to orient their antennas toward each other, based on computer-stored and predicted information at the ground station. Then PRN ranging is carried out through the relay element, and range and range rate computations are performed. The ground antenna is switched to auto-track for the contact period. Tracking measurements are continued over several orbital passes as required and tracking errors and ephemerides computed.

6. Inspection operations commence with activation of equipments and operations, including activation of an element black and white TV camera for video inspection of element status and operation.

7. Figure 2.13-1 of Operational Procedure No. 13-1, which shows a block diagram of the operations performed for the case of direct element to ground interfaces is also applicable to Operational Procedure No. 13-2, with the relay element acting only as the intermediate relay repeater. Additional tracking operations are indicated to include ground commands to orient the antennas of both space elements toward each other before ranging is begun. Otherwise, any differences are essentially

in degree rather than in kind. Operational Procedure No. 13-2 shows the detailed sequence of operations for all five operational functions, command and control, data transfer, monitoring and checkout, navigation tracking and ranging, and inspection. Also given are the rationale the each operation, the element performing the operation, and the reference to the functional requirements supported.

OPERATIONAL PROCEDURE NO. 13-2

TITLE: DETACHED ELEMENT OPERATIONS - GROUND OPERATIONS AND CONTROL

ELEMENT INTERFACES: Ground (MSFN) to Element via a Relay Element

A. Command and Control Operations

Operation		Performed by:	Rationale
1	Send command to relay to activate equipments, sensors, processing, antennas, etc. on controlled element and on relay element	GS (MSFN)	Preparation of all equipments on both elements for detached element operations; commands sent to relay element for transmission and implementation
2	Activation commands repeated to controlled element	relay element	Relay repeater sends commands to controlled element
3	All equipments activated and readiness signal returned	controlled and relay elements	Performance of operation commanded and reported ready
4	Send command(s) by S-band link through relay to controlled element	GS	Transmission of commands through relay repeater to controlled element - same sequence followed for each command
5	Receive/process/store cmd.	controlled element	Command is received, processed and decoded and stored pending verification and authorization
6	Send command verification signal through relay to ground	controlled element	Element retransmits command signal for verification & authentication

A. Command and Control Operations

OPERATIONAL PROCEDURE NO. 13-2

	Operation	Performed by:	Rationale
7	Receive/process/authenticate command	GS	Command is processed, compared with original
8	Send execute command (or correct command) through relay to element	GS	Provides authority to execute command
9	Execute command	controlled element	Commanded operation is performed
10	Monitor command operation	controlled element	Element records operation performance
11	Send operation executed signal/ digitized data through relay to ground	controlled element	GS is informed of operation performance
12	Receive operation executed signal and data process/display	GS	Information on operation performance is processed and displayed
13	Send signal commands to de-activate command equipment (ex. rcrv.) and sensors as req. through relay to controlled element	GS	During long periods between commands or sensing or out of contact, all powered equipment except receivers may be turned off to conserve power
14	Command equipment (except rcvrs and some sensors) deactivated	controlled element	All unnecessary equipments turned off on standby status until reactivated for use

B. Data Collection and Transfer Operations

OPERATIONAL PROCEDURE NO. 13-2

Operation		Performed by:	Rationale
1-12	Same as for C&C, Commands to start data collection (through relay)	GS/element and relay	Preparation of GS, element & relay equipments for C&C & mission operations; commands to activate selected element equipments & operations for data collection & transfer (depends on type of activity and data transfer - digital/analog, low/high data rates & bandwidths, data storage/dump or real-time transfer, etc.). Readiness reported and all commands received and verified; data is collected.
13	Data is recorded and stored	element	Data collected while out of contact with GS is stored for later transfer
14	Send command to dump data through relay to element	GS	Same sequence as 4-12 of C&C, command to dump is sent when element is in contact; large amounts of data stored may need to be transferred at high data rate (up to 50 Mbps) and large quantities of data (10^{10} bits/day)
15	Stored data is dumped (through relay)	element	Large amounts of data at high data rate transferred - relay requirement to handle such amounts and rates
16	Receive dumped data	GS	Ground station data handling center receives the dumped data for processing

B. Data Collection and Transfer Operations

OPERATIONAL PROCEDURE NO. 13-2

	Operation	Performed by:	Rationale
17	Dumped data processed/displayed and stored or used	GS	Data are processed and displayed for immediate utilization or stored for later use
18	Send command to start real-time data transfer	GS	Same sequence as 4-12 of C&C; when element is in contact and data are time-sensitive
19	Real-time data are transmitted through relay	element	When in contact and ready
20	Receive real-time data	GS	Type, rate, quality vary, perhaps > 5 Mbps digital data
21	Real-time data processed/displayed/stored	GS	After processing/display, data are used immediately or stored for later utilization
22	Send command to deactivate data collection/transfer equip (except rcvrs & some sensors) as required	GS	During long intervals between contacts and data collections to conserve power
23	Element data collection/transfer equipment deactivated to stand-by	element	All unnecessary powered equipment (except receivers) are deactivated as required; same sequence as 13-14 C&C

OPERATIONAL PROCEDURE NO. 13-2

	Operation	Performed by:	Rationale
1-12	Same as for C&G; commands to start scheduled continuous/periodic monitoring and check-out of element equipments and operations	GS, element & relay	Preparation of GS & elements for C&C & mission operations; selected equipments activated for monitoring begins on element & experiment subsystems; status on continuous or periodic basis; periodic checkout of condition/isolate faults; requires medium rate (up to 50 kbps) telemetry digital data, processing & display - computer capabilities between GS & element must be compatible; relay element capabilities must be compatible to element-GS requirements
13	Monitoring and checkout data are recorded and stored	element	Same as for data transfer sequence
14	Send command to dump data (through relay)	GS	"
15	Stored data are dumped (through relay)	element	"
16	Dumped data are received	GS	"
17	Dumped data are processed/displayed and stored or used by ground user	GS	"

OPERATIONAL PROCEDURE NO. 13-2

	Operation	Performed by:	Rationale
18	Send command to start real-time data transfer (through relay)	GS	Same as for data transfer sequence
19	Real-time data are transferred through relay	element	"
20	Receive real-time data	GS	"
21	Real-time data processed/displayed and used by ground user or stored	GS	"
22	Computer comparison of performance data to reference data	GS	Determine existence, level and impacts of error/fault on mission performance
23	Send command to correct fault (through relay)	GS	Correct by command during earliest contact period if possible
24-33	Repeat sequences 13-22 as required	GS/element	Error/fault corrected; if not corrected, determine mission loss and consequences
34	Report situation	GS	Report of situation - continue mission at degraded level or need replacement

OPERATIONAL PROCEDURE NO. 13-2

Operation		Performed by:	Rationale
1-12	Same as for C&C; commands to activate element transponder transmitter; GS tracking antenna etc.	GS, element and relay	Preparation of GS, element & relay equipments for C&C and mission operations; commands to activate selected equipments & operations for tracking & ranging operations. Readiness indicated. Element receiver monitoring cmd link frequency. Availability of ranging transponder & signal for tracking; capability to send certain types of data & simultaneously perform ranging turn-around function.
13	Send commands to relay to orient relay antenna toward element	GS	Transmission via link to relay; relay antenna must be oriented to predicted or known position of element during contact period of orbit; tracking can be initiated by utilizing computer orbital parameter data to drive tracking antenna
14	Receive command and orient relay antenna to element	relay	Relay tracking antenna is oriented to ground predicted/computed element location
15	Tracking command relayed to element for orienting element antenna to relay	relay	Relay element transmits tracking command to element for antenna orientation to relay

OPERATIONAL PROCEDURE NO. 13-2

Operation		Performed by:	Rationale
16	Tracking command received and antenna oriented	element	Orients antenna toward relay
17	Send PRN ranging code through relay to element	GS	To initiate ranging operation
18	Ranging code signal received by element and routed to transponder transmitter	element	Provide signals for processing/ranging and turn-around ranging
19	Transmit turn-around signal through relay to GS	element	Verifies ranging operation, starts turn-around ranging; relay is repeating
20	Receive and process turnaround signals	GS	For range and range rate measurement
21	Perform range and range rate computation	GS	Determine orbital parameters
22	Switch GS tracking antenna to auto-track mode and continue tracking operation	GS	Initiated as soon as signal from element is received through relay to ground; uses signals for auto-track operation and processing
23	Receive tracking data and signals through relay to ground for processing and computation	GS	Tracking data received for processing and computation through period of contact

OPERATIONAL PROCEDURE NO. 13-2

	Operation	Performed by:	Rationale
24	Compute tracking, errors and ephemerides of the elements from tracking and ranging data	GS	Determine direction, angle, range and orbital parameters and ephemerides of the elements
25	Continue tracking and ranging	GS, element and relay	As required, throughout each contact period, to update ranging & tracking data; to have available timely and accurate orbital and ephemeride data for continued mission operations; range accuracy at $\leq$ 30 ft RMS and range rate measurement accuracy of $\leq$ 0.2 fps at 4000 n mi are representative accuracy requirements; overall element position uncertainty for a single relay system to ground may not be less than one kilometer after 30 minutes of tracking and may require tracking over several orbital periods to improve this.

E. Inspection Operations

OPERATIONAL PROCEDURE NO. 13-2

Operation		Performed by:	Rationale
1-12	Same as for C&C; commands sent through relay to element to activate equipments and operations	GS element and relay	Preparation of GS, element & relay equipments for C&C & mission operations; commands to activate appropriate equipment for processing, sensing, viewing, transmitting and receiving, and for inspection and monitoring, etc; Element receiver monitors cmd link frequency; tracking and ranging operations activated; readiness of all operations indicated
13	Send command to activate TV inspection camera on relay	GS	Same sequence as 4-12 of C&C
14	TV camera activated	relay	Inspection of element by black and white television (utilizes approximated 2.9 MHz baseband analog signals); visual observation may also be possible in some cases
15	Monitor element condition and operation and transmit to ground	relay	Element condition is determined; telemetry data from element also used for evaluation on ground
16	Send commands (through relay) to correct/adjust element condition/operation	GS	As required; sequence 1-12 repeated

E. Inspection Operations

OPERATIONAL PROCEDURE NO. 13-2

	Operation	Performed by:	Rationale
17	Continue video inspection as required	GS, relay	As required through each orbital contact period as long as element is in line of sight.

OPERATIONAL PROCEDURE NO. 13-3

Detached Element Operations - Ground Operations and Control - Ground to Element Via TDRS

Assumptions

1. All communications between the ground and the detached (user) element are by way of the TDRS, and a VHF and Ku-band relay of FM or PM signals is provided.

2. Operational support of the detached element can be provided by two TDRS spacecraft in geosynchronous orbit.

3. The detached element will almost continuously be in line-of-sight contact with one or the other of the TDRS spacecraft.

4. All detached element operations and control (other than automated/preprogrammed operations) are directed from the ground station.

5. During short periods of loss of contact, detached element operations may be handed over from one TDRS to the other.

6. Simultaneous tracking of the detached element can be provided by two TDRS spacecraft.

7. A coordinated ground system network is available to include MSFN and user control centers as well as the TDRS ground station.

8. The user spacecraft is equipped with compatible transponder, antenna, and processing equipment for command/data transfer.

Initial Conditions

1. The user spacecraft is in the field of view of one or the other TDRS spacecraft and is in interface relationship with it and the ground.

2. User and TDRS spacecraft receivers and transponder/transmitters are on and able to receive and relay commands from the ground station.

Final Conditions

1. Depending on duty cycle requirements for various functions and operations, the detached element may deactivate certain equipments to conserve power by command from the ground station.

2. During periods of loss of contact (eclipse, handover, etc.), emergency operation is maintained at a minimum and preprogrammed/automated operations may be carried out.

Description

1. This procedure describes five operational sequences for ground-element interfacing links involving a TDRS relay element. These five operational sequences involve the same functions described in Operational Procedure No. 13-1 and No. 13-2, namely command and control, data transfer, monitoring and checkout, tracking and ranging, and inspection. The sequences of operations are basically similar as well. Since they all have features which may occur simultaneously and/or sequentially they are all integral to one procedure. Differences in functions and operations are only in degree.

2. Command and control operations commence with command requests generated at the user control center, to activate equipments, received at the TDRS network control center for processing, scheduling and signal generation, transmitted to the TDRS via Ku link, where it is received, repeated/frequency translated and sent to the user spacecraft. There it is processed and either executed and operation verified or returned the same way for verification and authentication. The ground handling center receives and processes such returns and the control centers confirm or correct the command. Command and control VHF handover is performed by activating a user spacecraft code, adjusting for doppler frequency shift and signal phase matching and switching over to another TDRS which reacquires the user spacecraft for continued operation.

3. Data transfer operations follow initial commands for activation, verification and execution, and the commands to orient user and TDRS antennas to each other and data transfer to begin. Data transfer follows a similar sequence of steps as in command and control. The data is received (in real time) by the TDRS, repeated and translated and transmitted to the processing center on the ground where it is reduced and sent to the user control center. Such transfer continues as long as required. Data acquisition and handover operations follow a similar sequence as in command and control. When the user is in a dark region out of sight of both TDRS's, data lock loss may occur due to the switchover; such loss or interruption in data transfer would have to be accepted, else a third TDRS would be required. Some preprogrammed operation may be performed in this time interval until lock-on is restored. In other handover cases, the switchover operation is one of slewing the antennas and commanding the user to carry out frequency search for lock-on and reacquisition.

4. Monitoring and checkout operations commence as soon as equipments, sensors, and controls are activated and operations commanded. Data obtained will be transferred in the same real time manner as with data transfer. The ground station receives, processes, displays and utilizes such data or stores it for later use. A computer will compare such data to a reference and cause commands to be initiated for corrections of faults if required. These sequences may be repeated as often as required.

5. Navigation operations involving tracking and ranging commence as soon as equipments, including antennas, RF equipments, transponders and receivers/transmitters, are activated and operations commanded. The ground station commands the TDRS and detached element to orient their antennas toward each other, based on computer-stored and predicted information at the ground station. Then PRN ranging is carried out through the TDRS, and range and range rate computations are performed. The ground antenna is switched to auto-track for the contact period. Tracking measurements are continued over several orbital passes as required and tracking errors and ephemerides computed.

6. Inspection operations commence with activation of equipments and operations, including activation of an element black and white TV camera for video inspection of element status and operation. Data is transmitted through the TDRS to ground, where it is processed and used for correction and control.

7. Operational Procedure No. 13-3 shows the detailed sequence of operations for all five operational functions, command and control, data transfer, monitoring and checkout, navigation tracking and ranging, and inspection. Also given are the rationale for each operation, the element performing the operation, and the reference to the functional requirements supported.

OPERATIONAL PROCEDURE NO. 13-3

TITLE: DETACHED ELEMENT OPERATIONS - GROUND OPERATIONS AND CONTROL

ELEMENT INTERFACES: Ground to Element Via TDRS   A. COMMAND AND CONTROL OPERATIONS

	Operation	Performed by:	Rationale
1	Command requests generated to activate User and TDRS (and ground) equipments, sensors, processing, antennas, etc., sent to TDRS Network Control Center (TDRSNET) or STADAN or MSFN	User Control Center (UCC) and TDRS Control Center (TDRSCON)	Prepare User and TDRS for operations; assumes User and TDRS receivers active
2	Command requests received at TDRSNET, processed for scheduling and support and signal generation	TDRSNET	Central scheduling and command signal generation at ground station
3	Scheduling and other information returned to UCC and other ground elements	TDRSNET	For user scheduling, operations and coordination
4	Command signal generated is sent to TDRS via Ku link	TDRSNET	TDRS acts as relay to User
5	TDRS receives command signal, signal repeated, frequency translated and sent to User	TDRS	Transponder repeater on TDRS sends command on appropriate link frequency to User--VHF for LDR, Ku for MDR and HDR; most commands may only require VHF; higher data commands at S or Ku will require antenna pointing
6	Command is processed and either executed and operation verified or returned for verification	User	Depending upon the command/operation, and the need for real-time operation, verification of command may be required before execution; some path links are used for return as forward

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	Operation	Performed by:	Rationale
7	Verification or execute signal received for processing and action or control	Data Handling Center, TDRSNET and/or UCC	After processing, rescheduling or recommending may be required at Ground and Control Stations and/or operation performed displayed
8	Command verification signal or execute signal sent; or new command sent	Ground System	Forward path links used as before
9	Perform C&C VHF handover between TDRS's as required	GS, TDRS and User	Handover/acquisition is required for G&C in situations where the user is entering a dark region of the orbit out of the field of view of either or both TDRS's, or in the case of a common field of view where a switchover between TDRS's is involved. At positions 1 & 2 for low altitudes, the user is in a dark region and out of sight of either TDRS; data and command lock is lost due to the switchover; importance of this will depend on the requirements. In positions 3 & 4 (for user altitudes at or near 500 Km the dark region is very small or zero) and for positions 5 & 6 where the user is in the field of view of both TDRS's, the problem is one of the time of slewing the antennas, of commanding the user to carry out frequency search for lock-on.
9a	Activate User Code for TDRS No. 2 forward link (upon direction and scheduling in TDRSNET)	GS, TDRS and User	
9b	Make adjustments for Doppler Frequency Shift and Signal Phase Matching		
9c	Make switchover from TDRS No. 1 to TDRS No. 2 and route transmissions through TDRS No. 2		
9d	Reacquire User and continue C&C operation		

OPERATIONAL PROCEDURE NO. 13-3 B. DATA TRANSFER

	Operation	Performed by:	Rationale
1-8	Same as for C&C; commands to orient user and TDRS antennas to appropriate pointing angles; execution and/or verification and execution signals sent and received	Ground System to TDRS and User	Preparation of all elements for C&C and data relay operations; commands to activate selected equipment for data transfer (depend on user and type of of data); execution and/or command verification of antenna pointing operation performance, readiness indicated (utilizes orbital parameter information from ground system tracking, scheduling and orbit determination operations); commands to orient antennas may utilize VHF link to user; GS controls antenna orientation by computed program until links and auto-track established.
9	Command to start data transfer and transmission to TDRS	GS to TDRS and User	Same command sequence; when links, data transfer equipment and auto-track are ready; sent to TDRS via appropriate link according to type of data
10	Data received, repeated, frequency translated and transmitted	TDRS	Data converted to Ku frequency for transmission to ground
11	Telemetry data received at processing center	GS Data Handling Center	Processes and reduces the raw data, confirms quality and utility of data
12	Reduced or processed data transmitted to User Control Center	GS DHC	For utilization by using agency
13	Continue data transfer as required	User to TDRS to GS	Loss of data lock may occur when user enters dark region of orbit out of field of view of either TDRS or when user is in common field of view and a switchover/handover between TDRS's is involved

OPERATIONAL PROCEDURE NO. 13-3

	Operation	Performed by:	Rationale
14	Perform handover/switching and acquisition between TDRS's; same operations as 9a-d for C&C	GS, TDRS, and User	Same as for C&C where user is in a dark region out of sight of both TDRS's, data lock loss will occur due to the switch-over; depending on the user data requirements such loss or interruption in data transfer may be accepted, otherwise a third TDRS may have to be considered; when user is in field of view of both TDRS's, the switchover problem is one of the times required to slew the antennas and commanding the user to carry out frequency search for lock-on; loss of data lock as a function of time and antenna slewing during switchover must be determined and evaluated

	Operation	Performed by:	Rationale
1-8	Same as for C&C; commands to perform monitoring and checkout of User element and TDRS equipment and operations	User and TDRS Control Centers	TDRS and User elements prepared for G&C and mission operations; readiness indicated; commands for monitoring and checkout of TDRS initiate at GS but status of TDRS is primarily indicated by its function as relay of user data and commands; user element status and condition is a concern of the Ground User Control Center and will be indicated through TDRS by the user functions in data transfer and supporting functions; monitoring and checkout of subsystems and element status requires forward commands and return telemetry data (up to medium rates of 50 Kbps) for processing in Ground Data Handling Center and transmission and display at Ground User/TDRS Control Centers
9	Monitoring and checkout data transferred to ground data handling center	TDRS and User	Continuous and/or periodic probes but real-time transmission through TDRS to ground
10	Monitoring and checkout data received/processed/displayed	Ground Data Handling Center	Status, errors or equipment fault screening
11	Data compared to reference	Ground Data Handling Center	Determine existence, level and impacts of error/fault on mission performance
12	Report status to ground control	Ground Data Hdlg. Center	Assess data and impact
13	Transmit correction commands if required	TDRS and User Control	Correction by command if possible; sequence of C&C command operations followed

OPERATIONAL PROCEDURE NO. 13-3

Operation		Performed by:	Rationale
14	Correction commands received and implemented	TDRS and User	Commands cause equipment and operations changes
15	Report back to ground	TDRS and User	Report operating condition reestablished

Operation		Performed by:	Rationale
1-8	Same as for C&C	GS, TDRS and User	Preparation of all elements equipments and sensors for mission operations; commands activate equipment and operations; readiness reported
9	Command request for tracking initiated	User Control Center	To track user element and determine ephemerides
10	Transmit command request to TDRSNET Control Station	User Control Center	Transmitted by ground communications to TDRSNET for integration and coordination with ground stored user scheduling; priority and orbit data
11	Command data input transmitted for signal generation	TDRSNET	Data input is sent to ground station signal generating unit for coding and signal generation
12	Command signal transmitted to TDRS	TDRS Control and GS Signal Generating Unit	Transmission via Ku link to TDRS for TDRS antenna orientation
13	Command signal received, TDRS antenna oriented	TDRS	TDRS Ku antenna is oriented to ground predicted/computed user location; then continues on auto-track
14	Command frequency translated and transmitted to user	TDRS	Tracking command transmitted via VHF, S or Ku link to user element
15	Tracking command received processed, antenna oriented	User	Tracking command is processed by user element and tracking antenna oriented to TDRS then placed on auto-track
16	Tracking data transmitted to TDRS	User	Tracking data is returned by same path to TDRS verification of tracking commands and operations indicated by data transfer

OPERATIONAL PROCEDURE NO. 13-3

	Operation	Performed by:	Rationale
17	Tracking data transmitted to ground data handling center	TDRS	Transmission of tracking data via Ku link to ground for processing and determination of orbit and attitude of user element
18	Transmit PRN ranging code to TDRS	GS, TDRS, Control Center	Generated by Ground System User Signal generating unit, same sequence followed as with tracking link; initiates ranging operation
19	Ranging code signal received, translated and transmitted to user	TDRS	Repeated through TDRS and translated in frequency for transmission to user via VHF, S or Ku link depending on type of user
20	Ranging code signal received by user and routed to transponder transmitter	User	Provide signals for processing/ranging and turnaround ranging
21	Transmit turnaround ranging signal to TDRS	User	Verifies ranging operation and starts turnaround ranging
22	Receive turnaround ranging signal by TDRS translate frequency and transmit to ground data handling center on Ku link; also receive antenna angle data for transmission to ground	TDRS	TDRS as relay/repeater; turnaround ranging signal is converted to appropriate frequency for transmission to ground; actual antenna pointing angles are also needed for accurate tracking and ranging computation
23	Processing of signals and computation of range/range rate	Ground Data Handling Center	Precision range and doppler tracking of user is easily implemented. Doppler measurements are made by observing total doppler shift on an RF carrier (originated at GS and transmitted round trip through TDRS and User). Doppler could be extracted from a side tone modulation on the carrier and thus not require a

	Operation	Performed by:	Rationale
23	(continued)		coherent transponder on the user. This technique is not as accurate as carrier doppler tracking; since a coherent frequency source on-board the user will generally be desirable for data transmission, carrier tracking is an obvious choice. Precision ranging could be implemented either using the GRARR side-tone ranging, or a PN modulation system. Because of large signal powers and bandwidths available, either system could easily provide the required accuracy; however, if orbit determination is selected which required near simultaneous ranging on user through two TDRS satellites, an omnimode must be activated on the user. The omnimode user links will have approximately 20 db less performance then the directional systems; therefore, the selection must be based on factors such as compatibility with the orbit determination method selected, user spacecraft impact and ground-station design. Delay times in the TDRS and User during ranging and relative movement and time jitter produced by the elements must be accounted for by ground station prior calibrations.

OPERATIONAL PROCEDURE NO. 13-3

	Operation	Performed by:	Rationale
24	Repeat tracking and ranging measurements to desired accuracy	GS, TDRS and User	Orbit and ephemerides determination requires measurements to a desired accuracy. Much more accurate measurements and much faster covergence to the desired accuracy can be obtained by simultaneous tracking by two TDRS's.
25	Transmit processed and computed data to ground terminal users for utilization	Ground Data Handling Center	Tracking, orbit and ephemeride data is received by terminal users (User Control Center, TDRSNET) for utilization, scheduling, control and mission planning

Operation		Performed by:	Rationale
1-8	Same as for C&C	GS, TDRS and User	Preparation of all elements, equipments and sensors for mission operations; commands activate equipment and operations; readiness reported
9	TV inspection camera on user element No. 1 activated and operated	User No. 1 (under TDRS Control)	Inspection of User Element No. 2 (assumed in line of sight but under control of MSFN) by black and white television (utilizes approximately 2.9 MHz baseband analog signals); visual observation may also be possible in some cases
10	Monitor condition and operation	User No. 1	Status and condition are determined
11	Transmit TV information on status and condition to TDRS	User No. 1	TV information coverted to signal/data for transmission to TDRS via Ku link
12	Receive inspection data, process and transmit to ground	TDRS	Inspection data is repeated, translated, and transmitted via Ku link to ground
13	Receive inspection data for processing/computation and transmite to User Control Center (MSFN)	Ground Data Handling Center	Data is processed by ground computer and transmitted to User Control Center (MSFN coordinated) for utilization
14	Transmit correction commands based on inspection data to User No. 2	User Control Center, MSFN	Commands sent to User No. 2 via MSFN to correct fault indicated
15	Repeat/continue video observation as required	GS, MSFN, TDRS, Users	Monitor correction of faults and status of operations

OPERATIONAL PROCEDURE NO. 13-4

Detached Element Operations - Space Operations and Control - Manned Space (Controlling) Element/Unmanned Space (Controlled) Element

Assumptions

1. Operations and control are implemented by a direct communications link from the controlling space element to the detached (controlled) element.

2. All operations support is provided by the controlling element (e.g., MSS/RAM).

3. The controlling element is manned for full operational capability.

4. The detached element is always in line-of-sight contact with the controlling element.

5. On-board processing and display and compatible element-to-element computer capability are available.

Initial Conditions

1. The detached element is in line-of-sight view of the controlling element and is in interface relationship with it for subsequent operations.

2. Detached element receivers are on and able to receive commands from the controlling element.

Final Conditions

1. Mission experiments and/or operations may be discontinued by command from the controlling element.

Description

1. This procedure describes five operational sequences for those space element to element interfacing links which involve a direct communications link. These five operational sequences involve the same basic functions described in Operational Procedure No. 13-1, 13-2, and 13-3, namely command and control, data transfer, monitoring and checkout, tracking and ranging, and inspection, except that the space controlling element replaces the ground control. The sequences of operations are basically similar as well. Since they all have features which may occur simultaneously and/or sequentially they are all integral to one procedure.

2. Command and control operations commence with the commands to activate the equipments in both space elements, to verify and authorize command execution, to indicate readiness, to command and control or monitor operations, and finally to deactivate all powered equipment not required.

3. Data transfer operations follow initial commands for activation, verification and execution. Two modes of data transfer are possible during the period of interfacing activity. In one data is collected and stored for later dumping to the controlling element. In the second, data is transferred in real time. In either case the data is received, processed, and used or stored for later use, or sent to ground for utilization.

4. Monitoring and checkout operations commence as soon as equipments, sensors, and controls are activated and operations commanded. Data obtained will be transferred in the same manner as with data transfer, by dumping and/or real time transfer. The controlling element receives, processes, displays and utilizes such data or stores it for later use. A computer will compare such data to a reference and cause commands to be initiated for corrections of faults if required. These sequences may be repeated as often as required.

5. Navigation operations involving tracking and ranging commence as soon as equipments, including antennas, RF equipments, transponders and receivers/transmitters, are activated and operations commanded. Controlling element commands cause both elements to orient their antennas toward each other, based on computer-stored and predicted information. Then PRN ranging is carried out and range and range rate computations are performed. The controlling element antenna is switched to autotrack mode. The controlling element also measures its own position with horizon sensors and star tracking in order to track and determine accurately the position and range of the controlled element. Tracking measurements are continued as required and tracking errors and ephemerides computed.

6. Inspection operations commence with activation of equipments and operations, including activation of an element black and white TV camera for video inspection of element status and operation and correction by command as required. This sequence is repeated as required.

7. Operational Procedure No. 13-4 shows the detailed sequence of operations for all five operational functions, command and control, data transfer, monitoring and checkout, navigation tracking and ranging, and inspection. Also given are the rationale for each operation, the element performing the operation and the reference to the functional requirements supported. Figure 2.13-1 of Operational Procedure No. 13-1, which shows a block flow diagram of the operations performed for the case of direct element to ground interfaces, is applicable, as amended for Operational Procedure No. 13-2, for this Operational Procedure No. 13-4 if the controlling element is substituted for the ground and relay elements.

OPERATIONAL PROCEDURE NO. 13-4

TITLE: DETACHED ELEMENT OPERATIONS - SPACE OPERATIONS AND CONTROL A. COMMAND AND CONTROL OPERATIONS

ELEMENT INTERFACES: Manned Space Element/Unmanned Space Element (Controlling Element/Controlled Element)

	Operation	Performed by:	Rationale
1	Activate MSE transfer/receiver/ processing equipment	MSE	Prepare controlling element for detached element operation
2	Send command signal to activate USE transfer/receiver/processing/ sensor and other equipments	MSE	Prepare controlled element for command/ control and mission operations; receiver monitors controlling element command link frequency
3	Send readiness signal	USE	Controlled element systems ready
4	Send command	MSE	Transmission of commands begins - sequence followed for each command
5	Receive/process/store command	USE	Command is processed, decoded and stored pending verification and authorization
6	Send command verification signal	USE	Controlled element retransmits command signal for verification and authentication
7	Receive/process/authenticate command	MSE	Command is processed, compared with original
8	Send execute command (or correct command)	MSE	Provides authority to execute or correct command
9	Execute command	USE	
10	Monitor command operation	USE	
11	Send operation executed signal/ digitized data	MSE	Controlling element is informed of performance of command operation

OPERATIONAL PROCEDURE NO. 13-4

Operation		Performed by:	Rationale
12	Receive operation executed signal/data	MSE	
13	Send signal to deactivate command equipment (ex. rcr.) as required	MSE	During long intervals between commands, all powered equipment except receivers may be turned off to conserve power
14	Command equipment (ex. rcr.) deactivated	USE	

Operation		Performed by:	Rationale
1-3	Same as for Command and Control (C&C)	MSE/USE	Preparation of both elements for C&C and mission operations, commands to activate selected equipment for data collection and transfer (depend on type of activity and data transfer--digital/analog, low/high data rate, and BW, voice/TV, frequency, antennas, modulation modes, data store/dump or real-time transfer, etc.)
4-12	Same as for C&C; command to start data collection	MSE/USE	Data collection operating
13a	Store data (recorder)	USE	
14a	Send command to dump data	MSE	Same sequence 4-12; command to dump when appropriate to both elements
13b	Send command for start real-time data transfer	MSE	Same sequence 4-12; command for real-time transfer when both elements ready
14b	Transfers data	USE	
15a	Receive dumped data	MSE	High data rate (50 Mbps) and large quantities of data
15b	Receive real-time data	MSE	Type, rate vary, possibly >5 Mbps digital data
16a1	Dumped data processed/displayed/used	MSE	Data is utilized by controlling element and/or ground
16a2	Store dumped data for later processing/display/use	MSE	Non-time sensitive data accumulated for appropriate later utilization by MSE and/or ground
16a3	Dumped data processed/sent to ground for utilization	MSE	Data user may be at ground element

OPERATIONAL PROCEDURE NO. 13-4

	Operation	Performed by:	Rationale
16b1	Real-time data processed/displayed/used	MSE	Data utilized by MSE and/or ground
16b2	Real-time data stored for later processing/display/use	MSE	Real-time required for collection opportunity but use may be deferred by MSE and/or ground
16b3	Real-time data processed/sent to ground for utilization	MSE	Data user may be at ground element
17	Send command to deactivate data collection	MSE	During long intervals between data opportunities or requirement, power conserved by deactivation of equipment
18-19	Deactivation for standby	MSE/USE	As required, same as 13-14 sequence of C&C

OPERATIONAL PROCEDURE NO. 13-4 — C. MONITORING AND CHECKOUT OPERATION

Operation		Performed by:	Rationale
1-3	Same as for Command and Control (C&C)	MSE/USE	Preparation of both elements for C&C and mission operations; commands activate equipments, processing, sensing, etc., for mission operations, and monitoring/checkout operations; readiness indicated
4-12	Same as for C&C; commands to start scheduled continuous/periodic monitoring and checkout of controlled element equipments and operations	MSE/USE	Monitoring of element and experiment subsystem equipment and status on continuous or periodic basis; periodic checkout of subsystems condition/ isolate faults; requires medium rate (up to 50 Kbps) telemetry digital data, processing and display and on-board computer compatible to both elements
13	Transfers monitoring/checkout data	USE	Continuous and/or periodic probes but real-time transmission
14	Data received/processed/displayed	MSE	Status, errors or equipment fault screening
15	Computer comparison of performance data to reference data	MSE	Determine existence, level and impacts of error/fault on mission performance
16	Send command to correct error/ fault	MSE	Correct by command if possible
17-19	Repeat sequences 13-15	USE/MSE	Error/fault corrected, if not corrected determine mission loss and consequences
20	Report to ground control	MSE	Report of situation; continue mission at degraded level or need for replacement

OPERATIONAL PROCEDURE NO. 13-4 D. NAVIGATION OPS - TRACKING & RANGING

Operation		Performed by:	Rationale
1-3	Same as for Command and Control (C&C)	MSE/USE	Preparation of both elements for C&C and mission operations; commands activate equipments, processing, sensing, etc., for mission operations; readiness reported. USE receiver monitoring command link frequency
4-12	Same as for C&C; command to active USE	MSE/USE	Availability of ranging transponder and signal for tracking; capability to send certain types of data and simultaneously perform ranging turn-around function
13	Tracking antenna oriented toward USE	MSE	Tracking antenna must be oriented to predicted or known position of controlled element; tracking can be initiated by utilizing computer orbital parameters data to drive tracking antenna; ground tracking data on MSE and USE may also be utilized where necessary
14	Send PRN ranging code	MSE	To initiate ranging operation
15	Receive PRN ranging code and routes to transponder transmitter	USE	Provide signals for processing/ranging
16	Transponder transmitter returns PRN ranging code signal to MSE	USE	Verify ranging operation and start turn-around ranging
17	Receive turn-around PRN ranging code and routes to computer	MSE	For range and range rate measurement computation
18	Perform range and range rate computation	MSE	Determination of orbital parameters
19	Switch tracking antenna to auto-track mode	MSE	Initiated as soon as signal from USE is received, uses signal for auto-track operation and processing

OPERATIONAL PROCEDURE NO. 13-4

Operation		Performed by:	Rationale
20	Compute tracking data and errors from auto-track signals	MSE	Determine direction of controlled element relative to controlling element; digital encoders on antenna axes provide a dual antenna pointing information to tracking computer for tracking data
20a	Measure own position with horizon sensors and star tracking	MSE	Position of controlling element must be known accurately in order to track and determine accurately the position and range of the controlled element
21	Computes ephemerides of elements	MSE	Determination of orbital parameters and accurate ephemerides of elements; range, range rate and tracking data utilized; controlling element ephemerides are derived from stored data in on-board computer, data from ground operation, and input tracking and ranging data; in some cases extensive ground support can provide navigation data to MSE simultaneously with element to element tracking and ranging information. Utilize data for required mission operations.
22	Continue ranging and tracking	MSE/USE	As required to update ranging and tracking data; to have available timely and accurate orbital and ephemeride data for continued mission operations; range accuracy at $\leq$30 ft RMS and range rate measurement accuracy at $\leq$0.2 fps at 4000 nautical miles are representative accuracies for the space element to element operations.

Operation		Performed by:	Rationale
1-12	Same as for C&C; commands sent and received to activate equipments and operations	MSE/USE	Preparation of both elements for C&C and mission operations; commands activate equipments, processing, sensing, etc., for mission operations, readiness reported. USE receiver monitoring and link frequency; all operations, including tracking and ranging, are active
13	Activate TV inspection camera	MSE	Inspection of detached element by black and white television (utilizes approximately 2.9 MHz baseband analog signals); visual observation may also be possible in some cases
14	Monitors USE condition and operation	MSE	USE condition is determined; telemetry data from USE is also utilized for evaluation
15	Sends commands to correct/adjust USE condition/operation	MSE	As required; sequence 1-12 repeated

2.13.2 PROCEDURES APPLICABILITY

Figure 2.13-2 summarizes the essential procedural operations developed for the four alternate approaches for detached element operations in order to indicate procedural commonalities, similarities and/or differences for applicability to various interface element situations. The major difference between space and ground control procedures results from the necessity to maintain continuity of the tracking and communications link. Communications operations procedures show similar differences. During space control operation, it is assumed that the command element is in continuous line of sight, allowing a continuous (as necessary) operation between elements until mission completion. When ground control is the operational mode, continuity cannot be guaranteed. If the MSFN stations are being used, handover from one station to the next must be accomplished until the mission completion. This means predictions of ephemerides, acquisition, verification, and continued operation of the link at each succeeding station. A similar handover is necessary from one TDRS to the other. TDRS could be a nearly continuous operation, whereas gaps are likely with MSFN.

Figure 2.13-3 presents in matrix format the procedures applicable to the interfacing elements in the space vehicle inventory. Moving to the right in the upper half of the figure is the list of potential detached space elements controlled for operations by one of the controlling space elements in the vertical list. Moving downward in the bottom half of the figure is the list of potential detached space elements controlling the operations of one of the detached elements in the horizontal list. Of the 17 elements listed, at least 5 are potential controlling elements while some 15 can be controlled elements. Most of the interactions involve interfaces with the orbiter (15) and the space-based tug (11). Within each coordinate box in the matrix, an entry is shown, indicating the applicable detached element operations procedure for the pair of interfacing elements involved. The only procedure involving two directly interfacing and interacting space elements, one as controlling element and the other as controlled element, is Operational Procedure No. 13-4 for the approach category of space operations and control. Since the ground system is not considered an element, by definition, the three operational procedures involving ground operations and control are not shown as entries into the matrix. However, each active potential element pair which has a matrix entry for Operational Procedure Number 4 may likewise be supported by a ground system either directly, or through another space relay element, or through TDRS. Therefore, each of these cases may also have in each relevant matrix box the entries for applicable Operational Procedures Numbers 13-1, 13-2, and 13-3. Applicability is basic, differing essentially in degree of implementation and complexity and the necessity to maintain continuity of tracking and communications (Figure 2.13-2 and discussion in preceding paragraph).

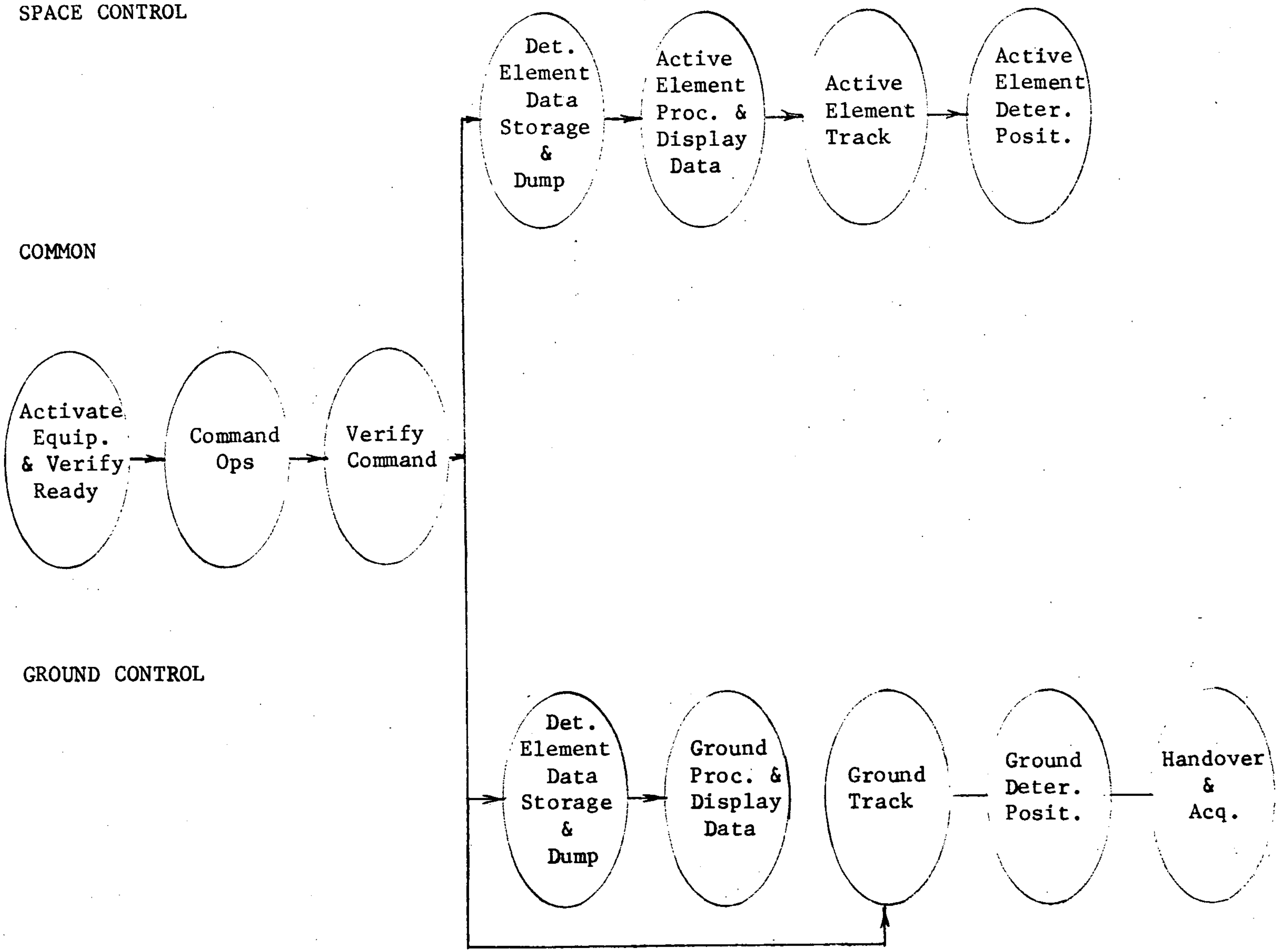

Figure 2.13-2. Detached Element Operations Procedural Comparison

CONTROLLING ELEMENT \ CONTROLLED ELEMENT		SPACE PROGRAM ELEMENTS																
		EOS	TUG		RAM				SATELLITE			EO RESUP. MODS	LOW EO MSS	CPS		RNS CLS	OLS	OPD
			RTN	SPACE BASED	ATT. EOS	DET. EOS	ATT. MSS	DET. MSS	EOS DELIV.	EOS + 3RD ST DELIV.	RETR, RESUP.			OIS	CLS			
	EOS	4	4	4	NA	4	NA	4	4	4	4	NA	4		4	4	4	4
TUG	RETURNABLE	NA								NA								
TUG	SPACE BASED	4		4			NA	4		NA	4	NA	4	4	4	4	4	4
RAM	ATT. EOS	NA																
RAM	DET. EOS	NA																
RAM	ATT. MSS	NA		NA									NA					
RAM	DET. MSS	NA		NA									NA					
SATEL	EOS DELIV.	NA																
SATEL	EOS + 3RD ST	NA	NA	NA														
SATEL	RETR, RESUP.	NA		NA														
	EO RESUP. MODS	NA		NA								NA	NA		NA	NA		NA
	LOW EO MSS	4		4			NA	4				NA	NA					
CPS	OIS			NA											NA	NA	NA	NA
CPS	CLS	NA		NA								NA		NA	4		NA	4
	RNS-CLS	NA		NA								NA		NA		NA	NA	4
	OLS	NA		NA										NA	NA	NA	NA	
	OPD	NA		NA								NA		NA	NA	NA		NA

NA - Not Applicable

Figure 2.13-3. Operational Procedures Applicability - Interface Activity: Detached Element Operations

2.14 ATTACHED ELEMENT TRANSPORT

This section presents the operational procedures for attached element transport, and includes one procedure for both alternate approaches identified in Volume II of this report. Also presented and discussed is the applicability of this procedure to each element pair included in the in-depth analysis portion of the Orbital Operations Study.

2.14.1 OPERATIONAL PROCEDURES

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

The procedure for attached element transport operations involving either internal attachment (e.g., orbiter) or external attachment (tug) with an attached RAM payload is described in the following Procedure No. 14-1. The operations are essentially identical for both internal and external attachment, and involve monitoring and checkout of the attached element, alignment of the thrust vector of the transporting element with the center of gravity of the combined elements, main engine thrusting, orbit verification and communications for command and data transfer. Mating of the elements is of course prerequisite to such operations.

Operational Procedure No. 14-1

Attached Element Transport - Internal or External Attachment with Local Control - Orbiter (Internal) or Tug (External) with RAM Payload

Assumptions

1. The element is secured internally in the EOS Orbiter cargo bay and externally on the Tug.

2. The transport activity will only be considered for inter-orbit transfer.

3. Manipulator or pivoting platform mechanism is available on the Orbiter and the attached element has compatible docking mechanisms at both ends.

4. The transporting element is the control center for transport operations and supplies the commands and navigation data for handover of the attached element.

5. Hardwire communications exist between the attached element and the transporting element.

Initial Conditions

1. The transporting vehicle is mated to the element to be transported. Mating may have occurred on the ground or in earth orbit.

Final Conditions

1. The thrusting maneuver has been completed and resultant orbital

Description

1. Figure 2.14-1 shows a block flow diagram of the operations involved. Essential operations during transport will include monitoring and checkout of the attached element, alignment of the thrust vector of the transporting element with the center of gravity of the combined elements, main engine thrusting, verification of the orbit, and communications for command and data transfer. These functions may be performed during all associated operations carried out while the elements are in orbital transport.

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

3. Operational Procedure 14-1 shows the detailed sequence of operations for attached element transport, including the element performing the operation, the rationale for the operation, and the reference to the functional requirements supported by this operation.

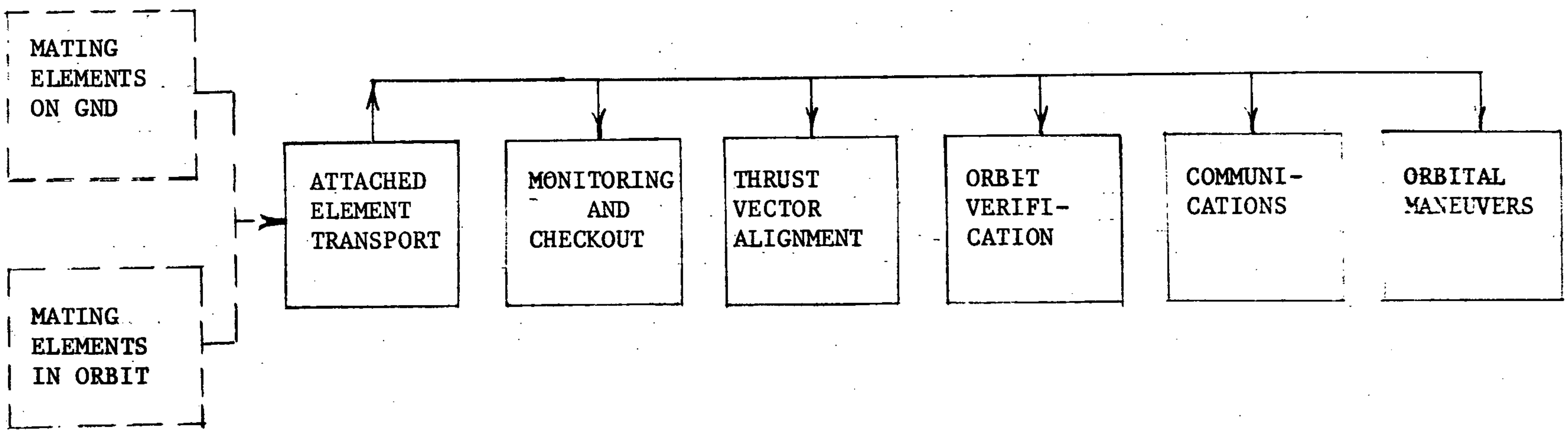

Figure 2.14-1. Block Diagram of Attached Element Transport Procedure Internal or External Attachment

OPERATIONAL PROCEDURE NO. 14-1

TITLE: ATTACHED ELEMENT TRANSPORT - INTERNAL OR EXTERNAL ATTACHMENT

ELEMENT INTERFACES: ORBITER (INTERNAL) OR TUG (EXTERNAL)/RAM
(TRANSPORTING ELEMENT)/(TRANSPORTED ELEMENT)

	Operation	Performed by:	Rationale
1	Mate transporting and transported element	Transport- ing Element	Except for those cases where the two elements are attached on the ground and brought up together to initial orbit, mating is a prerequisite to transport. For mating operations see Mating Procedure. Retrieval and logistics missions will also involve mating.
2	Monitor and checkout element status and condition	Transport- ing Element	Once deployed in initial orbit, before proceeding to the next phase of the mission, the attached element is monitored for security of attachment and checkout is performed on its conditions, the readiness of communications and controls, and the security from environmental factors and the operational readiness of all equipment.
3	Update state vector and compute burn parameters	Transport- ing Element	State vector of transporting element is updated preparatory to determing thrust vector needed for orbit maneuver or orbit transfer. Under automatic control the necessary sensing and computation is performed onboard. With local manned control, a ground station or other space element may support this. The onboard guidance computer determines magnitude and direction of the thrust vector needed to attain the next

OPERATIONAL PROCEDURE NO. 14-1

Operation		Performed by:	Rationale
			orbital phase, including amount of engine gimballing required and/or positioning of jets to get a thrust vector which passes through the center of gravity of the combined elements.
4	Maneuver to burn attitude and verify cg position and thrust vector alignment and readiness for thrusting	Transporting Element	Transporting element is maneuvered to the attitude required for thrusting. This maneuver is also used to verify the current position of the cg of the combined elements and to check the alignment of the thrust vector, and readiness of all equipments and controls for thrusting.
5	Report readiness to mission control	Transporting Element	Results of checks and tests and thrusting readiness may be telemetered to mission control
6	Perform burn maneuver to new orbital position	Transporting Element	Main engine and/or APS is fired for thrust to next orbital position.
7	Verify orbit attained	Transporting Element	State vector determined, errors assessed; if outside tolerance limits, corrections may be necessary; repeated maneuvers to achieve desired orbit may be necessary.
8	Repeat steps 2 through 7 above as required to continue toward rendezvous	Transporting Element	Transport operations are repeated as required for each change in the mission trajectory as the elements approach

OPERATIONAL PROCEDURE NO. 14-1

	Operation	Performed by:	Rationale
			rendezvous with another element or a point in space. Several orbit maneuvers or changes may be required to complete the mission.
9	Perform mission operations for payload experiment operations, mating, orbital assembly or separation as required.	Transporting Element	After rendezvous one of a number of missions may be carried out by the attached elements, while in transport, involving mating to another element or station, assembly to the station, or separation of the attached element.

2.14.2 PROCEDURES APPLICABILITY

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

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

Figure 2.14-2 presents in matrix format the procedures applicable to the interfacing elements in the space vehicle inventory. Moving to the right in the upper half of the figure is the list of potential elements that can be transported by one of the elements in the vertical list. Moving downward in the bottom half of the figure is the list of potential elements that can transport one of the elements in the horizontal list. Of the 17 elements listed, only four (EOS orbiter, RTN tug, space-based tug and OIS) are transporter vehicles of other elements; the CPS/CLS is considered only in a nonmodular mode, RNS and OLS in a modular mode, and OPD in either modular or nonmodular mode. Thus, EOS may transport 14 elements, RTN tug 1 element, space-based tug 12 elements, and OIS 2 elements.

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

TRANSPORTING ELEMENT \ TRANSPORTED ELEMENT		SPACE PROGRAM ELEMENTS: EOS	TUG		RAM				SATELLITE			EO RESUP. MODS	LOW EO MSS	CPS		RNS CLS	OLS	OPD
			RTN	SPACE BASED	ATT. EOS	DET. EOS	ATT. MSS	DET. MSS	EOS DELIV.	EOS + 3RD ST DELIV.	RETR, RESUP.			OIS	CLS			
	EOS	NA	1	1	1	1	1	1	1	1	1	1	1		NA	1	1	1
TUG	RETURNABLE	NA								1								
TUG	SPACE BASED	NA		1			1	1		1	1	1	1	1	1	1	1	1
RAM	ATT. EOS	NA																
RAM	DET. EOS	NA																
RAM	ATT. MSS	NA		NA									NA					
RAM	DET. MSS	NA		NA									NA					
SATEL	EOS DELIV.	NA																
SATEL	EOS + 3RD ST	NA	NA	NA														
SATEL	RETR, RESUP.	NA		NA														
	EO RESUP. MODS	NA		NA								NA	NA		NA	NA		NA
	LOW EO MSS	NA		NA			NA	NA				NA	NA					
CPS	OIS			NA											1	NA	NA	1
CPS	CLS	NA		NA								NA		NA	NA		1	NA
	RNS-CLS	NA		NA								NA		NA		NA	1	NA
	OLS	NA		NA										NA	NA	NA	NA	
	OPD	NA		NA								NA		NA	NA	NA		NA

NA - Not Applicable

Figure 2.14-2. Operational Procedures Applicability - Interface Activity: Attached Element Transport