AEROSPACE REPORT NO.
ATR-72(7316-01)-1, VOL. II-3

N73-11874

Advanced Missions Safety

Volume II: Technical Discussion

Part 3, Emergency Crew Transfer

Prepared by
SYSTEMS PLANNING DIVISION

15 October 1972

Prepared for
OFFICE OF MANNED SPACE FLIGHT
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C.

Contract No. NASw-2301

Systems Engineering Operations
THE AEROSPACE CORPORATION

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VOLUME II - TECHNICAL DISCUSSION

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PREFACE

The study on Advanced Missions Safety was performed as Task 2.6 of Contract NASw-2301 entitled, "Advanced Space Program Analysis and Planning." The task consisted of three subtasks:

Subtask 1 - Space Shuttle Rescue Capability (Vol. II-1 and Vol. III-1)
Subtask 2 - Experiment Safety (Vol. II-2 and Vol. III-2)
Subtask 3 - Emergency Crew Transfer (Vol. II-3)

Each subtask is an independent entity and is not related or dependent upon any activity under either of the other two subtasks.

The results of this study are presented in three volumes.

<u>Volume I:</u> <u>Executive Summary Report</u> presents a concise review of the results, conclusions, and recommendations for all three subtasks.

<u>Volume II:</u> <u>Technical Discussion</u> is in three parts, each presenting a comprehensive discussion of a single subtask.

<u>Volume III:</u> <u>Appendices</u> contains detailed supporting analysis for Subtasks 1 and 2 and is of interest primarily to the technical specialist.

This report, identified as Volume II, Part 3, contains the complete results on Subtask 3, Emergency Crew Transfer.

The Advanced Missions Safety Task was sponsored by NASA Headquarters and was managed by the Advanced Missions Office of the Office of Manned Space Flight. Mr. Herbert Schaefer, the study monitor, provided guidance and counsel that significantly aided the total effort. Mr. Charles W. Childs of the Safety Office, NASA Headquarters, provided valuable comments and suggestions on Subtask 3.

ACKNOWLEDGEMENT

The principal participants in Subtask 3 of the Advanced Missions Safety Task were:

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H. H. Yoshikawa	Transfer Systems

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1. INTRODUCTION

1.1 BACKGROUND

Since the initiation of manned space flight, many studies have been directed toward the problem of escape/rescue from a disabled spacecraft unable to provide for either sustaining its crew or returning them safely to earth. Many suggestions have been offered and numerous concepts proposed to deal with this problem. A review of the many possibilities examined is given in the survey made in 1967 by a committee of the U.S. House of Representatives (Ref. 1). Some ideas are presented merely as artist renditions, whereas other ideas have had extensive technical backup and analysis. The LMSC study, entitled "Emergency Earth Orbital Escape Device Study," falls into this latter category (Ref. 2).

Emphasis was initially placed on escape and reentry devices. Only recently has the interest been directed toward rescue by another vehicle and the space operations this involves. The paper presented by Wild and Schaefer at the 21st International Astronautical Congress (Ref. 3), and the recent study by The Aerospace Corporation on "Space Rescue Operations" (Ref. 4) are indicative of this redirected interest. But even with this reduction in scope, numerous alternatives are still available.

This study was undertaken to aid in clarifying the utility and application of the numerous means suggested for transferring personnel from a distressed vehicle and to relate the cost of each technique with its effectiveness.

1.2 STUDY OBJECTIVE

The objective of this study was to assess and compare the relative effectiveness of possible rescue configurations for emergency crew transfer from a distressed vehicle (DV) to a space rescue vehicle (SRV) while the two vehicles are not docked to each other. Factors such as unique capabilities, limitations, ease and speed of use, applicability, and development and procurement cost estimates were to be considered.

1.3 STUDY SCOPE

The evaluation of transfer means was limited to Space Station and Logistic Vehicle operations. Only in-space, on-orbit mission phases were treated. Accordingly, only emergencies which could occur during mission EVA, and Orbiter, Space Station, and RAM activities were considered.

While the objective of the study did not include emergency transfer between a distressed vehicle (DV) and a space rescue vehicle (SRV) in a docked mode, docking of a transfer device with the DV as well as with the SRV was considered.

Operating and design characteristics of the transfer means were based on information in the available literature. To expedite the analysis the individual devices were grouped into basic capability categories.

Where appropriate, the feasibility of foreign participation was considered.

The feedback effect of the transfer device on the design and cost of its parent spacecraft was beyond the scope of this study.

1.4 METHOD OF APPROACH

The first step in the procedure followed was to identify the emergency situations that could be faced during the following four manned mission categories:

a. EVA
b. Space Shuttle Orbiter
c. Space Station
d. Research Applications Module (RAM)

The emergency situations which could lead to the need for crew transfer were taken from a previous study (Ref. 4).

The second step was to characterize the many diverse concepts proposed for transferring a crew from a distressed vehicle to a rescue vehicle. Then, in order to reduce the total number of devices to be assessed, those having similar operational characteristics were grouped into general categories. A total of five different transfer concept categories resulted.

The third step was to undertake an operational assessment of these five transfer categories. This involved identifying operational evaluation criteria and subjectively scoring each general category on the basis of its operational effectiveness.

The fourth step was to identify a cost range for the devices in each general category. Both development and unit costs are provided.

Finally, the costs were combined with the operational effectiveness assessment, thus providing an overall comparative assessment of the five transfer categories.

It should be noted that the procedure is necessarily subjective and involved a scoring method devised for this purpose.

2. EMERGENCY SITUATIONS

Previous studies have treated hazards that can exist during manned space missions and the resulting emergency situations. Such analyses do not necessarily identify the specific spacecraft involved or their detailed design specifications. General conceptual characteristics are usually sufficient.

A useful summary of emergency situations which could occur and which might lead to a need for crew transfer from a distressed vehicle (DV) was identified in Ref. 4. A tabular summary of these situations and their applicability to the activities considered in this study are given in Figure 1. In rating the transfer concepts considered in this study, they were ranked on their ability to deal with the emergency situations on this list.

Emergency Situation	Mission EVA	Space Shuttle Orbiter	Space Station	RAM
Ill/Injured Crew	X		X	X (EVA only)
Metabolic Deprivation	X	X	X	X
Stranded/Entrapped Crew	X			X
*Inability to Communicate				
**Out of Control S/C		X	X	
Debris in Vicinity			X	
Radiation in Vicinity			X	
Non-habitable S/C Environment		X	X	X
Abandoned S/C (crew bailed out)		X	X	
Inability to Reenter and Land		X		

*Presents no requirement for DV crew transfer.

**S/C assumed to be stabilized prior to initiating crew transfer.

Figure 1. Potential Operational Emergencies

No single mission is likely to encounter all possible emergency situations. Generally, as the complexity of the activity and of the equipment involved increases, the greater the number of different emergency situations that may be encountered.

A detailed discussion of likely emergency situations for each of the four mission activities considered in this study is given in Appendix A.

3. TRANSFER CONCEPTS

3.1 GENERAL

Numerous proposals exist in the technical literature on methods for moving personnel away from a distressed vehicle (DV) and to a safe haven. Some suggestions involve systems for actually returning the crew to earth, whereas others involve a space rescue vehicle (SRV) which effects a rendezvous with the DV. Many of these ideas are only conceptual suggestions. A few are based on engineering designs, and some have even involved a limited hardware effort.

This study concerns itself with the transfer of personnel through space to a rescuing spacecraft which is not docked to the distressed vehicle. This includes direct transfer from either a DV or from a Bailout and Wait device in which the crew has found temporary shelter. A schematic diagram of the region of interest is illustrated in Figure 2. The distressed vehicle (or temporary crew shelter) may be separated from the rescuing vehicle by a distance of a few meters up to possibly 2 km.

Figure 2. Schematic Diagram of Region of Study Interest

This section describes various concepts with which such crew transfer might be accomplished. Some are proposed specifically for emergency use only, whereas others involve the use of hardware planned for other needs, such as EVA missions and operational crew or cargo transfer. Also, storage of the transfer device within either the DV or the SRV has been considered.

3.2 DISTRESSED CREW TRANSFER PATH

After the rendezvous of an SRV with a DV, an external survey is made by the SRV crew and communication established (if not yet initiated) between the SRV and the DV. Next, in order to avoid interference with transfer of the DV crew to the SRV, unwanted DV motion is either reduced or eliminated. The transfer of the DV crew is then initiated.

There are two possibilities for transferring the crew from a DV to an SRV while the two vehicles are not docked to each other. They are:

a. self-help transfer of the DV crew across the standoff distance

b. aided transfer of the DV crew across the standoff distance by the SRV crew who have approached and possibly even entered the DV

In the latter case the SRV crew transfers across the standoff distance to the DV and assists the DV crew back to the SRV. The mode for transferring the SRV crew may be either EVA or with a transfer device in which the SRV crew is housed. Whichever mode is involved, entry by the SRV crew into the DV to assist the DV crew may be required. For unassisted transfer of the DV crew, the possibilities include EVA and a transfer device routinely carried aboard the DV.

It should be noted that if provisions exist for the DV crew to use a bailout device as a temporary haven to await the arrival of the SRV, then, from a crew transfer operations viewpoint, this bailout device can be treated as a DV.

3.3 TRANSFER CONCEPT CATEGORIES

The most meaningful grouping in discussing individual techniques and aids for DV crew transfer is in terms of operational applicability. On this basis the transfer concepts considered in this study were divided into the following five categories:

a. Unassisted EVA

An individual crewman wearing a pressure suit and moving under self power.

b. Augmented Unassisted EVA

An individual crewman wearing a pressure suit and moving by means of a separate impulse source under his control.

c. Assisted EVA

A suited DV crewman aided in traversing the standoff distance by externally provided means not under his control.

d. Pressurized Transfer Vehicle

Devices which shuttle between the DV and the SRV and carry an operating crew plus passengers.

e. Special Purpose Devices

Devices which can be used for emergency transfer of personnel from the DV to the SRV.

A detailed discussion of the individual transfer devices under each of these five general categories is given in Appendix B.

It is worth noting that the Docking Module (DM) for the Apollo-Soyuz Test Project falls into category "e" and appears to offer interesting crew-transfer possibilities.

3.4 SUMMARY OF TRANSFER CONCEPTS

3.4.1 Design Characteristics

A summary of the design characteristics of typical devices which have been considered for use in transferring a crew from a DV to an SRV is given in Figure 3.

Configuration	Where Based	Stored Unit Weight		Stored Unit Volume		Capability		Operating Duration hr	Atmosphere			Remarks	Ref.
									Composition	Pressure			
		lb	(kg)	ft^3	(m^3)	Passenger	Crew			psia	(ata)		
Unassisted EVA													
IVA Suite	DV	15	7	1	0.03	1	-	1 - 4	100% O_2	8	0.6		MSC
EVA Suit	DV	65	30	4.5	0.13	1	-	4 - 8	100% O_2	8	0.6		MSC
Augmented Unassisted EVA													
AMU	DV	150	70	4	0.11	1	-	4 - 8	100% O_2	8	0.6	Installed $\Delta V \approx 100$ ft/s(30 m/s)	4, 5
Work Platform	DV	500	230	30	0.85	1 - 2	-	4 - 8	100% O_2	8	0.6		4
Assisted EVA													
Buddy (with AMU	SRV	65+150	30+70	4.5+4	0.13+0.11	1+	1	4	100% O_2	8	0.6		4
RMU (unmanned)	SRV	150	70	4	0.11	1	-	>4	-	-	-		1, 4, 5
Space Flyer	SRV	865	390	85	2.4	1 - 2	1	4 - 8	100% O_2	8	0.6		1, 5
Maintenance Capsule	SRV	2,000	910	70	2	1	1	24 - 48	SL	14.7	1		4
Pressurized Transfer Vehicle													
Bailout and Wait	DV	6,700	3,000	NA	NA	15	-	48	SL	14.7	1		4
Bailout and Transfer	DV	18,000	8,400	NA	NA	15	-	120	SL	14.7	1	Installed $\Delta V \approx 4$ kft/s(1.2 km/s)	4
Manned Tug	SRV	72,000	33,000	7,500	210	12	3	48	SL	14.7	1	Installed $\Delta V \approx 22$ kft/s(6.7 km/s)	4
Crew/Cargo Modules (with propulsion)	SRV	21,000	9,600	2,000	57	12	3	48	SL	14.7	1	Installed $\Delta V \approx 1$ kft/s(0.3 km/s)	4
Maintenance Capsule	DV	2,000	910	70	2	2	-	24 - 48	SL	14.7	1		4
Special Purpose Devices													
Expandable Transfer Capsule	SRV	500	230	50	1.4	2	-	8	SL	14.7	1	Mobility provided by external means	4
Portable Airlock	SRV	1,600	730	380	11	2	-	24	*	*	*	Mobility provided by external means	4
Apollo Soyuz Docking Module	SRV	3,360	1,524	200	5.7	2	-	~24	Variable				NASA, 10

*Operated from SL to 100% O_2 @ 8 psia (0.6 ata)

Figure 3. Transfer Device Design Characteristics Summary (See Appendix B for detailed descriptions.)

In general, as the utility of a category improves, the devices within that category become more complex and their weight and storage volumes increase. However, even within a given category, Assisted EVA or Pressurized Transfer Vehicle for example, there is a wide range of vehicle characteristics.

In many cases there are numerous designs for a given device (Bailout and Wait, for example). For such cases the selection for inclusion in Figure 3 was made on the basis of applicability to EVA, Orbiter, Space Station, and RAM missions as well as the potential for multipurpose utility. If desired, the ΔV capability of those designs with propulsion could be increased to greater values than indicated, but at the expense of stored weight and volume.

3.4.2 Operational Features

A summary of the operational features of the five general transfer concept categories is given in Figure 4. All factors considered, the Pressurized Transfer Vehicle is the most widely applicable and the most operationally favored category.

Characteristic	Transfer Categories				
	Unassisted EVA	Augmented Unassisted EVA	Assisted EVA	Pressurized Transfer Vehicle	Special Purpose Devices
Capacity	1	1	1-2	12-15	2
Storage site	DV	DV	SRV	SRV	SRV
Operated by	DV crew	DV crew	SRV crew	SRV crew	DV and SRV crews
Personnel in EVA	DV crew	DV crew	DV and SRV crews	None	SRV crew
DV crew dependence	Self-dependent	Self-dependent	Assisted	Assisted	Assisted
Added DV crew stress	Very great	Great	Moderate	None	Moderate
Mobility	Self-power	Auxiliary impulse source	Externally provided and controlled	Self-contained	Externally provided and controlled
Standoff distance	Negligible	to 2 - 4 km	to ~ 2 km	> 2 km	< 2 km
Operating duration	4 - 8 hours	4 - 8 hours	4 + hours	48 hours	8 - 24 hours
Environment	Pressure suit	Pressure suit	Pressure suit	Shirtsleeve	Shirtsleeve
Atmosphere	8 psia (0.6 ata) 100% O_2	8 psia (0.6 ata) 100% O_2	8 psia (0.6 ata) 100% O_2	Sea level	Sea level
Source of life support	Backpack or umbilical	Backpack	Backpack or portable ECLS	Self-contained ECLS	Self-contained ECLS
Injury accommodation	None	Slight	Moderate	Major	Major
Use with foreign spacecraft	Yes	Yes	Yes	Limited	Limited
Added skills/training	Minimal	Yes (DV crew)	Yes (SRV crew)	Yes (SRV crew)	Yes (DV and SRV crews)
SRV requirement	Receive EVA personnel	Receive EVA personnel	Discharge and Receive EVA personnel	Docking Fixture	Docking Fixture and Discharge and Receive EVA personnel

Figure 4. Transfer Category Operational Characteristics Summary

4. TRANSFER DEVICE OPERATIONAL EVALUATION

4.1 GENERAL

Some of the transfer devices listed in Figure 3 have unique capabilities and special-purpose applications, and others have similar or overlapping uses. In order to assess and rank the utility of these devices and establish criteria for an acquisition preference, an evaluation procedure had to be devised. The procedure employed was necessarily subjective.

The approach used offers a means of reaching an operational effectiveness comparison, which, when combined with cost, provides an overall comparison between transfer categories. Both the methodology and the conclusions reached are discussed in this section.

4.2 METHODOLOGY

Instead of separately assessing each individual transfer concept listed in Figure 3, the assessment was made of the general transfer categories.

Based on the information from the summary of transfer device design characteristics (Figure 3), a description was prepared for a typical device under each general transfer category. This design description plus the operational characteristics (see Figure 4) for each general category were the basis for all subsequent steps in the operational effectiveness ranking process.

A series of effectiveness criteria were then established and each category individually ranked on a scale of 10. After applying selected weighting factors to each criterion, the results were normalized and a total effectiveness value determined for each transfer category.

4.3 TRANSFER CATEGORY CHARACTERISTICS

To improve the visibility of this analysis, a further condensation of the available crew transfer possibilities was desirable. Consequently, a single typical design was identified for each transfer category, thus reducing the initial total of 16 devices to only the six shown in Figure 5.

Only devices based aboard a distressed vehicle (DV) are considered under the Augmented Unassisted EVA category. If such a device is based aboard a space rescue vehicle (SRV), it would probably be delivered by SRV crewmen who are then available to provide assistance to the DV crew.

The weights and volumes listed for both Augmented Unassisted EVA and Assisted EVA are the combined values for an AMU and an EVA suit. In the former instance, the suit is worn by a DV crewman, whereas in the latter case the suit is worn by the SRV crewman who delivers the AMU to the DV.

Two cases are listed under Pressurized Transfer Vehicle, since basing at either the DV or the SRV is feasible. The characteristics listed for DV basing apply to a Bailout and Wait device. The characteristics listed for SRV basing apply to a Crew-Cargo Module with a small amount of installed propulsion. In both cases, at least a 12-man transfer capacity is provided. The capacity of the other four general categories is significantly lower (one to two men only).

It is assumed that in the time frame of interest, the advanced EVA and IVA pressure suits available will operate at 8 psia (0.6 ata), 100% Oxygen. With such a pressure suit atmosphere, the change to or from a sea-level atmosphere (assumed standard for the Space Shuttle Orbiter and the Space Station) requires no adjustment period.

Unassisted EVA can accommodate only a small standoff distance, perhaps not more than 30 ft (10m). A tether from the DV would probably be used to avoid drifting into space should the crewman miss reaching the SRV through his own self-generated force.

Characteristic	Unassisted EVA	Augmented Unassisted EVA	Assisted EVA	Pressurized Transfer Vehicle		Special Purpose Devices
Base	DV	DV	SRV	DV	SRV	SRV
Stored Unit Weight, lb	65	* 215	* 215	6700	21,000	~ 1100
(kg)	30	100	100	3000	9600	~ 500
Stored Unit Volume, ft^3	4.5	* 8.5	* 8.5	NA	2000	~ 200
(m^3)	0.13	0.24	0.24	NA	57	~ 5.7
Crew Capacity, DV	1	1	1+	15	12	2
SRV	-	-	1	-	3	-
Operating Duration, hr	4-8	4-8	4+	48	48	8-24
Atmosphere, Composition	O_2	O_2	O_2	S.L.	S.L.	S.L.
Pressure, psia	8	8	8	14.7	14.7	14.7
(ata)	0.6	0.6	0.6	1.0	1.0	1.0
Available ΔV, ft/s	-	~100	50 - 100	-	1000	-
(m/s)	-	~30	15 - 30	-	305	-

* Includes EVA suit

Figure 5. Typical Transfer Category Design Characteristics Summary

The Special Purpose Devices (SPD) do not have maneuvering capability. Therefore, they require that the SRV crewmen with AMUs move them to a position from which they can be attached to the DV.

For crew transfer categories which have a ΔV capability, a nominal standoff distance of 450 ft (150 m) was assumed.

4.4 OPERATIONAL EFFECTIVENESS

4.4.1 Applicability to Emergencies

One major consideration in arriving at a comparative ranking of transfer categories is the degree of applicability to an emergency situation. For the situations requiring crew transfer, the only ones of interest here, the probability of occurrence was assumed equal. A weighting factor was introduced, however, to account for the number of mission categories to which each emergency situation applies. A situation which applied to all four mission categories was assigned a weighting factor of 1.0. For example, "Stranded/Entrapped Crew", which applies to two of the four mission categories (see Figure 1), was therefore weighted at 0.50.

4.4.1.1 Ranking Procedure

Although specific factors can be identified as influencing the applicability of a transfer category to an individual emergency situation, quantifying these factors is difficult. Thus, the ranking process becomes largely subjective and is based on an estimate of how effectively the transfer category being considered can deal with each emergency situation.

A tabulated ranking of each transfer category as a function of emergency situation is given in Figure 6, which also lists the weighting factors used to account for mission applicability of each situation. A separate rating is provided for each emergency. The most effective transfer category is given a rating of 10; the least effective a rating of 2. A completely ineffective category is rated 0. It should be noted that a rating of 10 does not necessarily imply a perfect, ideal solution to the DV crew transfer problem.

Missions Weighting Factor	Emergency Situation	Unassisted EVA	Augmented Unassisted EVA	Assisted EVA	Pressurized Transfer Vehicle		Special Purpose Device
					At DV	At SRV	
0.63	Ill/Injured Crew	2	3	5	10	10	8
1.00	Metabolic Deprivation	2	4	6	10	10	8
0.50	Stranded/Entrapped Crew	0	2	8	4	10	7
* -	Inability to Communicate	-	-	-	-	-	-
** -	Out of Control Spacecraft	-	-	-	-	-	-
0.25	Debris in Vicinity	2	8	6	10	4	3
0.25	Radiation in Vicinity	2	8	3	10	6	4
0.75	Non-habitable S/C Environment	6	8	4	10	5	2
0.50	Abandoned S/C	4	9	8	10	5	2
0.25	Inability to Reenter	2	8	6	10	9	4

* Presents no requirement for crew transfer.

** Spacecraft assumed to be stable prior to initiating crew transfer.

Figure 6. Score Tabulation for Effectiveness in Dealing with Emergencies

The factors considered in assigning a rating for operational effectiveness regarding applicability to emergencies include:

a. where the transfer device is based
b. the anticipated reaction time for transfer
c. the degree of DV crew self-dependence
d. whether group or individual action is involved

4.4.1.2 Emergency Applicability Ranking

In ranking the individual transfer categories, it became obvious that for some emergencies a different score should be given a Pressurized Transfer Vehicle based at the DV than for one based at the SRV. Each case is therefore listed separately under the PTV category.

After applying the mission weighting factor to the individual scores and adding up the columns, a total rating factor was established for each transfer category. This total was normalized for analytic convenience to a value of 10 as the maximum rating value. The resulting ranking of transfer categories and the normalized total scores are given in Figure 7.

A Pressurized Transfer Vehicle is clearly the most effective crew transfer mode. Some advantage occurs if the PTV is based at the DV. The PTV provides a shirtsleeve environment, accommodates severe DV crew incapacitation,

Rank	Transfer Category	Normalized Score
1	Pressurized Transfer Vehicle Based at DV	10.0
2	Pressurized Transfer Vehicle Based at SRV	8.3
3	Assisted EVA	6.3
4	Augmented Unassisted EVA	6.1
5	Special Purpose Device	5.7
6	Unassisted EVA	2.9

Figure 7. Rank Based on Emergency Effectiveness Only

carries the entire DV crew, reduces the stress imposed on the DV crew, and has broad application over the entire emergency situation spectrum.

EVA, with some form of assistance, is moderately effective, whereas Unassisted EVA, as might be expected, received the lowest score. The EVA categories are generally characterized by poor medical accommodation, involve individual crewmen, impose a greater crew stress due to the self-dependence requirement, and have only limited emergency situation applicability.

Since Special Purpose Devices generally involve an EVA phase (SRV crew, DV crew, or both), they score in the same range as Augmented or Assisted EVA.

4.4.2 Additional Criteria

Although the ability of a transfer device to deal with all anticipated emergency situations is of primary interest, there are additional criteria against which transfer device capability should also be measured. For example, certain design and operational differences between transfer categories may not affect their applicability to emergency situations but can markedly influence the effectivity with which the device can be used. These additional criteria include:

a. Operational Characteristics

   Involves device characteristics such as available ΔV, movement control, operating life, atmosphere composition and pressure, complexity due to EVA requirement, and other factors which influence the likelihood of a successful DV crew transfer.

b. Capacity

   Considers capability for delivery of rescue equipment to the DV and the number of DV crew transferred to the SRV per trip. Directly influences the duration of the crew transfer process.

c. Availability When Emergency Occurs

   Covers those features which can influence the time to rendezvous between the DV and the SRV, whether the device is stored aboard the DV, shelf life, and the need, if any, for verifying its operational readiness.

d. Exposure to Danger - DV Crew

Considers whether DV crew must go into EVA or is in shirt-sleeves, the actual transfer duration, and the ability to avoid radiation and debris.

e. Exposure to Danger - SRV Crew

Treats features such as SRV standoff distance, whether the SRV crew participates actively in the transfer, whether the SRV crew must go into EVA or is in a shirtsleeve environment, the time to reach the DV across the standoff distance, and the ability of the SRV crew to avoid radiation and debris generated by the DV.

f. Use Skills Index

Covers the need for special training of either the DV or SRV crew as well as the need, if any, of a specially provided rescue crew.

g. Multiple Usage

Considers device operational flexibility, its non-emergency applications, and its capability to carry and deliver equipment.

h. Foreign Spacecraft Accommodation

Considers utility of transfer device with disabled foreign spacecraft.

4.4.2.1 Ranking Procedure

The considerations in ranking the applicability of transfer devices to emergency situations (section 4.4.1.1) also apply to other criteria. Although such criteria can be identified (section 4.4.2), scoring their influence in a quantitative fashion is also largely subjective.

The influencing criteria from which the operational effectiveness of the transfer categories was established are tabulated in Figure 8, which also gives the criteria weighting factors used for establishing an overall ranking. On the right side of the figure are listed the scores for each category by individual criterion.

The score for "Emergency Effectiveness" was taken directly from Figure 7. The scores for the other criteria were again established as for the emergency

Weighting Factor	Criteria	Unassisted EVA	Augmented Unassisted EVA	Assisted EVA	Pressurized Transfer Vehicle		Special Purpose Device
					At DV	At SRV	
0.30	Emergency Effectiveness	2.9	6.1	6.3	10	8.3	5.7
0.15	Operational Characteristics	2	6	4	10	10	5
0.10	Capacity	2	4	5	10	10	6
0.10	Availability When Emergency Occurs	10	9	6	8	5	2
	Exposure to Danger						
0.05	- DV Crew	2	3	4	9	10	7
0.10	- SRV Crew	10	10	3	10	7	2
0.05	Use Skills Index	10	9	7	3	2	5
0.05	Multiple Usage	4	10	2	8	8	6
0.10	Foreign Spacecraft Accommodation	10	10	8	7	2	6
1.00							

Figure 8. Score Tabulation for Operational Effectiveness

situations. The most effective category, although not necessarily an ideal solution, was rated 10; the least effective rated 2. (A completely ineffective situation would be scored 0.) All other categories are scored between these values according to their estimated effectiveness.

A weighting factor was introduced for the various criteria so that the relative importance of an individual criterion could be given appropriate emphasis in influencing scoring. "Emergency Effectiveness" was considered to be the most important scoring criterion and was given a weighting factor of 30%. "Capacity," "Availability When Emergency Occurs," "Exposure of SRV Crew to Danger," and "Foreign Spacecraft Accommodation" were all weighted equally at 10%. Considered of lesser significance were the added "Exposure of the DV Crew to Danger," "Use Skills Index," and "Multiple Usage." These latter considerations were all weighted equally at 5%.

It should be noted that as the DV crew is already in danger, the criterion of "Exposure of the DV Crew to Danger" considers only the added impact of the transfer category. "Multiple Usage" will provide a large influence when costs are introduced (see Section 5) and is not considered a major "Operational Effectiveness" criterion. It was assumed that necessary "Use Skills" will be acquired and that this criterion does not represent a serious consideration. These three criteria were therfore assigned the lowest weighting factor.

4.4.2.2 Individual Criteria Ranking

The assessment of the six transfer categories on the basis of individual evaluation criteria is given on the right side of Figure 8. Again, the Pressurized Transfer Vehicle based at the DV and the PTV based at the SRV were entered as separate subcategories. In either case the PTV has the most desirable operational characteristics of all categories.

On the basis of availability when an emergency occurs, unassisted EVA is scored highest. Other DV-based categories receive a lower score due to more extensive preparation and use-verification requirements.

The PTV based at the SRV introduces the least additional exposure danger for the DV crew. Devices based at the DV introduce the least additional exposure to danger for the SRV crew since it may not be necessary for them to leave the SRV.

Unassisted EVA introduces the lowest requirement for additional crew skills.

Augmented Unassisted EVA was considered to have the greatest potential for both multiple usage and foreign spacecraft accommodation.

4.4.3 Weighted Effectiveness Summary

By applying the assigned weighting factor for each criterion to the individual category score, a total rating for each transfer category was established. The transfer categories are ranked in Figure 9 according to this total weighted score, normalized to a maximum value of 10.

Rank	Transfer Category	Normalized Score
1	Pressurized Transfer Vehicle Based at DV	10.0
2	Pressurized Transfer Vehicle Based at SRV	8.2
3	Augmented Unassisted EVA	7.9
4	Assisted EVA	5.9
5	Unassisted EVA	5.8
6	Special Purpose Device	5.5

Figure 9. Rank Based on Operational Effectiveness

The Pressurized Transfer Vehicle based on the DV is the most operationally effective crew transfer mode. Basing the PTV at the SRV causes a sizeable reduction in operational effectivity. Augmented Unassisted EVA scored nearly as high as the PTV at the SRV.

Assisted EVA scored just slightly better than Unassisted EVA.

As expected, the limited scope of Special Purpose Devices causes them to rank lowest on the basis of operational effectiveness. If they are already available to meet other requirements, however, their relative ranking will improve due to economic considerations.

5. COST ESTIMATES

5.1 GENERAL

As assessment of crew transfer devices involves not merely the operational effectiveness of the device but its cost as well. Both development and unit procurement costs are of interest. These cost values can be combined with the operational effectiveness score to reach an overall assessment of preferred transfer techniques as a function of acceptable cost expenditure. Separate assessments can be made of entirely new devices as well as devices already developed to meet other needs. Thus, the relative rank of a complex device already available and for which no further development is needed could improve significantly, considering both effectiveness and cost.

The cost estimates which were reported in Ref. 4 for many diverse transfer concepts are still generally valid and, therefore, have been utilized in this study. The RDT&E cost for the Apollo-Soyuz Docking Module is based on a rough NASA estimate.

Both RDT&E and First Unit Manufacturing Cost (given in 1970 dollars) are treated in this section. Initially, estimates are presented for the representative individual transfer devices. Next, a cost range was established for each transfer category. By comparing the costs for each category with the operational effectiveness of each category, cost effectiveness plateaus were established for both available devices and new devices requiring development.

5.2 INDIVIDUAL DEVICE COSTS

A listing of both RDT&E and First Unit Manufacturing Cost for individual transfer devices is given in Figure 10. Except for the Space Flyer and the Apollo-Soyuz Docking Module, all the cost estimates were obtained from Ref. 4. In most cases, the hardware definition is conceptual and the cost estimates are correspondingly approximate.

Transfer Device	Cost (million 1970 dollars)		Ref.
	RDT&E	First Unit Mfg.	
Unassisted EVA			
IVA Suit	40	1	4
EVA Suit	50	2	4
Augmented Unassisted EVA			
AMU - 1 man	25	1	4
Work Platform	50	2	4
Assisted EVA			
Buddy (with AMU)	75	3	4
RMU (unmanned)	120	6	4
Space Flyer	51	4	1
Maintenance Capsule	175	9	4
Pressurized Transfer Vehicle			
Bailout and Wait	164	8.7	4
Bailout and Transfer	330	17.4	4
Manned Tug - Tug	590	13	4
- Crew Module	457	24.5	4
Crew/Cargo Module (with propulsion)	439	20.2	4
Maintenance Capsule	175	9	4
Special Purpose Devices			
Expandable Transfer Capsule	5 (+24)*	0.25 (+1.3)*	4
Portable Airlock	13 (+24)*	0.65 (+1.3)*	4
Apollo - Soyuz Docking Module***	44	1.9**	NASA

*Cost of portable ECLS
**Aerospace Corporation estimate
***1972 dollars

Figure 10. Estimated Costs of Individual Devices

The costs given in Figure 10 are for self-contained transfer systems. Thus, the costs for the Portable Airlock and the Expandable Transfer Capsule also include the expense of a portable ECLS system.

The rough NASA estimate for the RDT&E cost of the Apollo-Soyuz Test Project Docking Module is $44 million. The First Unit Manufacturing Cost of $1.9 million was estimated by The Aerospace Corporation based on a DM weight of 3360 lb (1524 kg).

5.3 TRANSFER CATEGORY COSTS

The individual costs listed in Figure 10 can be combined into a representative cost range for each transfer category and are summarized in Figure 11. These cost ranges overlap only slightly between categories and are, therefore, characteristically representative of each transfer category. Both the RDT&E cost and the First Unit Manufacturing Cost have this characteristic.

The First Unit Manufacturing Costs for Unassisted, Augmented Unassisted, and Assisted EVA are given on a per man basis. The corresponding cost for an entire crew of a distressed vehicle (DV) is approximately this unit cost times the number of crewmen involved. The First Unit Manufacturing Cost for the Pressurized Transfer Vehicle category is on a per vehicle basis. These are 12- to 15-passenger devices, and a single PTV can accommodate an entire DV crew.

Because of a significant design and cost difference between a PTV based at a DV and one based at an SRV, the costs for each subcategory are separately identified.

Transfer Category	Cost (million 1970 dollars)	
	RDT&E	First Unit Mfg.
Unassisted EVA (per man)	40 - 50	1 - 2
*Augmented Unassisted EVA (per man)	25 - 50	1 - 2
Assisted EVA (per man)	*51 - 175	3 - 9
Pressurized Transfer Vehicle		
- based at DV (per crew)	164 - 330	9 - 18
- based at SRV (per crew)	439 - 1050	20 - 38
*Special Purpose Devices (2 - man)	29 - 44	1.6 - 2

*Does not include suit cost

Figure 11. Estimated Cost Range of Transfer Categories

6. OVERALL EFFECTIVENESS

6.1 GENERAL

Ranking the operational effectiveness of transfer devices is essentially subjective. Furthermore, corresponding cost estimates are based primarily on conceptual designs. In spite of these limitations, meaningful assessments can be obtained and an overview provided on the preference of transfer device categories as a function of cost.

Toward this end, cost data from Figure 11 were combined with the weighted operational effectiveness ranking from Figure 9 into two separate overall effectiveness evaluations. The first, discussed in section 6.2, treats the case of an entirely new hardware development. The second, discussed in section 6.3, treats the case involving the use of an already developed device or one being developed to meet another, non-rescue requirement.

6.2 NEW HARDWARE DEVELOPMENT

Transfer devices requiring a new hardware development were economically assessed on the basis of their RDT&E costs only. The contribution made by the unit procurement cost is generally only a small fraction of the development cost and can, therefore, be neglected without influencing the conclusions.

The total RDT&E cost range for each transfer category obtained from Figure 11 was combined with the weighted operational effectiveness ranking given in Figure 9 to provide a cost plateau effectiveness comparison (see Figure 12). Should every space vehicle already carry a pressure suit for each person aboard as standard equipment, the crew transfer device would not be charged with its development or acquisition. Values are, therefore, presented both with and without pressure suit costs.

Operational Effectiveness Rank	Transfer Category	Cost (million 1970 dollars)			
		RDT&E		First Unit Mfg.	
		Including Pressure Suit	Without Pressure Suit	Including Pressure Suit	Without Pressure Suit
5	*Unassisted EVA	40 - 50	0	1 - 2	0
6	Special Purpose Devices	69 - 94	29 - 44	2.6 - 4	1.6 - 2
3	*Augmented Unassisted EVA	75 - 100	25 - 50	2 - 4	1 - 2
4	*Assisted EVA	101 - 175	51 - 175	**4 - 11	1 - 9
1	Pressurized Transfer Vehicle at DV	204 - 380	164 - 330	10 - 20	9 - 18
2	Pressurized Transfer Vehicle at SRV	>450	>400	21 - 40	20 - 38

* Cost per man

** Includes EVA suit for SRV crewman and IVA suit for DV crewman

Figure 12. Cost Plateau Comparisons

It is interesting to note that the transfer categories can be listed in ascending cost plateaus. Unassisted EVA, which involves a pressure suit development only, has the lowest estimated total development cost. It is closely followed by the Special Purpose Devices category. Both of these categories, however, are at the bottom of the operational effectiveness ranking. Pressurized Transfer Vehicles, which have the highest effectiveness rank, are also the most expensive transfer devices to develop. The best compromise between total development cost and effectiveness appears to be Augmented Unassisted EVA.

It should be emphasized that EVA can be involved in all categories and is required for most. If, as is likely, an advanced pressure suit is developed to meet non-emergency requirements, then its RDT&E cost would not be charged against acquiring an emergency crew-transfer capability. However, if the advanced pressure suit is not available, an additional $40 to 50 million would be required for its development. The transfer categories most affected include Unassisted EVA, Augmented Unassisted EVA, Assisted EVA, and Special Purpose Devices.

6.3 AVAILABLE HARDWARE

Transfer devices based on hardware already available and developed to meet a non-rescue requirement were economically assessed on the basis of their unit manufacturing cost. The First Unit Manufacturing Cost range given in Figure 11 has also been included in Figure 12 to give a cost plateau effectiveness comparison for available hardware. Again, values are indicated both with and without pressure suit costs.

It is noteworthy that the order of cost plateau increase for available hardware is similar to that for new hardware. Unassisted EVA and Special Purposes Devices, which rank lowest in operational effectiveness, have the least unit costs. Pressurized Transfer Vehicles, which have the highest effectiveness rank, have the highest unit costs. On the surface, Augmented Unassisted

EVA is again the best compromise between unit manufacturing cost and effectiveness. Several subtleties, however, need consideration and may affect this conclusion.

If each spacecraft is equipped with an individual pressure suit for every crewman and passenger, the transfer categories involving EVA ought not to be assessed the cost of the suit. Only the additional equipment for use in case of an emergency should be considered. On this basis, the unit cost given in Figure 12, which includes the cost of a pressure suit, reduces to the values shown under the column entitled "Without Pressure Suit." In spite of the reduced unit costs, however, the observations made previously remain valid.

Some consideration ought also be given the capacity of the transfer device. Although this factor has already been considered in arriving at the operational effectiveness rank of each transfer category, it can also influence the number of units acquired for emergency use and, thus, the cost. For a DV carrying a 12-man crew, a single PTV would be adequate. However, with a Special Purpose Device, Augmented Unassisted EVA, or Assisted EVA only one or two DV crewmen can be processed at a time. As a result, either the same equipment is used for several transfer cycles with an attendant increase in the total time for transferring an entire DV crew, or several units must be available and used simultaneously. This may not always be feasible with Special Purpose Devices. Only Augmented Unassisted EVA and Assisted EVA lend themselves to such an approach.

Since achieving a low total transfer time is generally desirable, a transfer category cost comparison as a function of DV crew size is appropriate. Such a comparison is given in Figure 13.

For DV crews in the order of 2 to 8 men, Augmented Unassisted EVA appears to be the least costly, acceptable choice between competing transfer categories.

Category	*Cost (million 1970 dollars)							Operational Effectiveness Rank
	Unit	Total						
		DV Crew Size						
		2	4	6	8	10	12	
Unassisted EVA	0	0	0	0	0	0	0	5
Augmented Unassisted EVA	1 - 2	2 - 4	4 - 8	6 - 12	8 - 16	10 - 20	12 - 24	3
Special Purpose Device	1.6 - 2	1.6 - 2	1.6 - 2	1.6 - 2	1.6 - 2	1.6 - 2	1.6 - 2	6
Assisted EVA	1 - 9	2 - 18	4 - 36	6 - 54	8 - 72	10 - 90	12 - 108	4
PTV at DV	9 - 18	9 - 18	9 - 18	9 - 18	9 - 18	9 - 18	9 - 18	1
PTV at SRV	20 - 38	20 - 38	20 - 38	20 - 38	20 - 38	20 - 38	20 - 38	2

* Pressure suit costs not included

Figure 13. Effect of DV Crew Size on Available Device Cost Comparison

For larger DV crews (>8 men), however, the most operationally effective transfer category, a Pressurized Transfer Vehicle based at the DV, appears also to offer the potential for lowest cost.

6.4 INTERACTION WITH PARENT VEHICLE

The effect of the stored volume and weight of a transfer device on the parent vehicle was not considered. In the case of a Space Station, this effect is relatively small when compared with the effect on the Space Shuttle Orbiter, as Orbiter load-carrying capability would be penalized on every flight. In the case of an Orbiter being used as an SRV, however, the effect would probably be negligible, as the weight of total emergency payload, which would include the transfer device(s), is relatively small compared to the Orbiter's payload-carrying capability.

Any final selection decision must consider this interaction between the transfer device and the parent vehicle and can be made only after the design details of the spacecraft involved have been established.

7. SUMMARY

The assessment made in this study of devices for on-orbit, emergency crew transfer was essentially subjective. Moreover, the RDT&E and manufacturing costs were necessarily estimated from available conceptual designs. In addition, the effect of a transfer device on the parent spacecraft was not considered. In spite of such limitations, a reasonably valid indication was obtained of the capability preference among transfer devices as a function of dollar expenditure. This section provides an overview of the procedures employed and the significant study conclusions.

Past studies have proposed and described a diverse assortment of transfer devices, which generally fall into one of the following categories:

a. Unassisted EVA

   An individual crewman wearing a pressure suit and moving under self power.

b. Augmented Unassisted EVA

   An individual crewman wearing a pressure suit and moving by means of a separate impulse source under his control.

c. Assisted EVA

   A suited distressed crewman aided in traversing the standoff distance by externally provided means not under his control.

d. Pressurized Transfer Vehicle

   Devices which shuttle between the distressed vehicle and the space rescue vehicle and carry an operating crew plus passengers.

e. Special Purpose Devices

   Devices which can be used for emergency transfer of personnel from the distressed vehicle to the space rescue vehicle.

The features of each category were characterized and then the crew emergency transfer utility of each category was ranked against selected operating criteria. A range of estimated development and manufacturing costs was also established for each category.

A crew transfer device based at a distressed vehicle (DV) is generally preferred to one which originates at the rescuing spacecraft. Thus, a Pressurized Transfer Vehicle (PTV) based at the DV gained the best score. Since costs increase with transfer technique complexity, however, it was concluded that Augmented Unassisted EVA offers the best solution at moderate cost for a small crew. However, if a PTV has already been developed to meet non-emergency needs, then it is not only operationally preferred but it is most cost effective as well for transferring a large crew (>8 crewmen).

It is likely that an advanced pressure suit will be developed and will be available for the missions being considered. Also, every space vehicle may carry a suit for each person aboard as standard equipment. On this basis, Augmented Unassisted EVA will involve an estimated development cost of $25 to $50 million, whereas a PTV based at the DV will have an estimated development cost of $164 to $330 million. If already developed for other, non-emergency needs, the first unit manufacturing cost is estimated at $1 to $2 million for Augmented Unassisted EVA and $9 to $18 million for a PTV.

Neither the effect of the stored volume and weight of the crew transfer device on the performance of the parent vehicle nor the spacecraft design features needed for compatibility with the transfer device were considered. Future studies should examine these questions. It is also appropriate that detailed studies of specific transfer devices be initiated in order to confirm these conclusions, which were reached by considering only general transfer category characteristics.

8. ACRONYMS AND ABBREVIATIONS

AMU	Astronaut Maneuvering Unit
ASTP	Apollo-Soyuz Test Project
ata	atmospheres, absolute
BOT	Bailout and Transfer Device
BOW	Bailout and Wait Device
CCM	Crew/Cargo Module
DM	Docking Module
DV	Distressed Vehicle
ECLS	Environmental Control and Life Support
ETC	Expandable Transfer Capsule
EVA	Extravehicular Activity
FFR	Free-Flying RAM
IVA	Intravehicular Activity
kg	kilogram
km	kilometer
lb	pound
PAL	Portable Airlock
psia	pounds per square inch absolute
PTV	Pressurized Transfer Vehicle
RAM	Research Applications Module
RMU	Remote Maneuvering Unit
S/C	Spacecraft

SL	sea level
SPD	Special Purpose Device
SRV	Space Rescue Vehicle

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APPENDIX A

EMERGENCY SITUATIONS

APPENDIX A

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APPENDIX A

EMERGENCY SITUATIONS

A.1 GENERAL

Past studies have treated the hazards that can exist during manned space missions and the resulting emergency situations. Such analyses do not necessarily identify the specific spacecraft involved or their detailed design specifications. General conceptual characteristics are usually sufficient.

Ref. 4, which was such an analysis, provides a useful compilation of emergency situations which could occur and which may lead to a crew transfer requirement from a Distressed Vehicle (DV). The identified emergency situations are listed in Figure A-1.

A discussion is presented in this appendix of the likely occurrence of the emergencies listed in Figure A-1 during each of the four missions considered in this study.

A.2 EVA EMERGENCIES

A.2.1 Operational Characteristics

Although past on-orbit Extravehicular Activity (EVA) has involved only a single crewman, future EVA operations may involve one or more crewmen. For safety considerations it has been proposed that future operational EVA over extended periods employ the "Buddy" system. This leads to the fact that more than one crewman will be in EVA at the same time. They may be tethered to the parent vehicle or to each other. Life support may be self-contained or may be provided by the parent vehicle through the tether. External mobility aids may be provided by the parent vehicle at the scene of mission activity.

For more ambitious EVA missions an Astronaut Maneuvering Unit (AMU) could be used. The AMU is basically a miniaturized spacecraft operated by an EVA crewman to distances of about 2 km from the parent spacecraft and capable of sustaining its user(s) for four or more hours (Ref. 1).

Single-place and multiplace configurations have been examined and both backpack units, Figure A-2, and more complex work platform configurations, Figure A-3, are feasible.

In all cases each crewman is protected by an individual EVA space unit. It is anticipated that future suits will be designed for a 100% O_2, 8 psia (0.6 ata) atmosphere. This atmosphere does not require a lengthy period of acclimatization from a sea-level condition, which is the intended atmosphere for a Space Station and the Space Shuttle Orbiter. The suit also provides appropriate radiation protection, thermal conditioning, and communication capability between individual crewmen with the parent spacecraft and with each other.

A.2.2 Operational Emergencies

The emergency situations that could occur during an operational EVA mission fall into two general categories.

a. An injured or incapacitated crewman

b. Crewman stranded in EVA and unable to return to the parent vehicle

The stranding may be caused by

- excessive separation from the parent vehicle
- blocked entry hatch
- inoperative airlock
- unsafe parent vehicle which no longer provides shelter

A. 3 SPACE SHUTTLE EMERGENCIES

A. 3. 1 Operational Characteristics

The scope of this study limits attention to an Orbiter operating in a stable, low earth orbit. The Orbiter, as currently defined (Ref. 6), includes both an airlock and a docking fixture. A flight and payload operations crew of up to four men will be used. Special experimenters and logistics passengers may also be carried on certain flights. All personnel in the cabin area are in shirtsleeves and under a sea-level environment. Communication with Mission Control, the Space Station, and the manned Research Applications Module (RAM) is normally available.

A. 3. 2 Operational Emergencies

The orbital emergencies which could lead to a personnel transfer requirement during an Orbiter operational mission fall into two general categories:

a. Orbiter unable to reenter
b. Personnel must leave the Orbiter

The need for the crew to leave the Orbiter while still in space can occur if

- the life support is exhausted
- the Orbiter is out of control
- the Orbiter propulsion is disabled and debris is in the vicinity or radiation is in the vicinity
- the Orbiter environment is non-habitable

It should be noted that the above situations can occur individually or in combination.

A. 4 SPACE STATION EMERGENCIES

A. 4. 1 Operational Characteristics

Operational characteristics suitable for the needs of this study are based on currently available Space Station study results (Ref. 7 and 8).

The Station is considered to be in a stable, low earth orbit. It is equipped with an airlock, a docking fixture, and at least two access hatches. Also, the design will involve at least two separable and independent modular components, either of which is habitable. Personnel aboard the Space Station may include the housekeeping and operating crew, experimenters (as required), and in-transit crews. At any specific time, a minimum of six people may be involved. A shirtsleeve, sea-level environment is normally provided.

Communication is available with Mission Control, arriving and departing logistics vehicles, and mission-involved EVA personnel.

A. 4. 2 Operational Emergencies

The orbital emergencies which may lead to a transfer-of-personnel requirement from an orbiting Space Station fall into two general categories:

a. Ill or injured crewman requiring immediate medical attention not available in the Station

b. Personnel must leave the Station

The requirement for all personnel to leave the Station can occur if

- all life support is exhausted
- Station is out of control
- debris in vicinity
- radiation in vicinity
- Station environment is non-habitable

It should be noted that these situations can occur individually as well as in combination.

In all cases, emergency transfer of personnel would be required only if the conventional transfer means, namely, docking the logistics vehicle to any of several ports on the Space Station, could not be achieved. Should such a situation occur, an additional emergency situation, i. e., crew trapped in the Space Station, might also prevail.

A. 5 RESEARCH APPLICATIONS MODULE EMERGENCIES

A. 5. 1 Operational Characteristics

Manned Research Applications Module (RAM) concepts fall into two general categories: the Sortie RAM and the Free-Flying RAM. The operating characteristics for each are based on the results of a recent study (Ref. 9).

A. 5. 1. 1 Sortie RAM

The Sortie RAM (Figure A-4) is attached to either an Orbiter or a Space Station. It is inhabited only as required by the experiments involved. Two experimenters will probably be in the RAM simultaneously. Their living quarters are in the parent vehicle, and intra-vehicular procedures are involved in entering the RAM through a hatch and airlock. The Sortie RAM will probably be self-contained with an independent environment control and life support system (ECLS) During experimenter occupancy, the same atmosphere as in the parent vehicle will be provided. Otherwise, unless required by a specific experiment, the RAM interior will be under vacuum conditions. The RAM is also equipped with an independent power supply. Crew mobility aids and restraint devices for the 0-g environment and an additional hatch for emergency escape are strategically located.

A. 5. 1. 2 Free-Flying RAM

The Free-Flying RAM (FFR) is a pressurizable RAM which is placed in orbit by a Shuttle and remains unmanned during all orbital operations except for the initial deployment and periodic servicing. The requirements for habitability are very limited, and support is provided by a Sortie RAM which is attached to an Orbiter and which docks directly to the FFR (see Figure A-5). The crew enters the FFR from the Sortie RAM only as necessary. All experiment test and checkout procedures are performed from a display and control console in the Sortie RAM. Should entry of crew into the FFR be required during servicing operations, the Sortie RAM provides the oxygen and nitrogen needed to pressurize the FFR. Portable fans are used to distribute the atmosphere. In general, only one man is expected to occupy the FFR. The second crewman will remain in the Sortie RAM.

It should be noted that some EVA may be required during the experiments maintenance phase.

A.5.2 Operational Emergencies

Operational emergencies for which crew transfer may be required are generally similar for both the Sortie RAM and the FFR. The Sortie RAM is always attached to the Orbiter and, when manned, the FFR is always docked to the Sortie RAM, becoming in effect an extension of the Sortie RAM.

RAM operating emergencies involve either IVA or EVA personnel. In the IVA case, emergency transfer means are required if

a. IVA personnel are trapped by a blocked passageway
b. the Orbiter is not habitable

In the EVA case, emergency transfer means are needed if

a. an EVA crewman is incapacitated
b. an EVA crewman is stranded
c. the Orbiter is not habitable

Whether in IVA or EVA, non-habitability of the Orbiter can be due to the following emergency situations:

- all life support is exhausted
- the environment is non-habitable

In addition, the Orbiter may be unavailable to EVA personnel because it is out of control.

- ILL / INJURED CREW (PHYSICAL, CHEMICAL, DISEASE, MENTAL)
- METABOLIC DEPRIVATION
- STRANDED / ENTRAPPED CREW
  - DURING EVA OPERATIONS
  - IN VEHICLE
- INABILITY TO COMMUNICATE
- OUT-OF-CONTROL SPACECRAFT
  - TUMBLING IN SAFE ORBIT
  - DECAYING ORBIT
  - UNSAFE TRAJECTORY
- DEBRIS IN VICINITY
- RADIATION IN VICINITY
- NON-HABITABLE ENVIRONMENT IN SPACECRAFT
  - LACK OF ENVIRONMENTAL CONTROL (TEMP., HUMIDITY EXTREMES)
  - CONTAMINATION (EXPERIMENTS, ANIMALS, BACTERIA, INSECTS)
  - RADIATION (INTERNAL)
- ABANDONMENT (CREW IN EVA AFTER BAILOUT)
- INABILITY TO REENTER

Figure A-1. Possible Emergency Situations (Ref. 4)

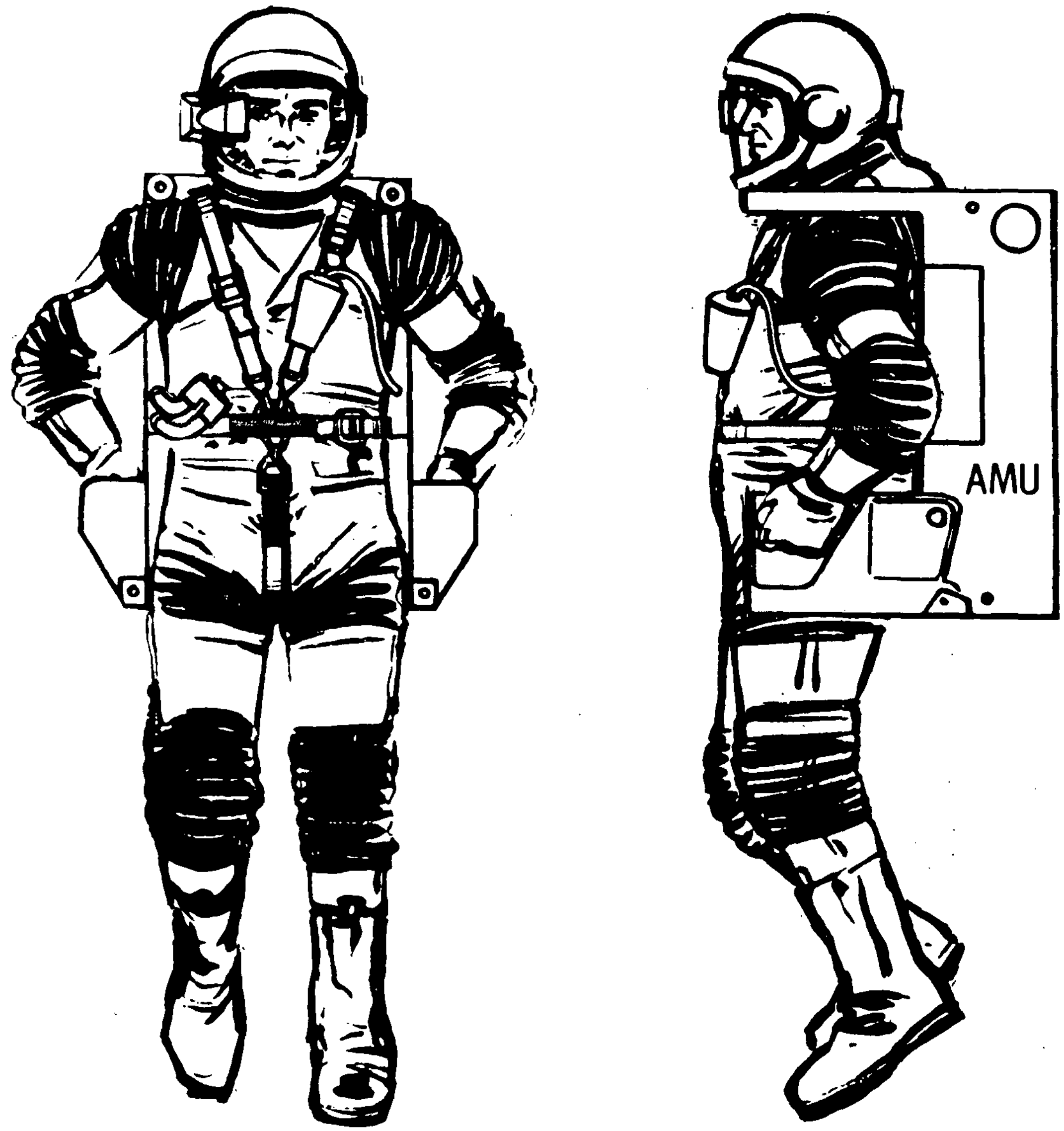

Figure A-2. Backpack Astronaut Maneuvering Unit (Ref. 5)

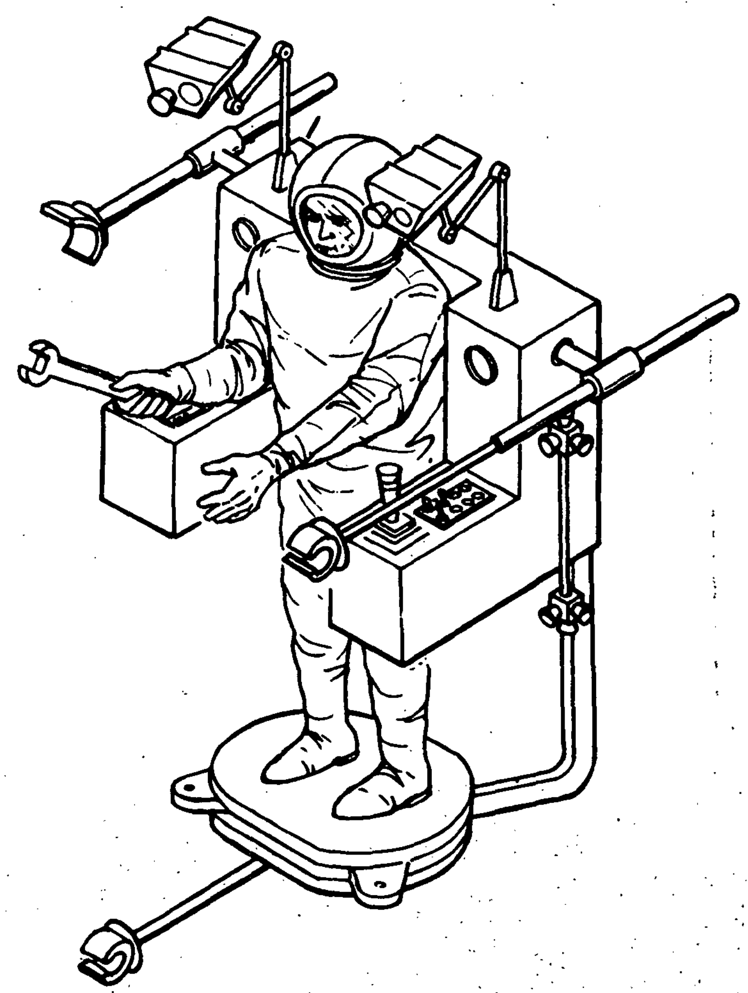

Figure A-3. EVA Work Platform (Ref. 4)

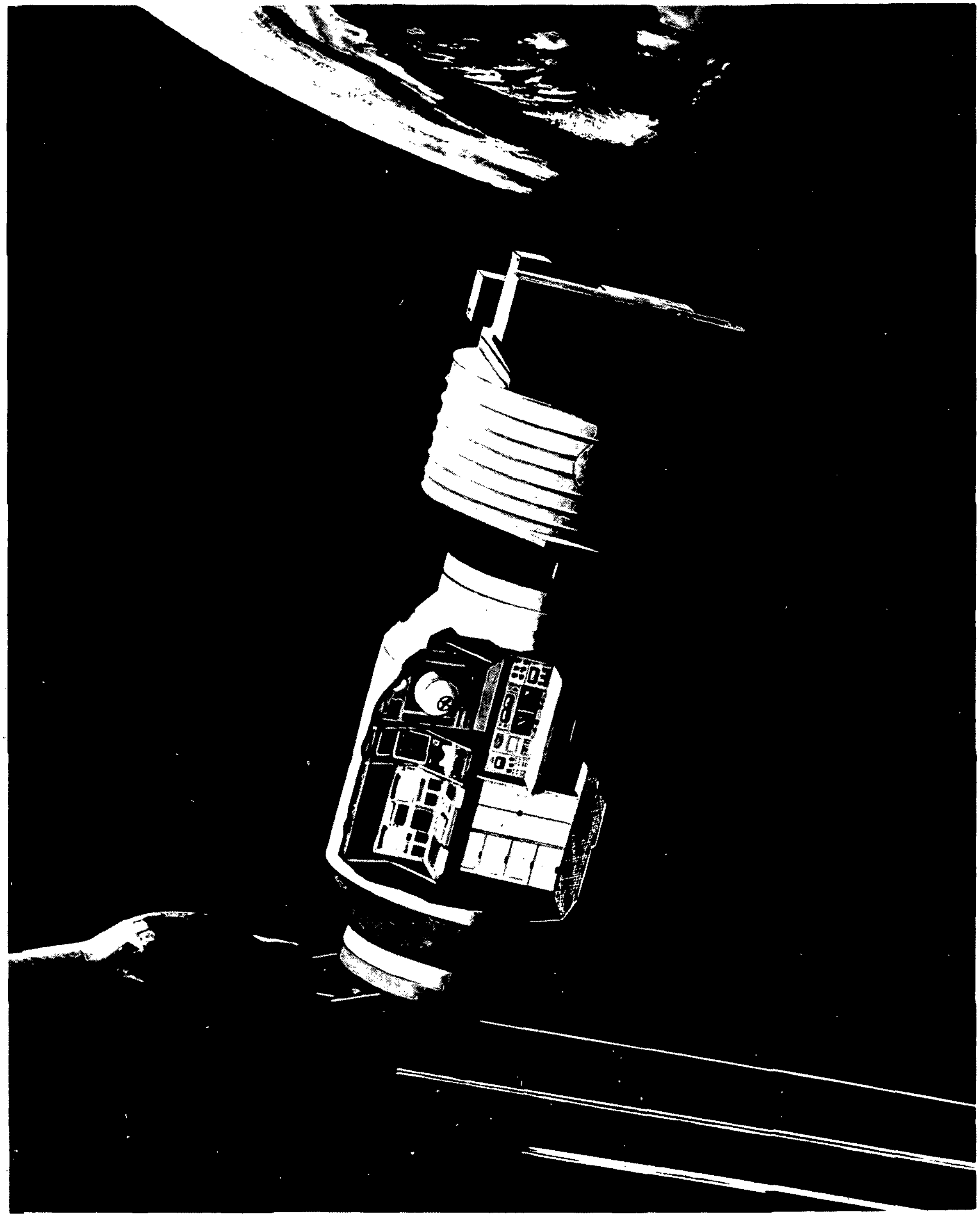

Figure A-4. Sortie RAM in Erected Position

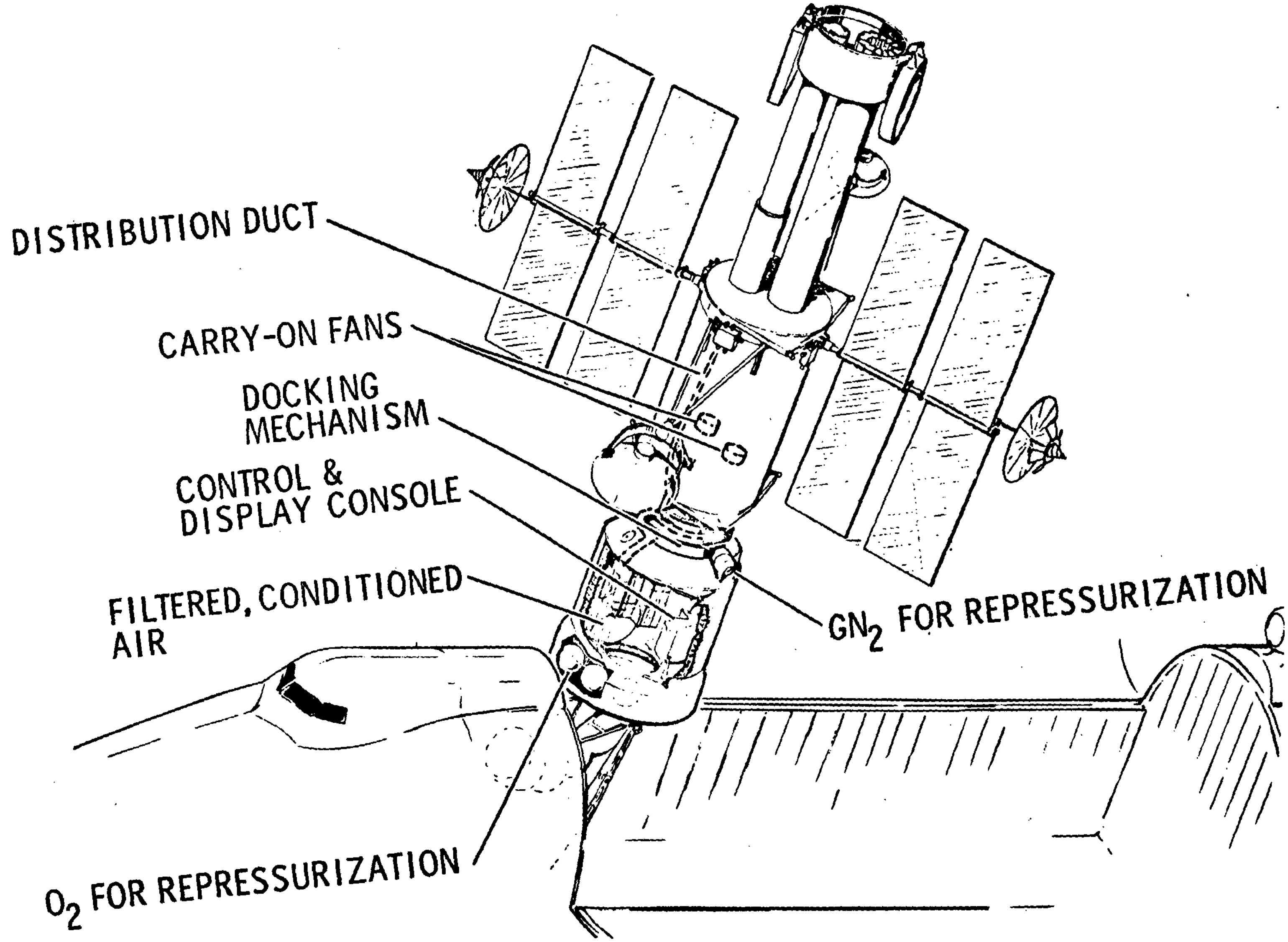

Figure A-5. Free-Flying RAM Docked to Sortie RAM for Servicing (Ref. 9)

APPENDIX B

TRANSFER DEVICES

APPENDIX B

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APPENDIX B

TRANSFER DEVICES

B. 1 GENERAL

As discussed in section 3. 3, the transfer devices considered in this study were divided into five categories:

a. Unassisted EVA
b. Augmented Unassisted EVA
c. Assisted EVA
d. Pressurized Transfer Vehicle
e. Special Purpose Devices

B. 2 DESCRIPTION

B. 2. 1 Unassisted EVA

Unassisted EVA refers to the case of an individual Distressed Vehicle (DV) crewman wearing a pressure suit and moving under self power. Obviously the standoff distance between vehicles cannot be very large, and mobility aids and handholds on both the DV and the Space Rescue Vehicle (SRV) are desirable. It is likely that the crewman may be initially tethered to his parent vehicle.

For the time period of interest, pressure suits will probably be using an 8 psia (0. 6 ata), 100% Oxygen atmosphere. With such an atmosphere little or no pre-breathing is necessary when adapting from a sea-level atmosphere. Equal or better mobility than with the existing Apollo-type suit is anticipated. The expected weight for the suit is about 65 lb (30 kg) and the storage volume will be similar to current suits. A four- to eight-hour life support duration is typical of self-contained configurations. Longer periods will probably depend upon an umbilical line to the parent spacecraft. There may also be developed a quick-donning, lightweight IVA suit which could be donned within perhaps 30 sec and which may weigh as little as 12 lb (5.5 kg). Such a suit would be ideal not only as an emergency suit for use inside a DV, but might also be used for short-duration EVA emergency transfer. (This information is based on discussions with the Advanced Suit Development Section at NASA-MSC.)

B.2.2 Augmented Unassisted EVA

Augmented Unassisted EVA refers to the case of the individual crewman wearing a pressure suit and moving by means of a separate impulse source which is under his control. Astronaut Maneuvering Units (AMU), as illustrated in Figure A-2, and Work Platforms, Figure A-3, fall into this category. They may be single or multiplace, and individual pressure suits with self-contained life support are required. Movement across standoff distances as large as 2 to 4 km may be feasible. Devices in this category will probably be stored aboard the DV.

B.2.3 Assisted EVA

Assisted EVA involves a suited DV crewman who is aided in traversing the standoff distance to the SRV by externally provided means not under his control. This category includes:

a. a Buddy EVA crewman (Figure B-1) generally aided by an AMU
b. an unmanned Remote Maneuvering Unit (RMU) (Figure B-2)
c. a multiplace Space Flyer (Figure B-3) which might be a derivative of a Lunar Flying Vehicle
d. a Manned Maintenance Capsule (Figure B-4)

Devices in this category usually originate at the SRV and are especially useful in dealing with injured or incapacitated crewmen. Large standoff distances (approaching 2 km) can be accommodated, but probably only one DV crewman at a time will be transferred. An exception would be the Manned Maintenance Capsule which could be based at the DV.

B.2.4 Pressurized Transfer Vehicle

The Pressurized Transfer Vehicle category includes devices which shuttle between the DV and the SRV and are capable of carrying their operating crews plus passengers. Some devices in this category are quite large and include a cargo capacity, an airlock for EVA, a docking capability, an extensive propulsion capability, and external manipulators. Such devices will generally be operational vehicles developed for other than rescue applications. Included in this category are:

a. an operational Crew-Cargo Module (CCM) with propulsion (Figure B-5)

b. a Manned Tug (Figure B-6)

c. a Manned Maintenance Capsule (Figure B-4)

Such devices are all multiplace, but only types (a) and (b) can accommodate an entire DV crew. Basing can be at either the SRV or the DV. If based at the DV this category also includes Bailout and Wait (BOW) and Bailout and Transfer (BOT) systems (see Ref. 4). These latter two devices are likely to be less sophisticated than SRV-based devices.

B.2.5 Special Purpose Devices

Special purpose devices which can be used for emergency transfer of personnel from a DV to an SRV are included under this category. Devices originally intended for other applications as well as devices specifically intended for emergency crew transfer are included. The following items fall into this category:

a. Apollo-Soyuz Test Project (ASTP) Docking Module (Figure B-7)

b. Portable Airlock (PAL) (Figure B-8)

c. Expandable Transfer Capsule (ETC) (Figure B-9)

In all cases the device is intended to be attached to the DV either at a hatch or a docking fixture. If this is feasible, unsuited crewmen can be accommodated as well as injured crewmen requiring litter handling. When direct entry from the DV is not possible, EVA is required. Lightweight IVA (intravehicular activity) suits, which are designed to be worn as a coverall, but are acceptable in emergency for short EVA excursions, might be used.

Devices in this category could be carried abroad an SRV and would be delivered to the DV by auxiliary means such as an RMU, a rescue crew in EVA, or a pressurized capsule. Capacity is at least two DV crewmen but less than the entire DV crew.

The proposed use of these special devices for emergency transfer involves shirtsleeve crewmen. This requires a complete ECLS system as an integral part of such a device.

B. 3 OPERATIONAL CHARACTERISTICS

Since many of the suggested crew transfer devices have similar operational characteristics, they were grouped into generic categories. The general operational characteristics of each category can be defined and, for the purpose of this study, the utility and relative effectiveness ratings of only the individual categories need to be determined. The same grouping into five separate categories provided in Section B. 2 will be maintained for the discussion in this section as well.

B. 3. 1 Unassisted EVA

Unassisted EVA is the simplest approach to emergency crew transfer, but its utility is limited. The rescue vehicle must be in close proximity to the DV, either docked or undocked. In this category only the DV crew goes into EVA. Individual pressure suits, either EVA or IVA designs, are worn. The suits are designed for life-support plug-in to either backpack, spacecraft, or another EVA crewman's source.

Possible EVA modes includes free or tethered operation. The former requires a backpack source of life support, whereas the latter can be either a backpack or an umbilical source. In either case radio communications with both the DV and the SRV will probably be available.

Since an EVA crewman is essentially self-dependent, this mode of crew transfer is of limited use if a crewman is injured or incapacitated. The crewman generates his own motive power and depends upon either handholds and mobility aids strategically positioned on both the DV and the SRV or a tether between them.

The DV must be able to discharge its crew into EVA, and the SRV must have facilities for receiving personnel from EVA. Airlocks are preferable but not absolutely required. The alternative is to depressurize the receiving compartment of the SRV.

Both Orbiter and Space Station planning specify a sea-level atmosphere. To avoid an acclimatization period, pressure suits should be designed for a 100% Oxygen, 8 psia (0. 6 ata) atmosphere and with mobility equivalent to that available with the current Apollo suit.

It is noteworthy that unassisted EVA allows emergency crew transfer both to a foreign SRV and from a foreign DV.

B. 3. 2 Augmented Unassisted EVA

An improvement in the transfer capability of the Unassisted EVA crewman is achieved by providing him with an impulse source under his control to aid in traversing the standoff distance between the two vehicles. This added capability allows a significant increase in the maximum SRV standoff distance over which a non-augmented EVA crewman can operate. Except for this single operational feature and its impact on related operational procedures, the Augmented Unassisted EVA case has most of the same characteristics as the basic Unassisted EVA category.

As in the Unassisted EVA case only the DV crew goes into EVA. Individual pressure suits are worn. For large standoff distances the EVA excursion may be of significant duration, and IVA suits may not be adequate. Should this be the case, only an EVA suit will be acceptable. The suit must be either self-contained or draw upon life support included in the impulse-source package. An umbilical line to the DV is not feasible if a large standoff distance is involved.

With this mode the individual EVA crewman remains self-dependent, and little if any crew injury or incapacitation can be accommodated. The impulse source is under the control of the crewman, and strategically located handholds and mobility aids on both the DV and the SRV are still required. In addition to being able to discharge its crew into EVA, the DV must also carry and make available to an EVA crewman the impulse source to be used in reaching the SRV. As in the Unassisted EVA case, airlocks in both the DV and the SRV are desirable but not absolutely necessary. If not available, depressurization of at least one vehicle compartment with an exit hatch is required.

As was assumed in section B. 3. 1, both the DV and the SRV will have a sea-level atmosphere and the EVA suit will operate at a 100% Oxygen, 8 psia (0. 6 ata) atmosphere. Communication between individual EVA crewmen and the DV and SRV will be available.

An AMU is the most probable motive power source. The simple backpack AMU (Figure A-2) represents one approach. A more sophisticated design such as a Maneuverable Work Platform (Figure A-3) offers added utility. In either case standoff distances as great as 2 to 4 km could be traversed. Such distances make a tether between vehicles unlikely.

The Augmented, Unassisted EVA transfer mode also permits emergency crew transfer both to a foreign SRV and from a foreign DV. If non-similar atmospheres are involved between the DV and the SRV, the acclimatization period occurs only at the SRV. Suit and DV atmospheres are assumed compatible.

B. 3. 3 Assisted EVA

Assisted EVA overcomes the shortcoming of complete self-reliance for the EVA crewman who must leave a DV and enter an SRV. The procedure in this category of transfer devices is to provide external aid to an EVA crewman in order to assist his transfer to the SRV. This aid may take the form of unmanned assistance such as an RMU controlled from the SRV (Figure B-2), manned assistance from the DV such as a Buddy DV crewman (Figure B-1), or manned assistance from the SRV. In the latter case the SRV aid can be an EVA crewman (probably aided with an AMU), a Space Flyer -- which involves crewmen in pressure suits -- (Figure B-3), or a pressurized Maintenance Capsule (Figure B-4) with its crew in shirtsleeves.

Except for the RMU all devices in this category require the participation, either in EVA or in a small self-contained spacecraft, of at least one crewman. The devices would normally be based at the SRV and could accommodate a significant standoff distance.

Under this general category a DV crewman is again in EVA and protected by a pressure suit. He may be injured or incapacitated, but the degree of his difficulty cannot be such as to interfere with his going into EVA. Since large standoff distances may be involved[1], an umbilical line is not practical. Consequently the pressure suit must be self-contained and equipped for drawing additional life support, if necessary, from the transfer device.

All systems in the Assisted EVA category are able to maneuver and transfer a disabled EVA crewman. Any assistance that the DV crewman is capable of providing reduces the difficulty and duration of his transfer to the SRV. Also, these devices and their procedures are amenable to the simultaneous transfer of more than one DV crewman at a time.

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[1] A large standoff distance may be necessary if the region adjacent to the DV presents a hazard to the SRV (for example, debris from an explosion or radiation from a nuclear power source).

Several of the devices in this category (RMU and Maintenance Capsule, for example) will probably be equipped with a manipulator. Special skills must be developed by the rescuing crewman in using this manipulator. Skills must also be developed by the SRV crewman who will operate the Space Flyer or the Buddy AMU.

As is characteristic of all transfer modes involving EVA, both the DV and the SRV must be able to discharge personnel into EVA. In addition, the SRV must be able to receive EVA personnel. The SRV must also carry and make available to the rescue crew the devices not already on the DV to be used in retrieving, transferring, and delivering the rescued crew. To function effectively the SRV should be equipped with an airlock.

Communication between the DV crew and the SRV rescue crew is assumed. Additional emergency communication links to the DV and SRV are desirable.

In addition to handholds and mobility aids on the DV and the SRV, previously suggested as necessary for EVA operations (see sections B. 3. 1 and B. 3. 2), they must also be available on the transfer device itself. Also, as was indicated in those sections, both the DV and the SRV will have a sea-level atmosphere, whereas the pressure suits will operate at 8 psia (0. 6 ata), 100% Oxygen.

Devices in the Assisted EVA category are also useful for emergency crew transfer both to a foreign SRV or from a foreign DV.

B. 3. 4 Pressurized Transfer Vehicle

Devices in the Pressurized Transfer Vehicle (PTV) category are intended to avoid the problems associated with EVA crewmen. They are self-contained, pressurized spacecraft, preferably multiplace, which are capable of docking to both a DV and an SRV. The specific vehicle design establishes whether hard or soft docking is involved. Devices in this general category are especially useful in dealing with the "injured crewman" situation. Not only is manned aid available during evacuation, but emergency medical treatment can be given during the transfer process.

As indicated in section B.2.4, devices in this category which are based at the SRV include a CCM with propulsion, a Manned Tug, or a Manned Maintenance Vehicle (see Figures B-4, 5, and 6). Although different names are used to describe functions, a single vehicle design could be employed for all three applications. Such vehicles are designed for a sea-level atmosphere. Propulsion is available and very large standoff distances (>2 km) are acceptable.

With an Orbiter as the SRV, very large PTVs are feasible, and a special rescue crew would be provided. Moreover, the entire DV crew could probably be accommodated in a single PTV. Such a PTV would probably be equipped to allow EVA excursions and could take aboard crewmen (U. S. or foreign) in EVA.

Devices in the PTV category could also be based at the DV, thus providing improved availability. If based at the DV, the Bailout and Wait (BOW) and Bailout and Transfer (BOT) Capsules also fall into the PTV category. These devices are pressurized, contain limited life support, and can accommodate the entire DV crew. Their purpose is to provide a safe haven for the DV crew until the arrival of an SRV. The BOW has no impulse source and must be externally manipulated and delivered to the SRV. The BOT has some installed impulse and is capable of limited travel across a small standoff distance. A capability for docking the SRV with a passive PTV is assumed. A feasible but less desirable alternative is EVA transfer between the PTV and the SRV.

A module of a modular Space Station could be considered as being a BOW or BOT device. Also, if the Orbiter is provided with an ejection capsule for its crew, such a capsule would fall into the BOW category (assuming ejection in space).

B. 3. 5 Special Purpose Devices

B. 3. 5. 1 Apollo-Soyuz Test Project Docking Module

The Docking Module (DM) being planned for the Apollo-Soyuz Test Project, ASTP (Ref. 10), has a 2-man DV crew transfer capability. It is a rigid air-lock with a hatch and docking fixture at both ends, and it provides its own pressurization and life support. There is no impulse available and transfer across the standoff distance would be by means of SRV-provided devices (RMU; Tug; AMU-equipped EVA crewman). Although the specific pressure and atmosphere are not as yet specified, they will undoubtedly be compatible with a sea-level environment.

When carried by a DV as a transfer device, a DM can accommodate an ill or injured crewman who is a litter case. The DM is maintained at the same condition as the DV cabin and the DV crew can enter the DM in shirtsleeves. Communication is provided to the SRV and with the SRV rescue crew.

After the DV crew members are in the DM and its hatch is sealed, it separates from the DV. Since it must be carried across the standoff distance by a device supplied by the SRV, strategically located mobility aids for grasping the DM should be provided on its exterior. After it is maneuvered to and docks with the SRV, the DM pressure and atmosphere are equalized to that of the SRV, if necessary. The hatch can then be opened and the DV crewman, still in a shirtsleeve condition, can be taken directly aboard the SRV.

If the DM must be returned to the DV for additional crewmen, the return trip generally involves the same procedures as if the DM had been originally stationed at the SRV. It must be transferred to the DV, docked to the DV, and its interior atmosphere equalized to that of the DV. Only then can the hatch sealing the DM from the DV be opened and DV crewmen accepted.

When direct docking to the DV is not possible for an SRV-based DM, the DV crew must go into EVA in order to enter the DM. In this case, some of the advantages stated for the DM are lost. These include the shirtsleeve environment and the ability to handle litter-case DV crewmen.

It should be noted that until the arrival of the SRV, a DM attached to a DV can also be used as a BOW device. The DM can remain attached to the DV or be separated. In either case it is a sealed, pressurized container with its own life support.

Since the DM is intended to allow docking and crew transfer between U.S. and U.S.S.R. spacecraft, it could also be used for emergency crew transfer between spacecraft of the two nations.

B.3.5.2 Portable Airlock

The Portable Airlock, PAL (Figure B-8), is an SRV-supplied device which is generally similar in function and operation to the ASTP Docking Module (section B.3.5.1). The essential difference between the two devices is that the ASTP-DM is a rigid design, whereas the PAL is expandable. Thus, the PAL should be lighter and occupy less storage volume (see Ref. 4).

The ASTP-DM is intended for use between two spacecraft and provides a rigid joint between them. The PAL, on the other hand, is intended for entry into a DV by EVA rescue crewmen. It is transported to the DV by SRV crewmen in EVA, attached to the DV at an entry hatch, and then erected. The PAL itself has two hatches, one for entry of an EVA crewman and, at the other end, a hatch leading to the DV. Sizing is generally adequate to accommodate two men simultaneously and pressurization and life support are self-contained.

Use of the PAL for emergency crew transfer requires that SRV crewmen in EVA transport the PAL from the SRV, attach it to the DV, and erect and pressurize it to match the DV atmosphere. DV crewmen in shirtsleeves could then enter and seal the PAL from the DV. Injured or incapacitated crewmen could be accommodated. Once sealed, the PAL would be detached from the DV and moved across the standoff distance to the SRV by means of external aids. Extensive EVA by the SRV crew is clearly required and manipulator-equipped devices such as a Tug or a Maintenance Capsule may also be necessary. Before the DV crew can leave the PAL, it must be attached to the SRV at a hatch or docking fixture and its pressure adjusted to that of the SRV.

It should be noted that once the PAL is attached to the DV it is possible for the SRV crew in EVA to enter the PAL and then pass into the DV to render assistance, if required, prior to DV crew transfer.

If direct attachment ot the DV is not feasible the DV crew must go into EVA in order to enter the PAL. In this case, the advantages of a shirtsleeve environment and the ability to handle a litter-case DV crewman are lost. SRV crewmen in EVA can erect the PAL near the DV, however, and the DV crew in IVA suits can negotiate the small standoff distance involved.

Unless the PAL is designed for attachment to a foreign DV, the DV crew would have to engage in EVA in order to enter the PAL.

B. 3. 5. 3 Expandable Transfer Capsule

The Expandable Transfer Capsule, ETC (Ref. 4), is similar in concept and use to the Portable Airlock. The ETC is also expandable, self-pressurized, and attached to the DV at a hatch or docking fixture. It would be delivered to a DV by an SRV and placed in position and erected by manipulators or EVA crewmen. The inflatable section is shaped to accommodate a personnel carrier or litter. The breathing atmosphere is also the pressurizing gas.

The basic difference between the ETC and the Portable Airlock is that the former has only a single means of entry. Thus, it can be entered only when attached to the DV and emptied when attached to the SRV.

As a minimum, an ETC is sized for at least two crewmen, one of whom can be incapacitated. Larger designs might accommodate the entire DV crew.

Pressure suits are not required. The DV crew could remain in shirtsleeves during the entire transfer operation.

A large SRV standoff distance is feasible. The actual standoff distance selected is influenced by the technique employed in transporting the ETC from the SRV to the DV and back to the SRV. Also, both the DV and the SRV must be equipped so that the ETC can be attached. If the ETC were to be used with a foreign spacecraft, it too would have to be so equipped.

It is conceivable that an ETC could be designed for erection and use without being rigidly fastened to the DV. In this case the DV crew would be required to go into EVA for a short time in order to enter the ETC. Whether or not the ETC could be rigidly fastened to the DV, the ETC would need to be equipped with mobility aids to facilitate its handling both in the collapsed and expanded states.

B.4 SUMMARY OF OPERATIONAL FEATURES

A summary of the operational features of each transfer category discussed in this appendix is given in Figure B-10. As an aid in assessing the utility of each category, and in identifying differences between categories, their operational features are listed as favorable or unfavorable.

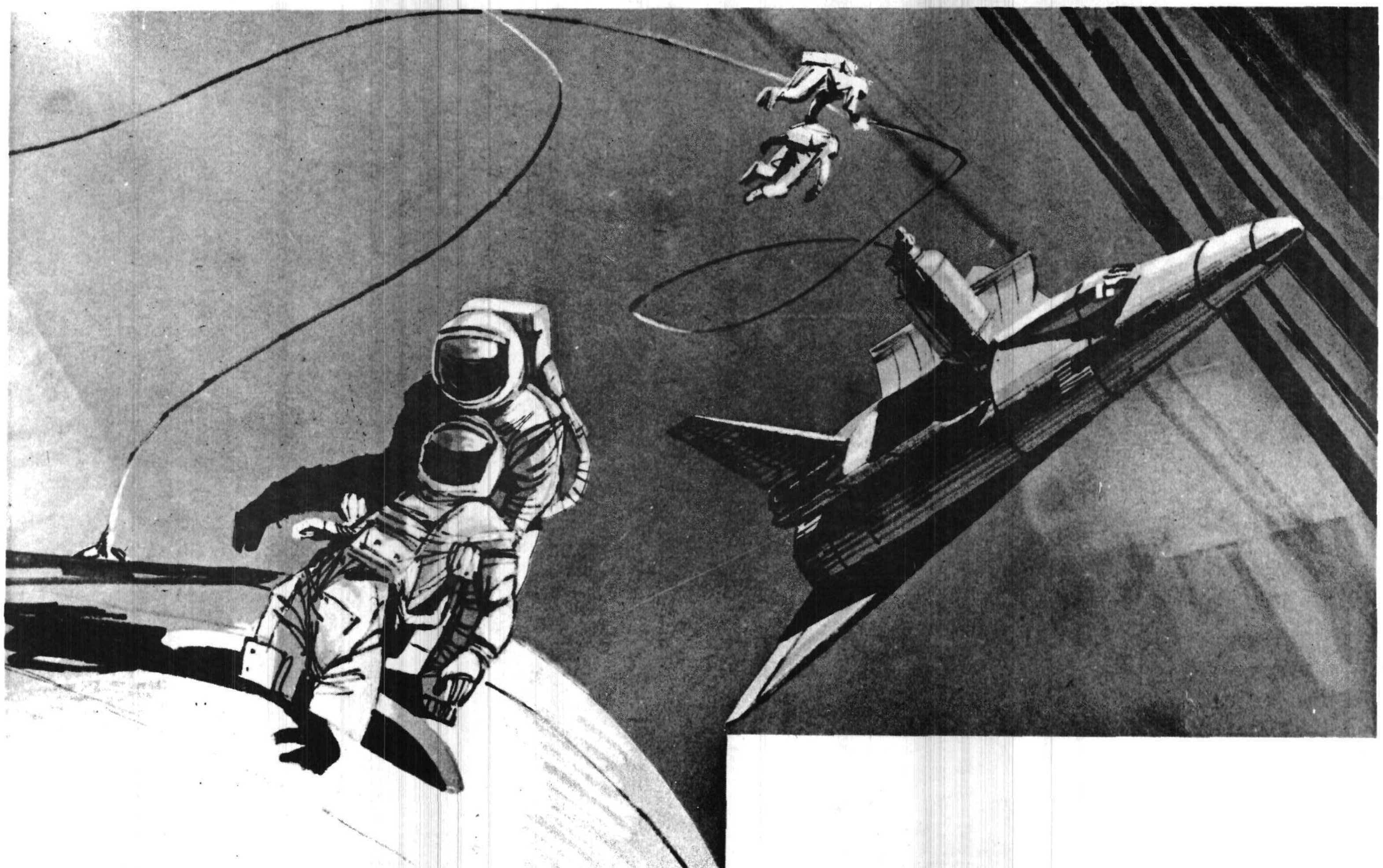


Figure B-1. Assisted EVA by Buddy Crewman

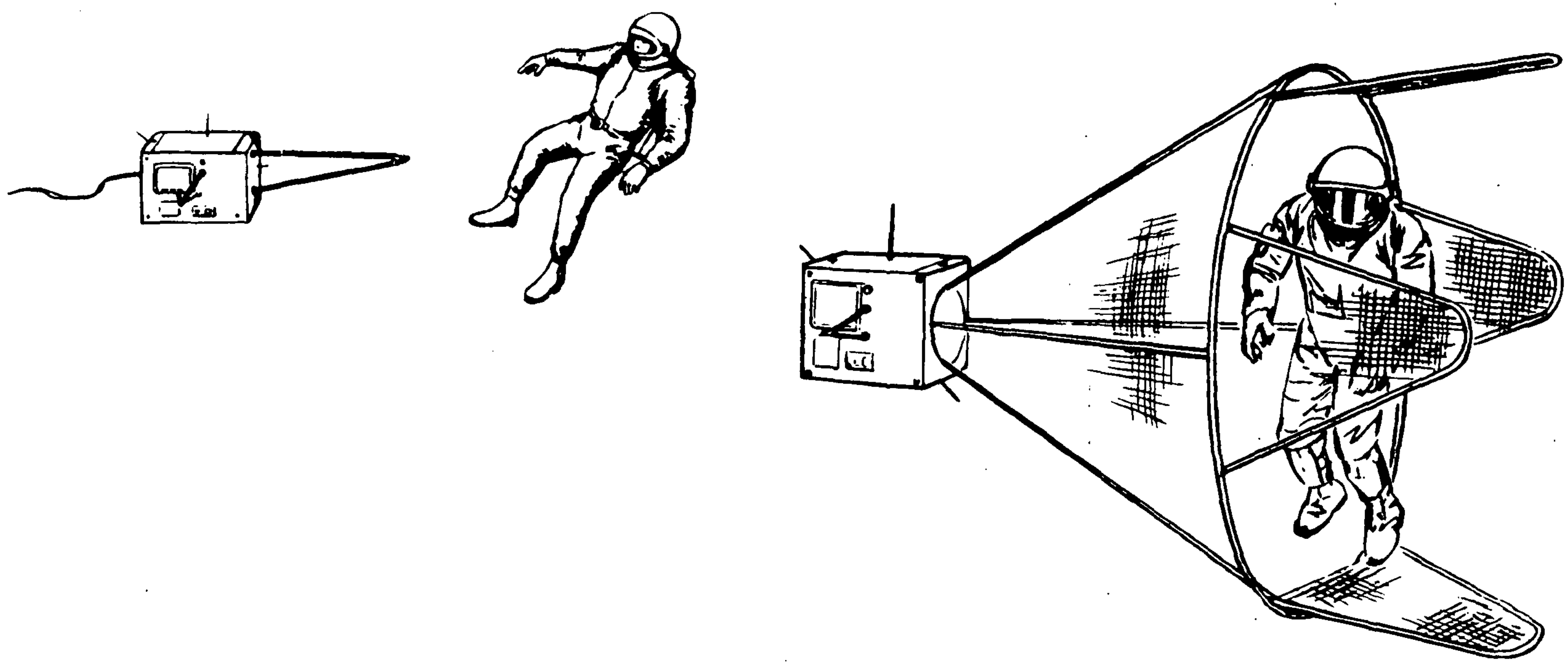


Figure B-2. Assisted EVA by Remote Maneuvering Unit (Ref. 5)

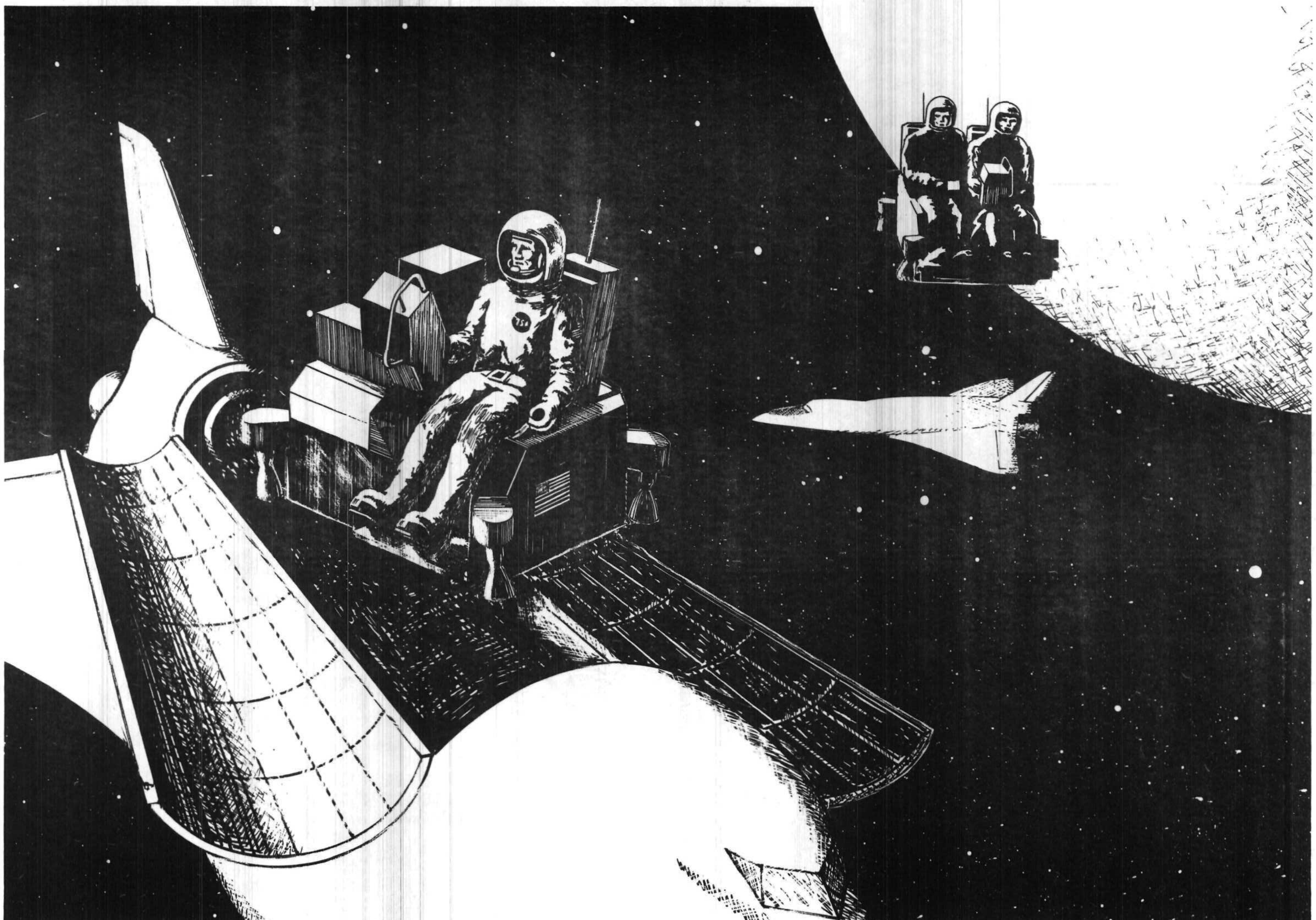


Figure B-3. Assisted EVA by Multiplace Space Flyer (Based on Ref. 5)

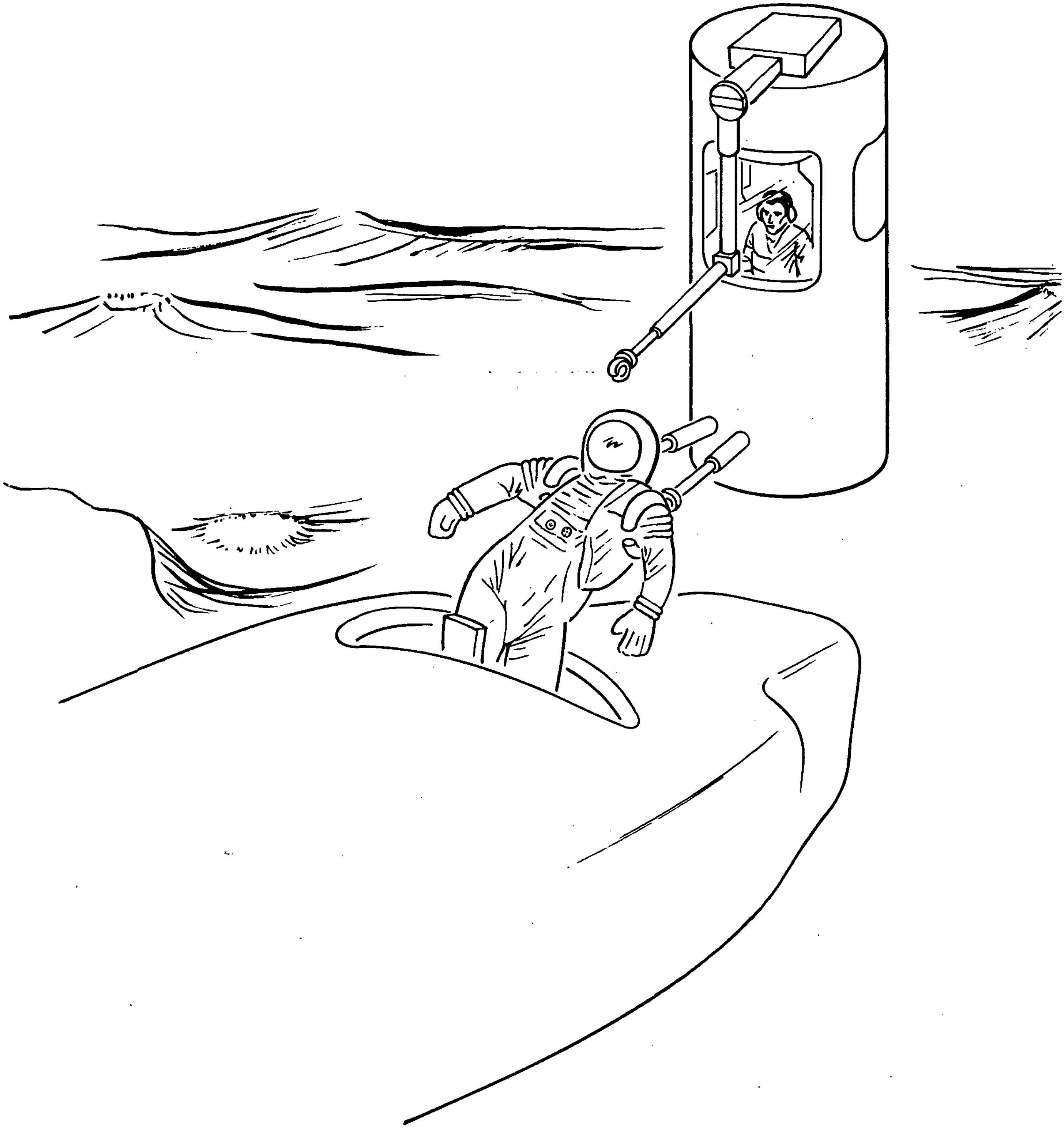


Figure B-4. Assisted EVA by Manned Maintenance Capsule (Ref. 4)

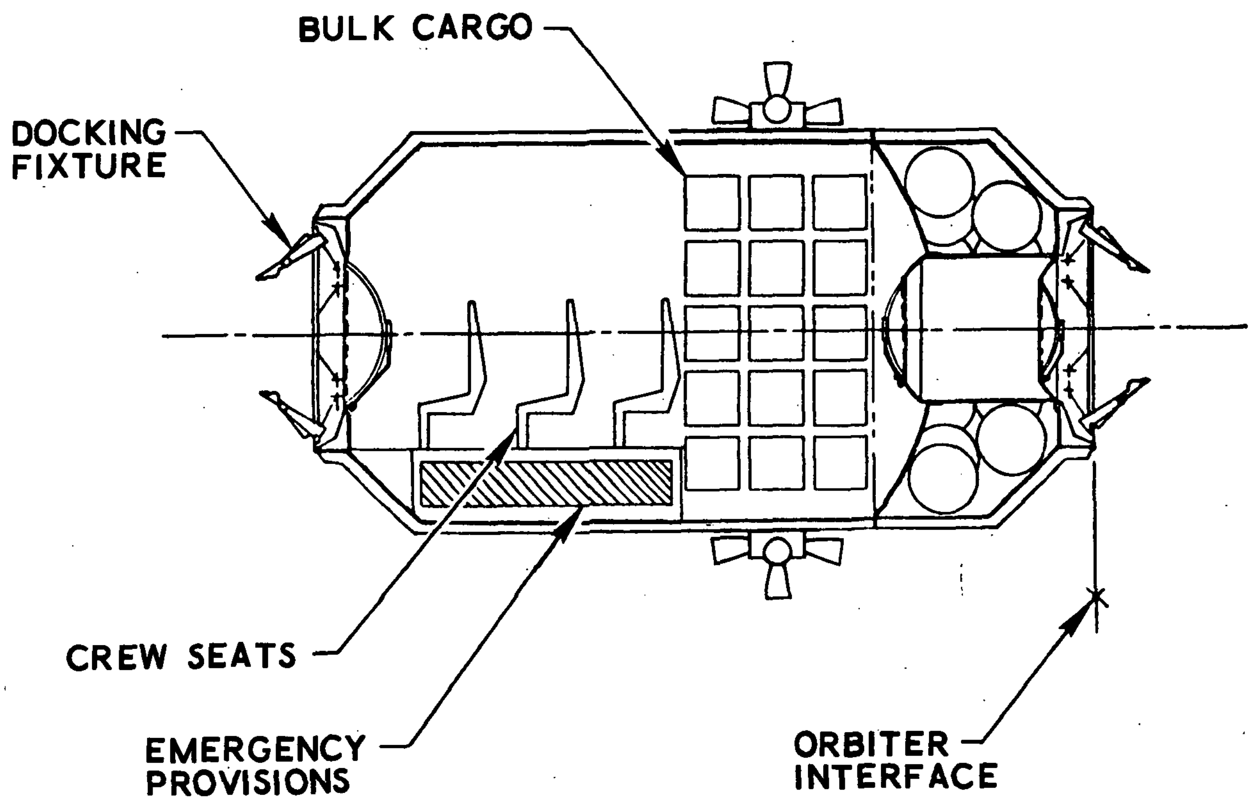


Figure B-5. Crew-Cargo Module with Propulsion

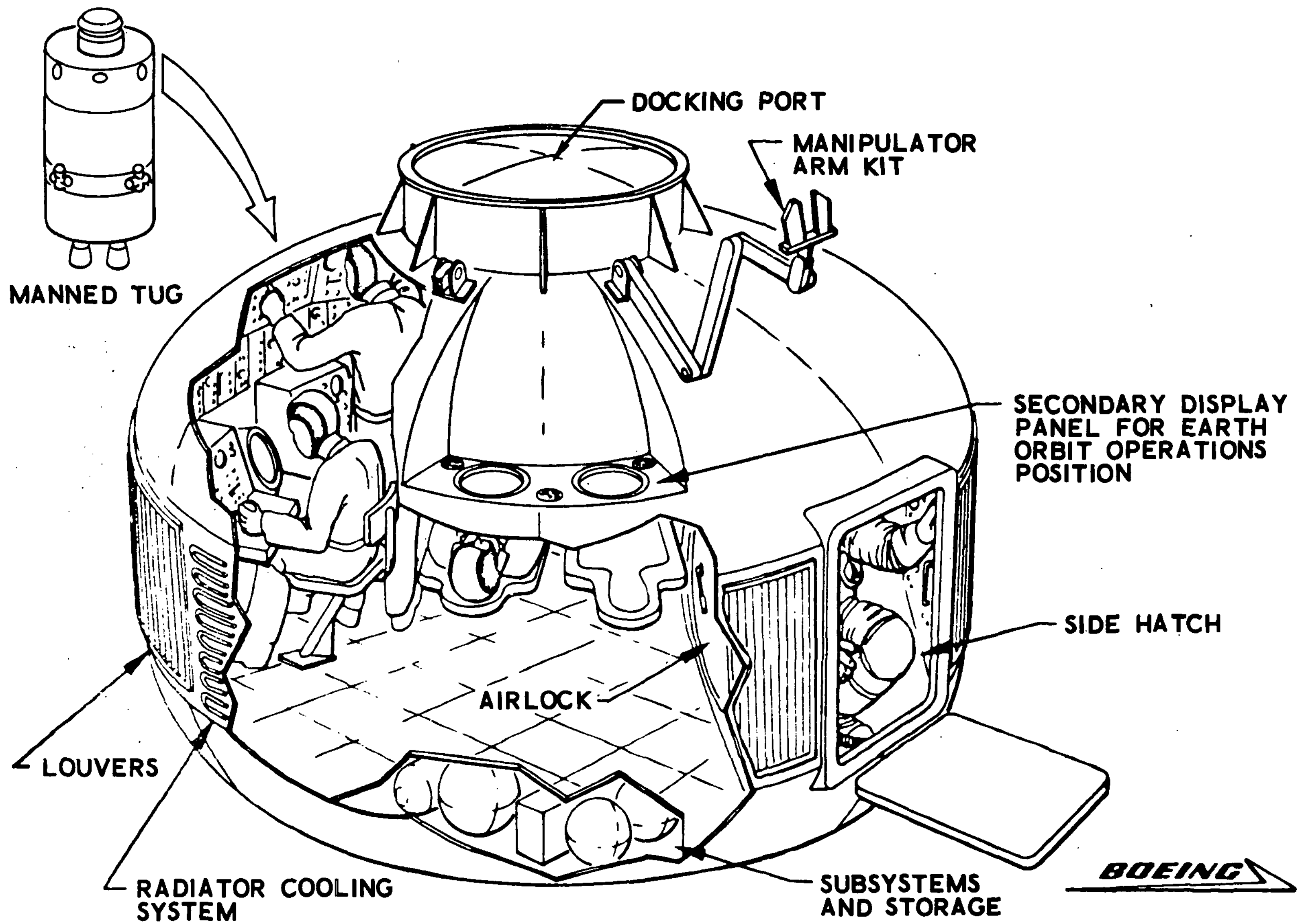
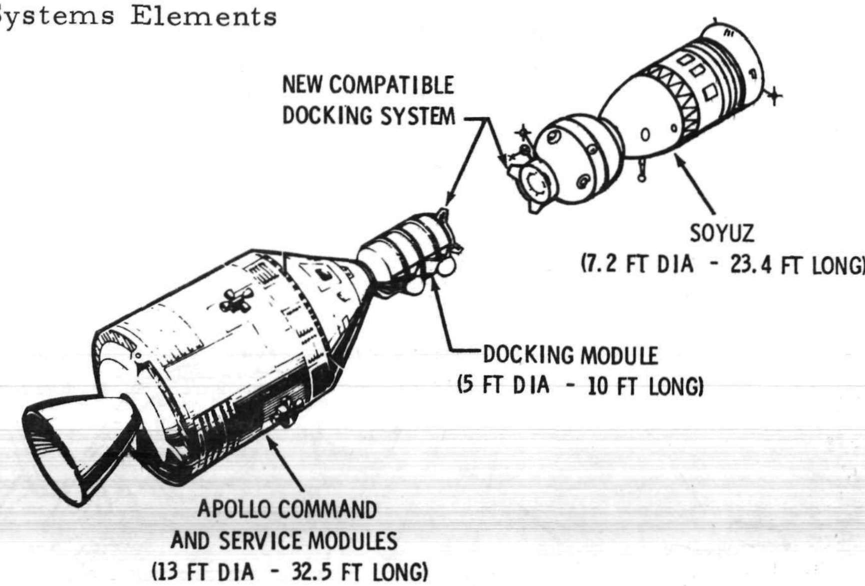


Figure B-6. Crew Module of Manned Space Tug

(a) Systems Elements



(b) Model of Docking Adapter

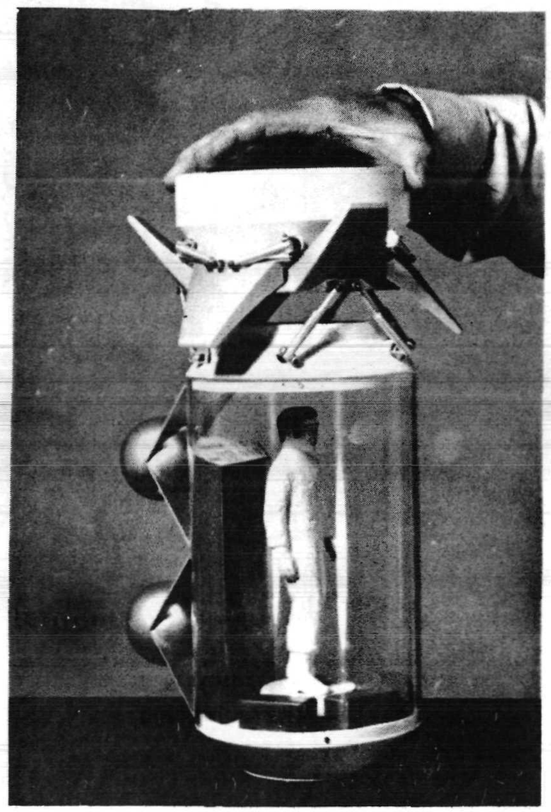


Figure B-7. Apollo-Soyuz Test Project

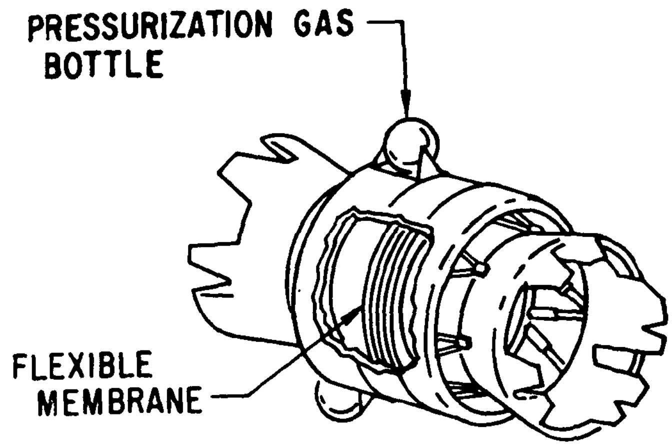


Figure B-8. Portable Airlock (Ref. 4)

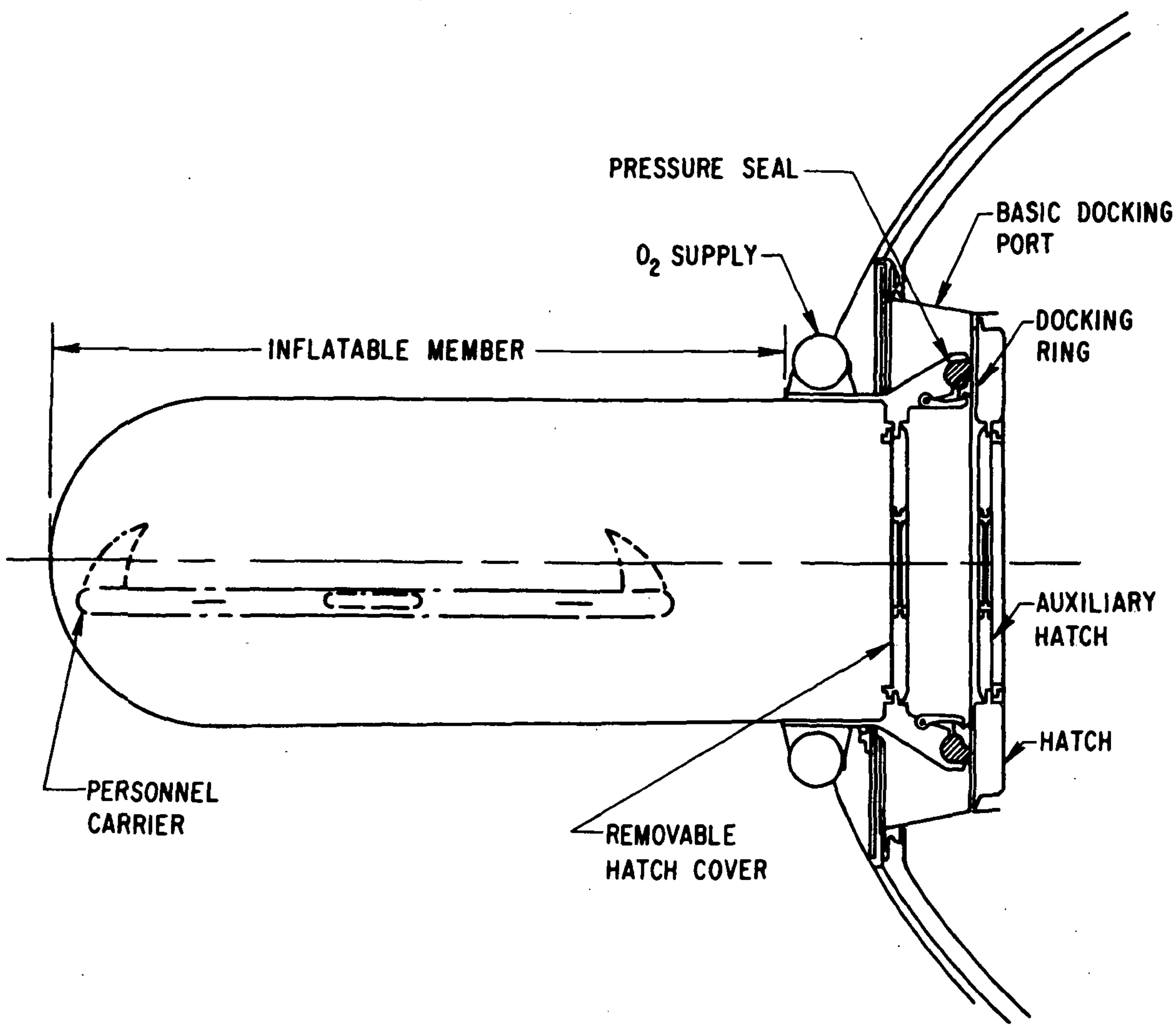


Figure B-9. Expandable Transfer Capsule (Ref. 4)

FAVORABLE FEATURES	UNFAVORABLE FEATURES
o DV crew self-dependent o Simple approach o Only DV crew goes into EVA o Useful with foreign S/C	o Requires suited DV crew o Limited to small standoff distance o Tether/umbilical restrains mobility o Operation limited to ~4 to 8-hour duration o Crew exposed to EVA hazards o Requires performance under stress o Moves one crewman at a time o Limited utility o Individual suit needed for each crewman o Requires handholds and mobility aids o Accommodates little if any injury or incapacitation o SRV needs facility for receiving EVA personnel o May take more than one attempt for success o Requires training

Figure B-10. Summary of Operational Characteristics (1 of 5)
(a) - Unassisted EVA

FAVORABLE FEATURES	UNFAVORABLE FEATURES
o DV crew self-dependent o Allows significant standoff distance (~2 to 4 km) o Improves crew mobility o Increased duration possible over Unassisted EVA o Available at DV for other applications o Only DV crew goes into EVA o Useful with foreign S/C	o Requires suited DV crew o Augmenting device carried by DV o Crew exposed to EVA hazards o Requires performance under stress o Moves one to two crewmen at a time o Individual suit needed for each crewman o Limited accommodation of injury or incapacities o SRV needs facility for receiving EVA personnel o Requires training o Operation limited to ~4 to 8 hours

Figure B-10. Summary of Operational Characteristics (2 of 5)
(b) - Augmented Unassisted EVA

FAVORABLE FEATURES	UNFAVORABLE FEATURES
o Allows large standoff distance (~2 km) o External aid provided o DV crew cooperation not essential o Moderate accommodation of injury or incapacitation o Multiplace possibilities o Useful with foreign S/C	o Requires suited DV crewman o DV crew exposed to EVA hazards o Also involves SRV crew in EVA o Moves one to two crewmen at a time o Individual suit needed for each crewman o SRV needs facility for receiving EVA personnel o Involves training and performance under stress o Operation limited to 4 to 8 hours

Figure B-10. Summary of Operational Characteristics (3 of 5)
(c) - Assisted EVA

FAVORABLE FEATURES	UNFAVORABLE FEATURES
o Shirtsleeve environment	o Based at SRV (usually)
o Accommodates entire DV crew	o Requires special operating skills
o May be able to dock to DV	o May require DV crew into EVA (if docking not feasible)
o Versatile (propulsion, manipulators, airlock)	o Large and heavy device
o Operational Vehicle developed for other applications	o Limited use with foreign S/C
o Can be based at DV (BOW, BOT)	
o Accommodates ill/injured crewman	
o Large standoff distance feasible (>2 km)	
o Long operating duration (~48 hours)	
o DV crew cooperation not essential	
o Externally provided aid	

Figure B-10. Summary of Operational Characteristics (4 of 5)
(d) - Pressurized Transfer Vehicle

FAVORABLE FEATURES	UNFAVORABLE FEATURES
o Developed for other uses o Accommodates unsuited DV crew o Accommodates ill/injured DV crewman o Allows moderate standoff distance (<2 km) o Moderate operating duration (8 to 24 hours)	o Based at SRV o Limited capacity (~2 men) o Requires external manipulation source o Must be delivered/attached to DV (generally) o May require DV crew into EVA (if attachment to DV not feasible) o Limited use with foreign S/C o Involves special SRV crew training o Usually involves SRV crew in EVA

Figure B-10. Summary of Operational Characteristics (5 of 5)
(e) - Special Purpose Devices