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SPACE RESCUE OPERATIONS

Volume III: Appendices

Prepared by
Systems Planning Division

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THE AEROSPACE CORPORATION
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PREFACE

This study was supported by NASA Headquarters and managed by the Advanced Missions Office of the Office of Manned Space Flight. Mr. Herbert Schaefer was the study monitor. Supported by Mr. Charles W. Childs of the NASA Safety Office, he provided guidance and counsel that significantly aided this effort.

The results of the study are presented in three volumes: Management Summary Report (Volume I), Technical Discussion (Volume II), and Appendices (Volume III).

The Management Summary Report (Volume I) presents a brief, concise review of the study content, and summarizes the principal conclusions and recommendations. The purpose of the Summary Report is to provide a condensed, easily assimilated overview for management.

The Technical Discussion (Volume II) is the principal volume in the series. It provides a comprehensive discussion of the problems of assuring crew and passenger safety in the post-Skylab Integrated Program. Operational procedures and the use of "standard" and specially-designed equipment are treated.

Much of the material presented in Volume II was derived through detailed analyses. These analyses and other backup material are presented in Volume III, Appendices. The contents of Volume III are of interest primarily to specialists in the areas discussed.

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MISSION MODEL AND HARDWARE DEFINITION

APPENDIX A

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MISSION MODEL AND HARDWARE DEFINITION

A. 1 GENERAL

The Integrated Program is based upon the multi-purpose use of basic hardware elements. These include:

1. A reusable Earth Orbit Shuttle, consisting of a Booster and an Orbiter, for crew rotation and passenger and cargo delivery into low earth orbit, and for delivery of experiments.
2. Space Station Modules with application as
   a. Low earth orbit space station
   b. Synchronous earth orbit space station
   c. Low earth orbit space base
   d. Orbiting lunar station
   e. Lunar surface base
   f. Mars exploration spacecraft
3. A Tug for Cargo Transfer in
   a. Earth orbit
   b. Lunar orbit
   c. Between lunar orbit and lunar surface (lunar lander)
4. A Space Shuttle either nuclear or chemically powered, for Cargo and Passenger Transfer between low earth orbit and
   a. Geosynchronous orbit
   b. Lunar orbit

A. 2 EARTH ORBIT MISSIONS

A. 2. 1 Low Earth Orbit

Both the Space Station and the Space Base are planned for a 270 n mi circular orbit at an inclination of 55°. Crew size for the station is between 6-12, whereas the crew size of the base is between 50 - 100. Periodic crew rotation and resupply are provided by the Earth Orbit Shuttle. Tugs stationed on-orbit aid in transfer of cargo, as required. Direct docking of the EOS to the station/base is via a crew/cargo module carried by the orbiter and equipped with a docking fixture. Cargo volume is nominally a 15-ft-diam cylinder, 60 ft long, and cargo weight is nominally 50,000 lb.

A. 2. 2 Geosynchronous Orbit

The Space Station in geosynchronous orbit is similar to the Low Earth Orbit Station. It is delivered to geosynchronous orbit and resupplied from low earth orbit by the space-based Space Shuttle. Tugs stationed in geosynchronous orbit aid in cargo transfer, as required.

A. 3 LUNAR MISSIONS

A. 3. 1 Orbiting Lunar Station

The Orbiting Lunar Station is derived from Low Earth Orbit Space Station hardware. It is assembled in low earth orbit (260 n mi, 31.5° inclination) and delivered to a 60 n mi lunar polar orbit by the Space Shuttle. Resupply and crew rotation are provided from low earth orbit via the Space Shuttle. Delivery into low earth orbit is by EOS. Tugs stationed in lunar orbit aid in cargo transfer and are also available for transportation between lunar orbit and the lunar surface.

A. 3. 2 Lunar Surface Base

The Lunar Surface Base is also derived from Low Earth Orbit Space Station hardware. Component delivery and assembly in low earth orbit depend upon EOS and Tug support. Delivery to lunar orbit is by Space Shuttle, and transfer from lunar orbit to the lunar surface is by a lunar tug. Resupply is provided via Tug from the Orbiting Lunar Station.

A. 4 PLANETARY MISSION

A Mars conjunction mission was selected for evaluation. Due to the advanced nature of the mission, little planning has been done and hardware and mission details are vague. An 8-man crew in a nuclear-powered vehicle employing buddy-system concepts was considered. Vehicle components were assumed to be delivered to low earth orbit by the EOS and then assembled. Propellant was also delivered by the EOS and then stored in an Orbiting Propellant Depot until the vehicle was fueled.

A. 5 SUMMARY OF INTEGRATED PROGRAM PLAN

The foregoing Integrated Program missions and hardware elements are summarized pictorially in Figure A-1. Also shown is the unmanned Saturn V (Int-21) and various unmanned planetary probes which were not part of the present study. Although a Space Shuttle with nuclear propulsion is illustrated, the decision between nuclear and chemical propulsion has not yet been made.

A listing of documents reviewed (Ref. A-1 through A-10) follows.

References*

A-1. Space Station Program Description Document (March 1970).

A-2. Space Station Program Definition - Phase B (24 April 1970).

A-3. "Overview of NASA's Space Station Program" AAS Paper No. 70-020 (June 1970).

A-4. 1971 NASA Authorization Hearings Before The Committee on Science and Astronautics, U. S. House of Representatives, Feb. 1970.

A-5. Space Shuttle Program Requirements Document (1 July 1970).

A-6. Space Tug Program Description Document (24 April 1970).

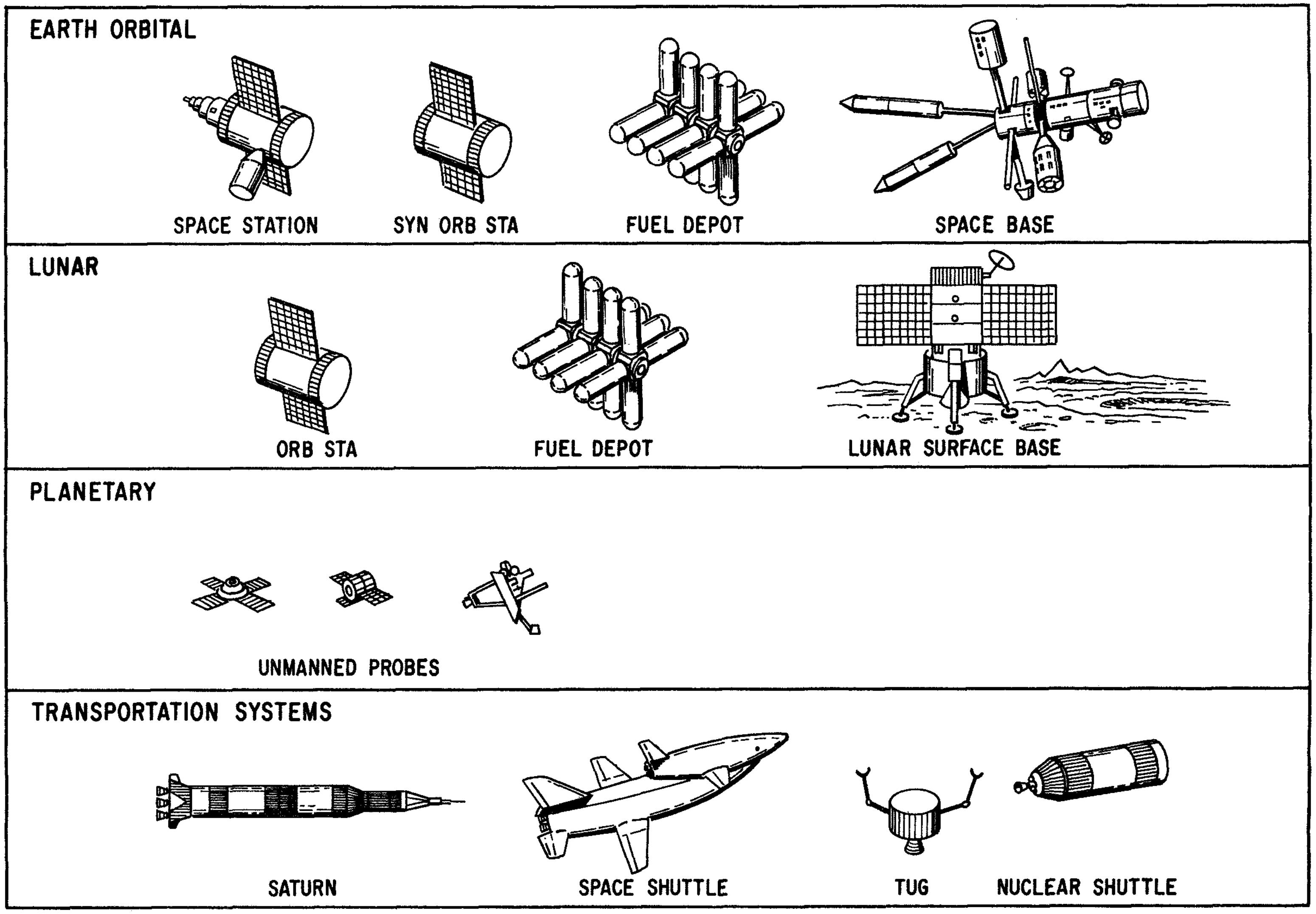
A-7. Orbiting Lunar Station Program Description Document (April 1970).

A-8. Lunar Surface Base Program Description Document (15 June 1970).

A-9. Project Description Document - Nuclear Stage, Vol. I (13 April 1970).

A-10. Manned Mars Exploration Program Description Document (20 March 1970).

*NASA Documents unless otherwise specified.



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HAZARDS SURVEY AND EMERGENCY IDENTIFICATION ANALYSES

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APPENDIX B

HAZARDS SURVEY AND EMERGENCY IDENTIFICATION ANALYSES

B.1 GENERAL*

Hazards and resulting emergency situations applicable to the Integrated Program are summarized in Volume II. The purpose of this appendix is to present the more extensive results of (1) a literature survey of space hazards and (2) those supporting analyses upon which the material in Volume II is based.

The objectives of this effort were to:

1. Analyze the gross safety hazards to crew and passengers inherent in the proposed hardware concepts for, operations of, and interactions between major elements of the Integrated Program
2. Analyze potential emergency situations and isolate, where possible, those emergencies unique to various phases of the Integrated Program (IP).

In meeting the foregoing objectives, an approach was utilized consisting of the following essential steps:

1. Identify the operations and operational events required by any IP element in performing basic mission objectives
2. Collect and review the data base relevant to manned space flight hazards
3. Identify, categorize, and summarize those hazards resulting from the data review
4. Identify the potential IP emergency situations which may exist due to the occurrence of a hazard.

A major study guideline limited the hazards review to those hazards pertinent to orbital or space operations. Thus, operations related to pre-launch, launch, ascent, and reentry were not considered. Further, the hazards analysis effort was restricted to a review and updating of previous study results which

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*This Appendix is based on work by M. Hinton and N. Campbell.

are applicable to the currently projected Integrated Program. Consideration of the probability of occurrence of any given hazard was beyond the scope of the analysis.

B.2 MISSION OPERATIONS ANALYSIS

B.2.1 General

The specific objective of this subtask was to identify the operations and operational events required by an IP element in performing its basic mission objectives. This objective was met by developing functional block diagrams identifying all major sequences of operations, with particular emphasis on the interactions between various vehicles. From these block diagrams the operational events that may involve hazards were identified.

B.2.2 Results

B.2.2.1 Missions/Operations Examined

Figure B-1 summarizes the spectrum of missions/operations examined. Figures B-2 through B-13 are functional block diagrams depicting the basic mission operations required for each of the elements of Figure B-1. Tables B-1 through B-5 are a listing of operational phases and their associated detailed on-orbit operations for selected vehicles.

For example, Figure B-3 illustrates all of the top-level functional operations required of the earth orbit shuttle (EOS) in performing the mission objectives presently defined for the EOS, from pre-launch operations through ascent to orbit, orbit operations, and reentry and landing operations. Table B-1 is a summary listing of the orbit operations of the EOS (present study restricted to on-orbit periods) together with those operational phases/events required in performing the orbit operations (orbit change, docking, transfer, etc.).

B.2.2.2 Basic Mission Operational Phases/Events

Inspection of Tables B-1 through B-5 indicates that in order to perform the multiplicity of space operations required for the various Integrated Program missions, there are a number of "basic" phases or events which are required after placement and/or assembly and checkout in a desired space position. As can be seen in Figure B-14, these "basic" operational phases/events range from the standard or nominal "on-orbit" (or "on-surface") operating mode to such unique requirements as retrieval/recovery operations, or hardware disposal operations.

For the manned vehicles of the Integrated Program, Table B-6 summarizes in matrix format the required operational phases as a function of space placement (mission). As can be seen, the space tug and the nuclear shuttle are required to perform in many of the basic operational phases in a variety of space placement scenarios. It should be noted that the nuclear shuttle is in essence a "space shuttle" which provides transportation to/from low earth orbit and the geosynchronous and lunar orbits. Such a "space shuttle" could be chemically-fueled instead of the nuclear shuttle used as a reference system herein.

B.2.3 Summary

The analysis of space operations and operational phases/events via functional block diagrams has shown that all of the manned orbital vehicles in the Integrated Program utilize certain basic planned operational phases in performing their designated missions. These basic phases include:

1. On-orbit
2. Orbit change
3. Docking
4. Transfer (crew/cargo/payload/fuel/etc.)

Orbit-to-orbit transfer vehicles (such as nuclear shuttle, space tug, manned Mars vehicle) utilize the additional phases of:

1. Injection into the transfer trajectory
2. Arriving orbit insertion

Orbit-to-surface transfer vehicles (lunar landing tug, manned Mars landers) also utilize the phases of descent/ascent to/from surface.

Deorbit (from low earth orbit) is unique to the EOS, while retrieval/recovery is unique to the manned Mars vehicle (MMV) unless the final plan calls for direct earth entry for the MMV.

Disposal operations are not unique to the nuclear shuttle. If nuclear power sources are used for the space station, both the station and the tug would be involved in disposal operations.

B. 3 HAZARDS ANALYSIS

B. 3. 1 General

The particular objectives of the hazards analysis effort were (1) to review the applicable gross hazard information contained in the reference data base and (2) to systematically collect, integrate, and categorize gross hazards as to source. In this regard, hazards were treated as "discrete forcing functions or events which can lead to situations affecting life and/or well-being of crew or passengers."

It was recognized that a number of "hazard categories" had been defined by NASA (Ref. B-1). These categories (safety catastrophic, safety critical, safety marginal, and safety negligible) are summarized in Figure B-15. The hazards review of the present study was limited to the catastrophic and critical hazard categories since the marginal and negligible categories do not lead to the requirement for escape or rescue, the primary subject of this study.

B. 3. 2 Data Base

A literature survey of studies either specifically concerned with the problem of space safety of treating safety as an adjunct to examintion/delineation of space hardware (e. g., space station) revealed twelve relevant studies conducted by ten companies/agencies in the 1963-1970 period. The particular companies/agencies are identified in Table B-7 and the specific studies are noted as Refs. B-2 through B-13.

B.3.3 Results

B.3.3.1 Specific Hazards Listings

Figures B-16 through B-28 and Tables B-8 through B-15 summarize the salient results from each of the studies noted above (Refs. B-2 through B-13).

As can be noted by observation, some analyses were restricted to single hardware elements and/or missions (e.g., space station studies) while others encompassed a wide range of missions/equipments. Similarly, it is observed that numerous terms were used to describe hazards:

- Emergency situations
- Abort situations
- Causes of crew loss
- Hazard threats
- Hazards
- Hazard events
- Credible accidents

This varied terminology appears to be the result of the particular identification technique employed (failure analyses, operations analyses, examination of space environment effects, examination of man's basic needs) and whether the analysis was made to determine cause (the forcing function) or effect (the result of the occurrence of the forcing function). However, when treating the term "hazard" as the causative factor whose occurrence leads to a situation wherein the life or well-being of crew or passengers is adversely affected, the variously-described factors identified by the numerous observers can be shown to have considerable commonality.

Table B-16 illustrates this commonality feature by comparing the "hazards" listings of several of the reference studies. While some listings are restricted (due to the identification technique employed), the overall summation of specific hazards and hazard groups indicates a definite consensus based on a wide range of hazard identification approaches.

B. 3. 3. 2 Consolidated Hazards Listing

Inspection of Figures B-16 through B-28 and Tables B-8 through B-15 indicates that the basic space hazards can be segregated as to those (1) internal to a given space vehicle and (2) those external to a given space vehicle. Figure B-29 summarizes the basic internal hazards and Figure B-30 summarizes the basic external hazards. These two groups are combined in Figure B-31 to present an overall hazards listing applicable to vehicles/missions of the Integrated Program.

It should be pointed out that the hazards shown are not mutually exclusive, and that the occurrence of one may trigger or cause the occurrence of another. This is particularly true of basic subsystem malfunctions; e.g., where loss of electrical power could lead to a variety of other hazards.

B. 3. 4 Summary

A review of twelve different studies relating to the hazards of manned space flight has indicated a consensus as to those gross hazards which may be faced. Comparison of the missions/hardware elements of the Integrated Program to the previously-identified spectrum of hazards indicates that this spectrum is also applicable to the Integrated Program.

Although there was a diversity of nomenclature in defining or categorizing "hazards," when the hazard is viewed as a causative factor there is excellent agreement as to the overall spectrum of hazards as listed in Figure B-31.

B. 4 EMERGENCY SITUATION IDENTIFICATION

B. 4. 1 General

The specific objectives of this subtask were to (1) identify those gross or general potential emergency situations applicable to the Integrated Program and (2) to identify, if possible, those emergencies unique to various phases of the Integrated Program.

The approach followed in this regard consisted of two basic steps. First, the gross hazards as identified in Figure B-31 were converted into gross emergency situations by observing the effect resulting from the occurrence of each hazard. Second, these gross emergency situations were compared to each manned IP element and operational phase for a subjective determination of applicability.

B.4.2 Results

B.4.2.1 Gross Emergency Situations

As mentioned, the previously-defined gross hazards were examined to determine the effect of the occurrence of the hazard. These resultant effects were grouped as generic situations with which a matrix of resulting emergency situations versus hazards was developed, Table B-17. Each gross hazard event was assumed to be a non-catastrophic discrete event (no chain reactions).

Based on this matrix checklist, the final summary of emergency situations is as shown in Figure B-32. As can be noted, the situations apply in general to IP elements, except for the "inability to reenter" category which applies only to the EOS.

B.4.2.2 Situation/Mission Phase Matrices

As a further check on the general validity of the resulting emergency situations the relationship between emergency and mission phase was identified. This interrelation is subjective in nature, and although providing some insight into the likelihood of emergency/operational phase interaction, does not provide any basis for quantifying the probability of occurrence.

A summary of the applicability, by hardware element, of the selected emergency situation categories to the various Integrated Program missions is summarized in Table B-18.

B. 4. 3 Summary

As indicated in Table B-18, the selected typical gross emergency situations apply in "general" to all mission orbits and IP hardware elements except for:

1. "Unable to Reenter Earth's Atmosphere"
2. "Out-of-Control Spacecraft"

The "unable to reenter" category is unique to the EOS (mission/hardware peculiar); however, it would apply to the MMV also if direct reentry is chosen for this program.

The "out-of-control" category is also restricted. "Tumbling" does not apply to surface-based vehicles (LSB, tug on lunar surface). "Decaying orbit" probably applies to all orbits except geosynchronous. "Unsafe trajectory" does not apply to stable orbits.

B. 5 CONCLUSIONS

As delineated above, the hazards facing the IP program are generally similar to those previously identified in space safety studies. Although unique nuclear components (power generation, propulsion, radioisotope heaters and experiments) and unique equipment operation (X-ray machines, laser projections, etc.) may introduce new hazardous equipment, the basic hazard sources have not changed (equipment failure, hostile environment, personnel error, etc.).

Hazards (as causes)have often been confused with the resulting emergency (effect). The gross emergency situations identified herein (the result of the occurrence of a hazard) apply "in general" to all missions and hardware elements of the IP (except as restricted in Section B. 4. 3).

The specific quantitative requirements necessary to deal with any given emergency situation obviously depend quite strongly upon the specific mission, hardware element, and phase of the mission. These factors combine with the occurrence of a hazard as a causative factor to describe the specific needs to alleviate the emergency.

In general, however, it can be seen from the foregoing hazards analysis that any vehicle called upon to provide rescue capability should be able to supply

1. A habitable haven
2. Medical aid
3. Life support
4. A communication function
5. Emergency power
6. Transportation from the scene of the emergency to a final haven of safety

and may need capability for

1. Collision avoidance
2. Radiation protection
3. Docking to a disabled spacecraft
4. Arresting a tumbling spacecraft
5. Retrieving personnel (EVA, spacecraft)

Appendix B

References

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- o Int 21
- o Earth Orbit Shuttle
- o Space Tug
  - Earth Orbit
  - Lunar
- o Nuclear Shuttle
  - Synchronous Orbit
  - Lunar Orbit
- o Space Station/Base
  - Earth Orbit
  - Synchronous Orbit
  - Lunar Orbit
- o Propellant Depot
  - Earth Orbit
  - Lunar Orbit
- o Lunar Surface Base
- o Mars Mission

Figure B-1. Mission/Operations Examined

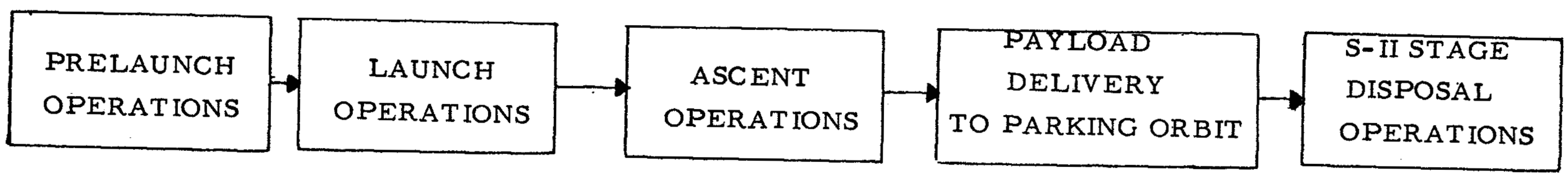


Figure B-2. Saturn V Int-21 Mission Operations

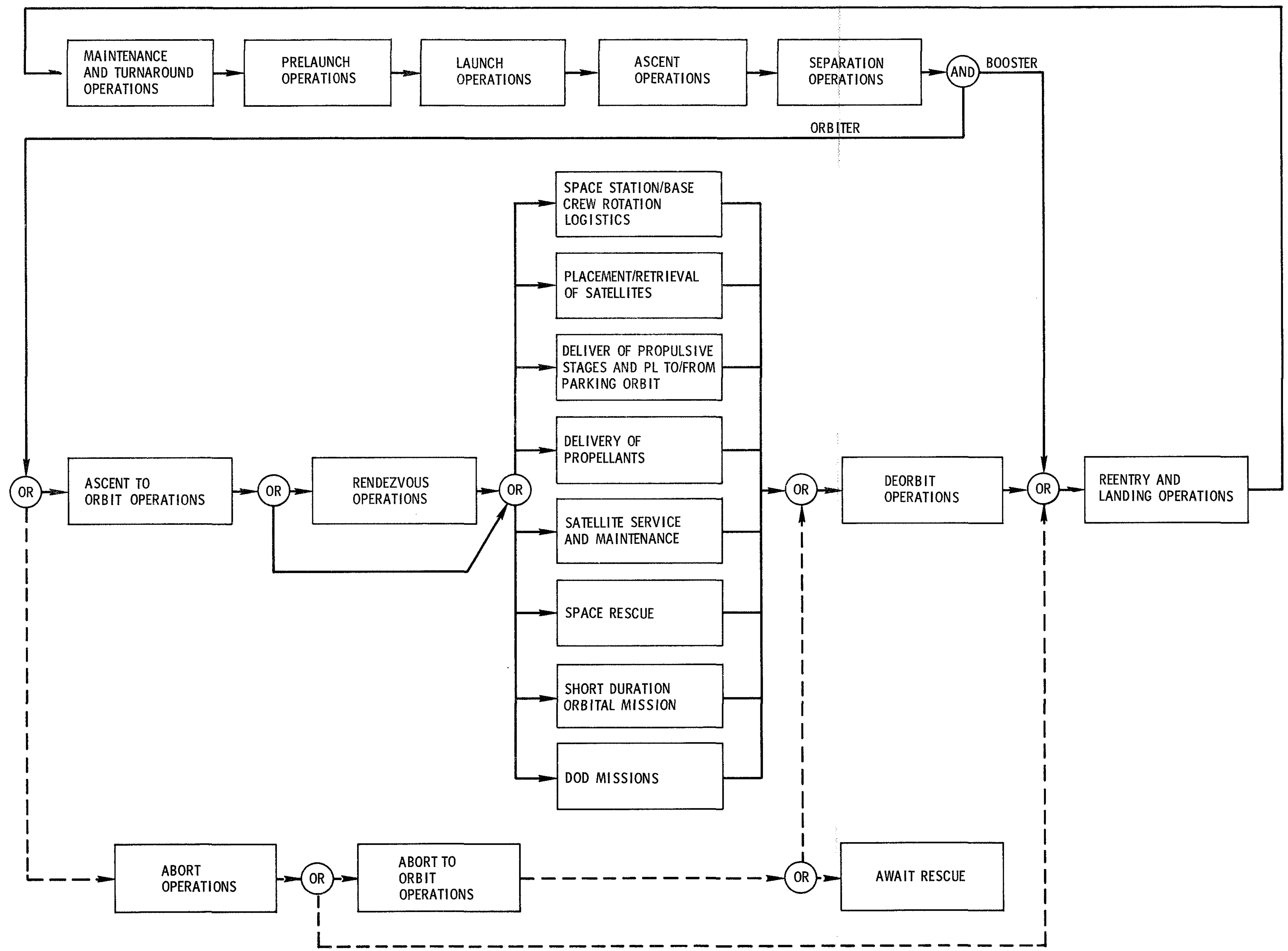


Figure B-3. EOS Mission Operations

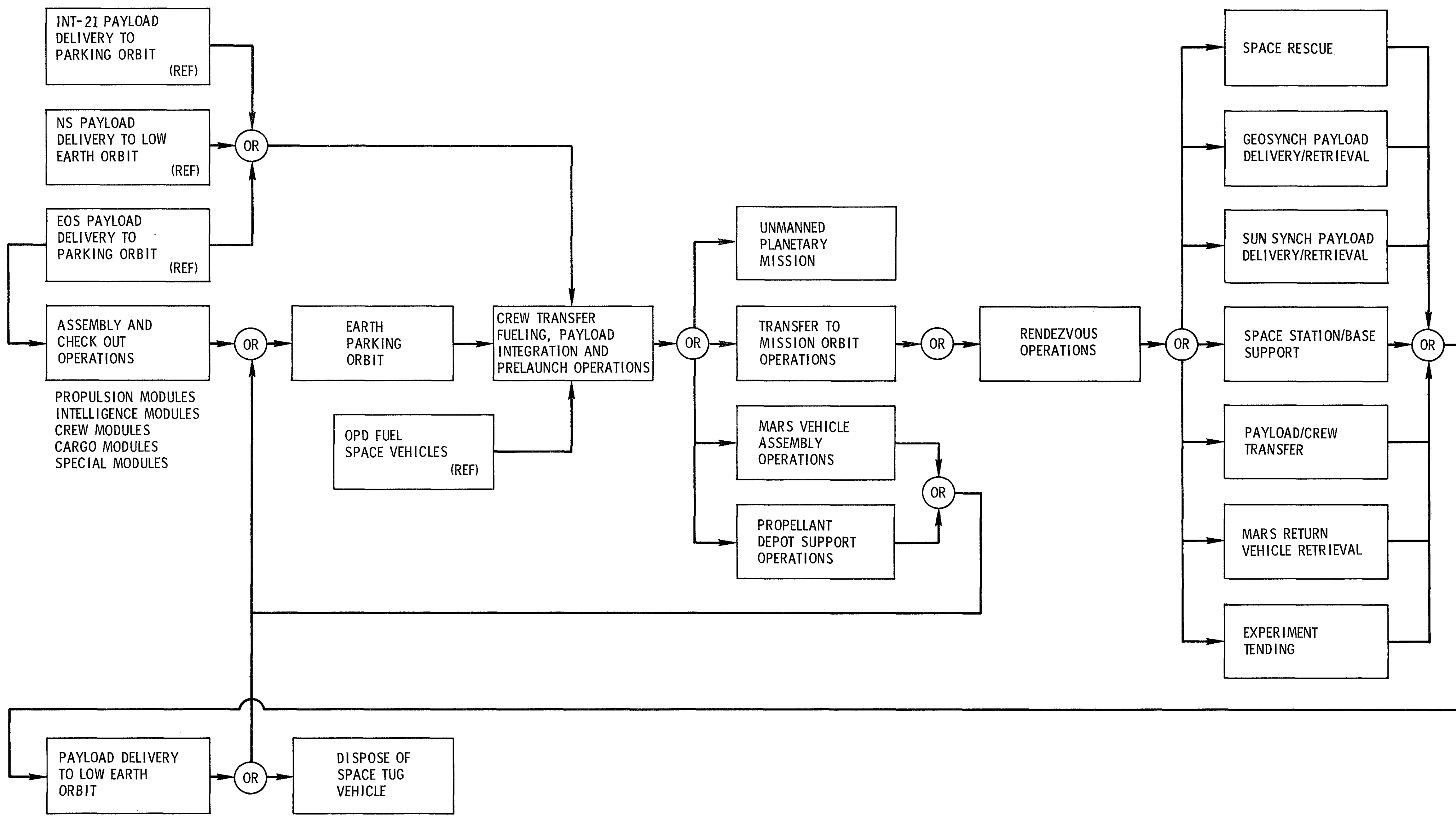


Figure B-4. Space Tug: Earth Orbit Mission Operations

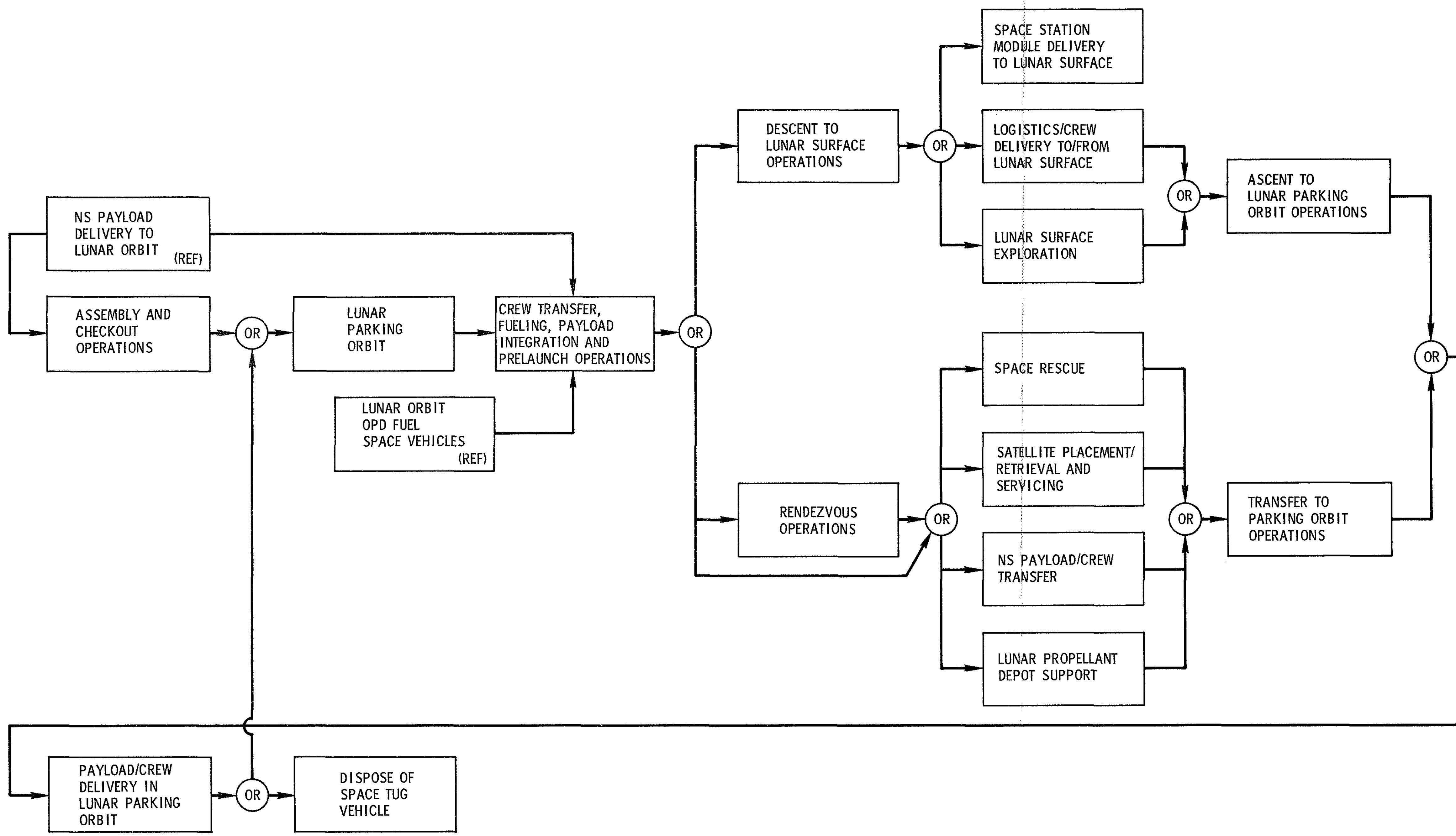
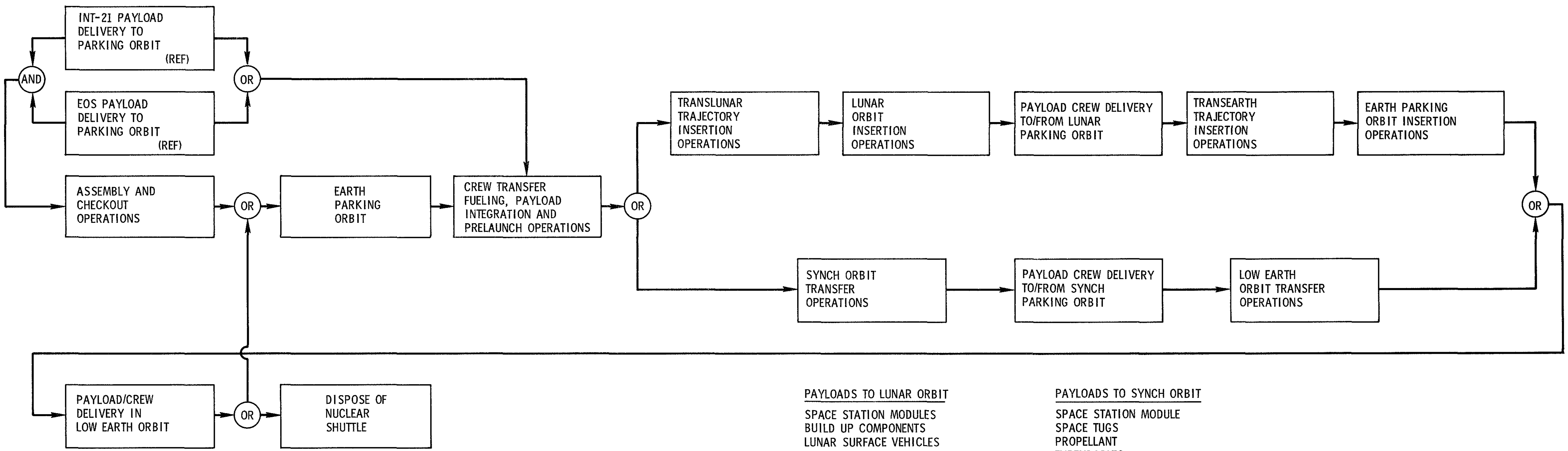


Figure B-5. Space Tug: Lunar Mission Operations



PAYLOADS TO LUNAR ORBIT

SPACE STATION MODULES
BUILD UP COMPONENTS
LUNAR SURFACE VEHICLES
SPACE TUGS
PROPELLANT DEPOTS
EXPENDABLES
PERSONNEL
EXPERIMENTS

PAYLOADS TO SYNCH ORBIT

SPACE STATION MODULE
SPACE TUGS
PROPELLANT
EXPENDABLES
PERSONNEL
EXPERIMENTS

Figure B-6. Nuclear Shuttle Mission Operations

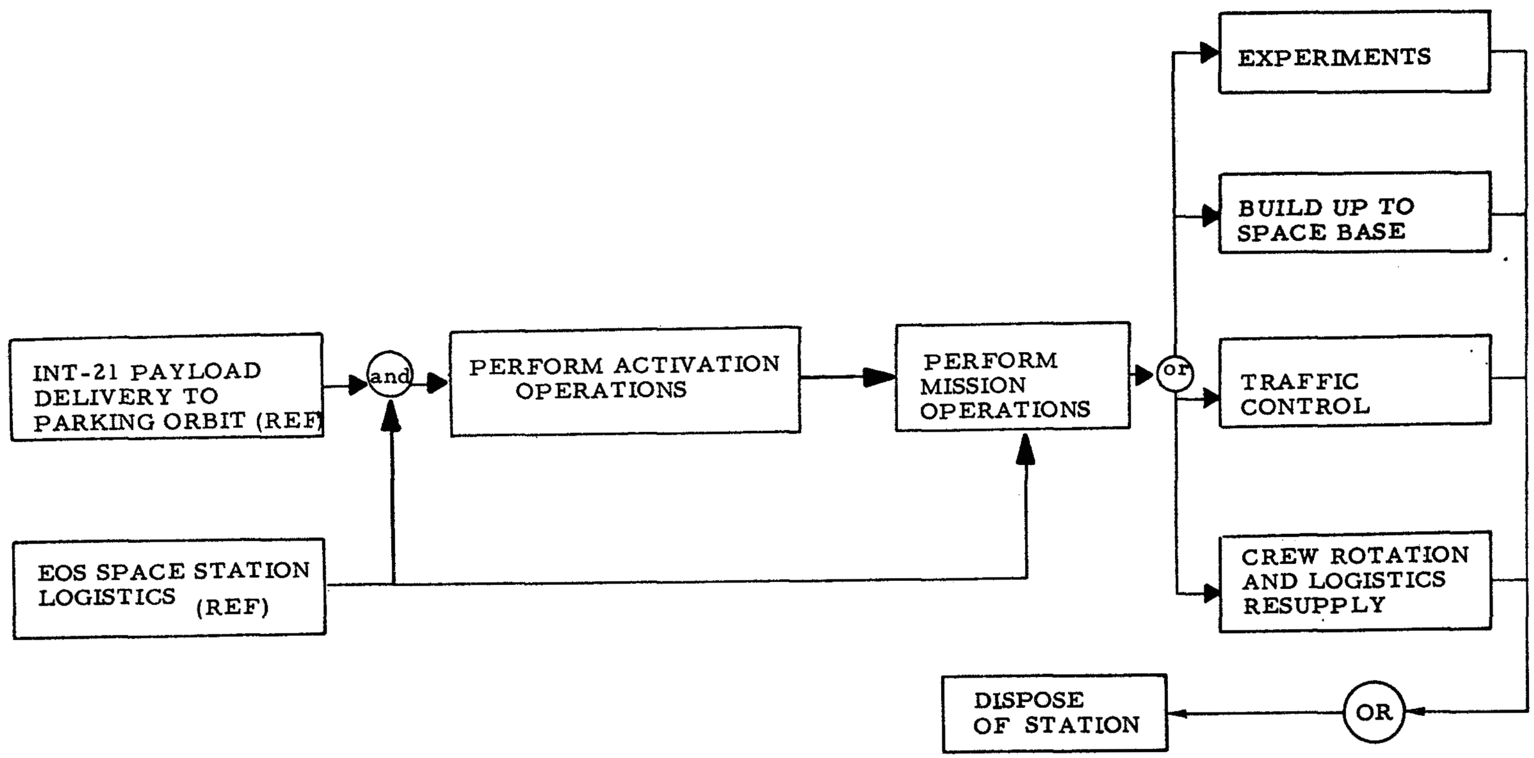


Figure B-7. Space Station/Base Mission Operations

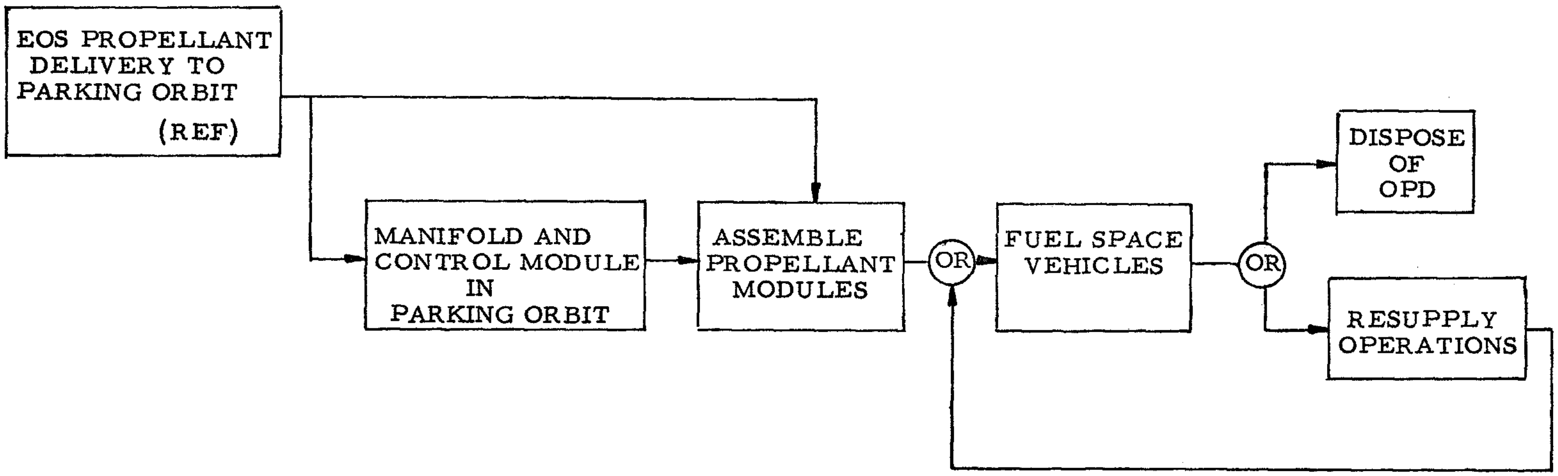


Figure B-8. Earth Orbit Propellant Depot Mission Operations

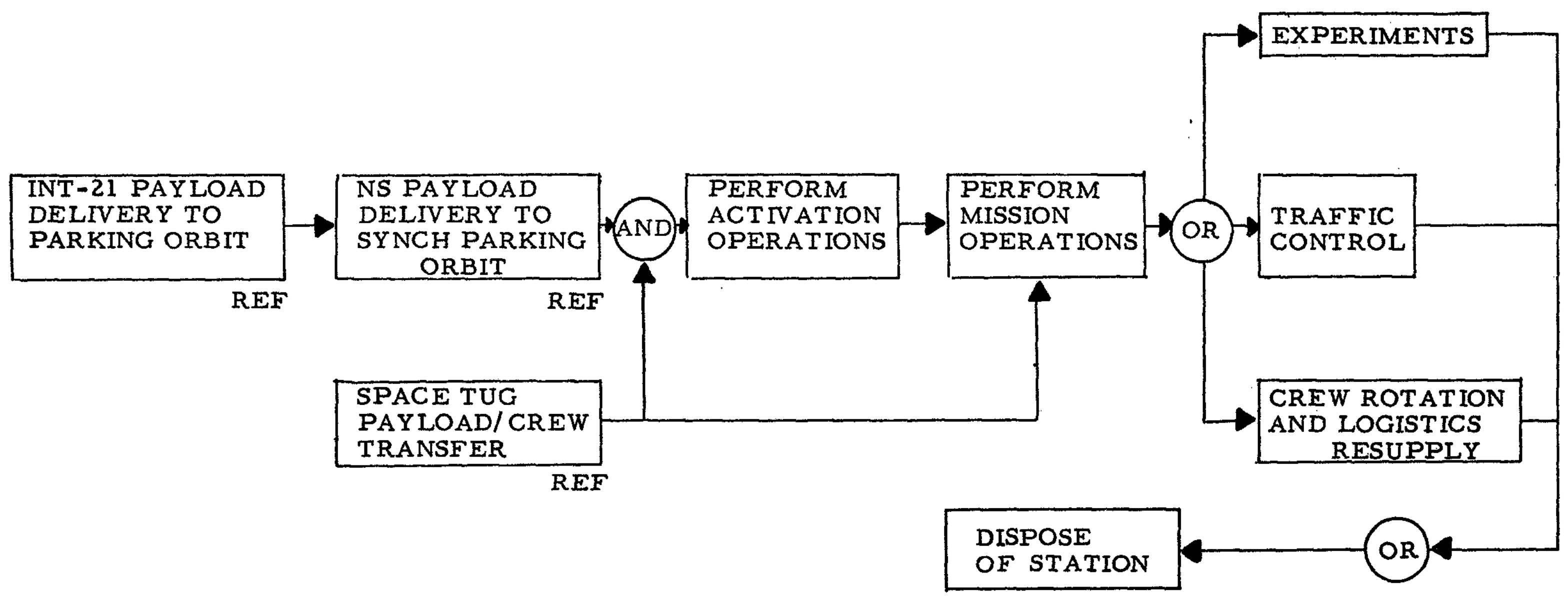


Figure B-9. Synchronous Orbit Space Station Mission Operations

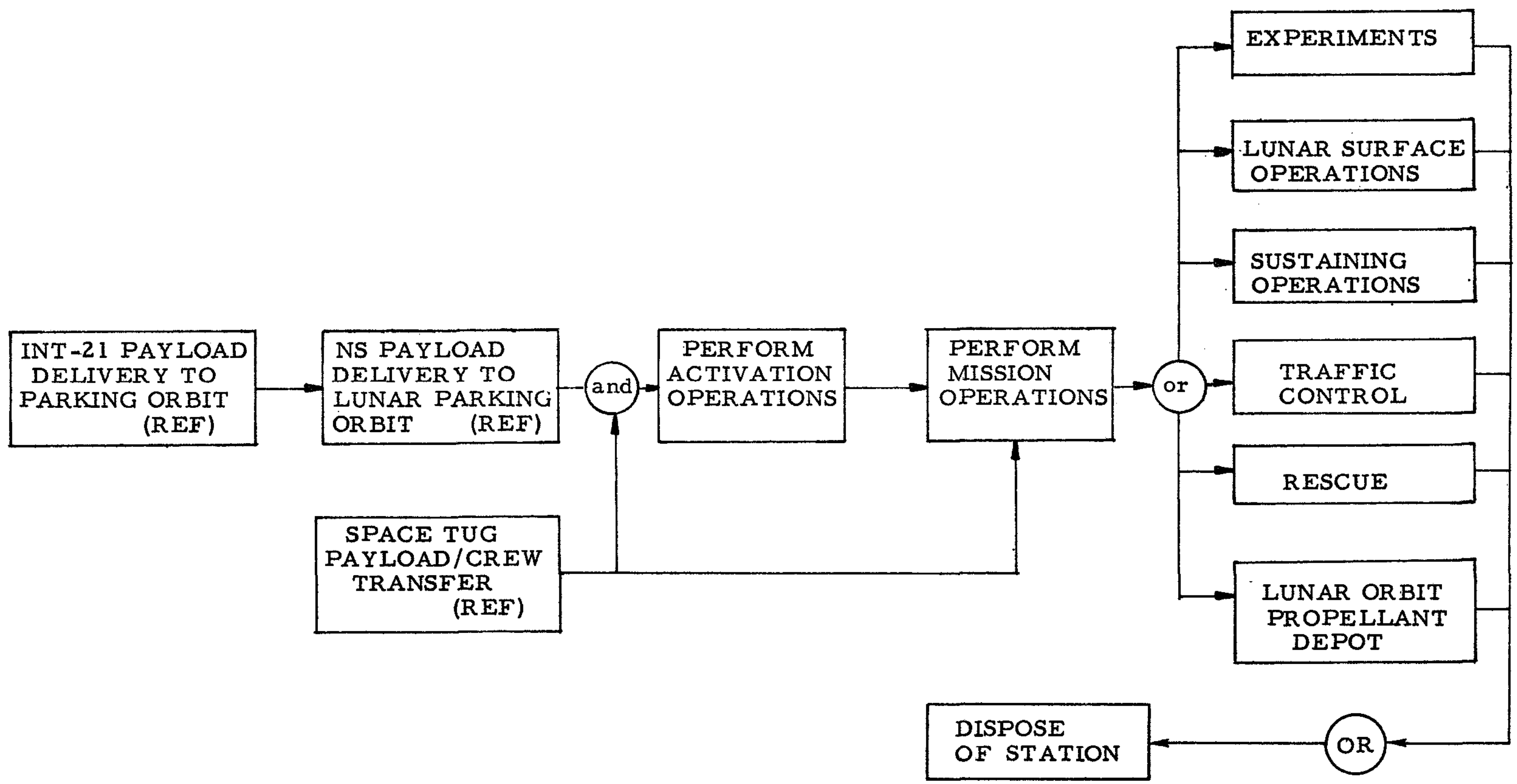


Figure B-10. Lunar Orbit Space Station Mission Operations

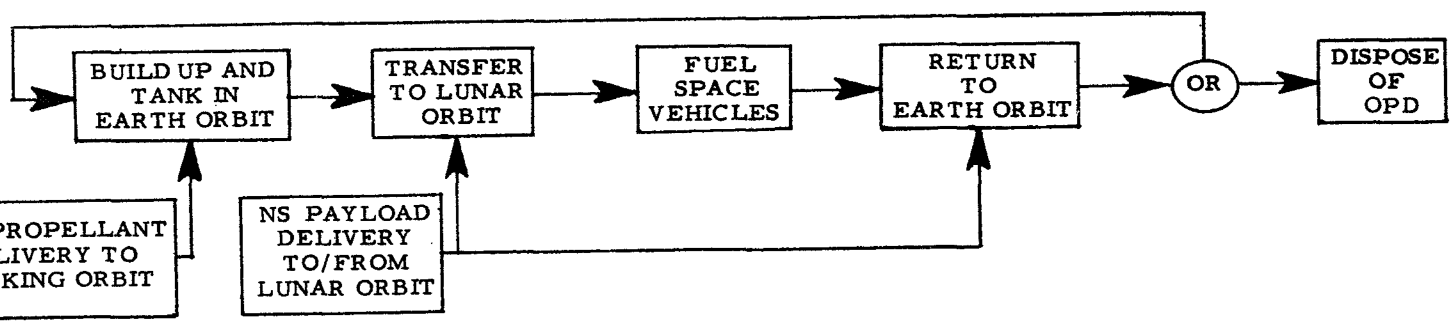


Figure B-11. Lunar Orbit Propellant Depot Mission Operations

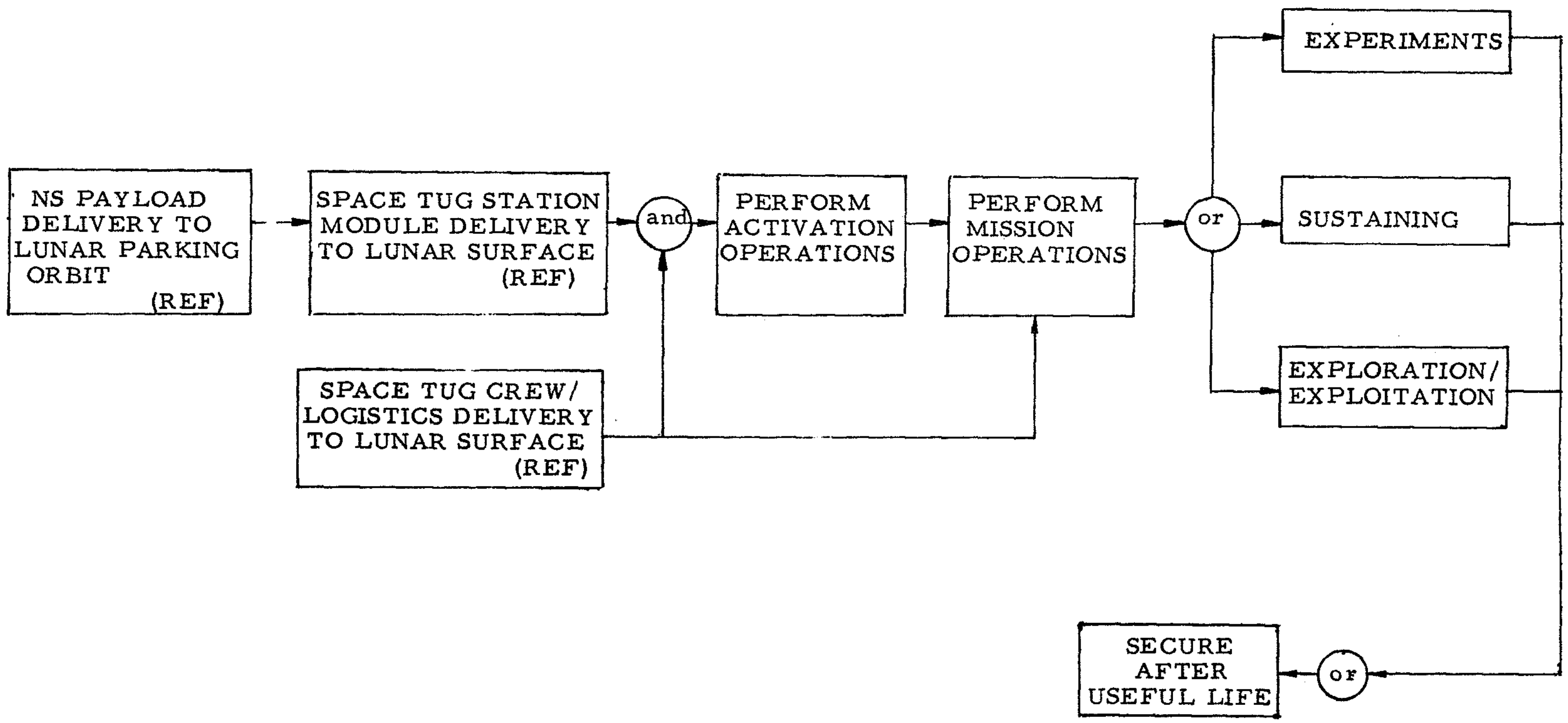


Figure B-12. Lunar Surface Base Mission Operations

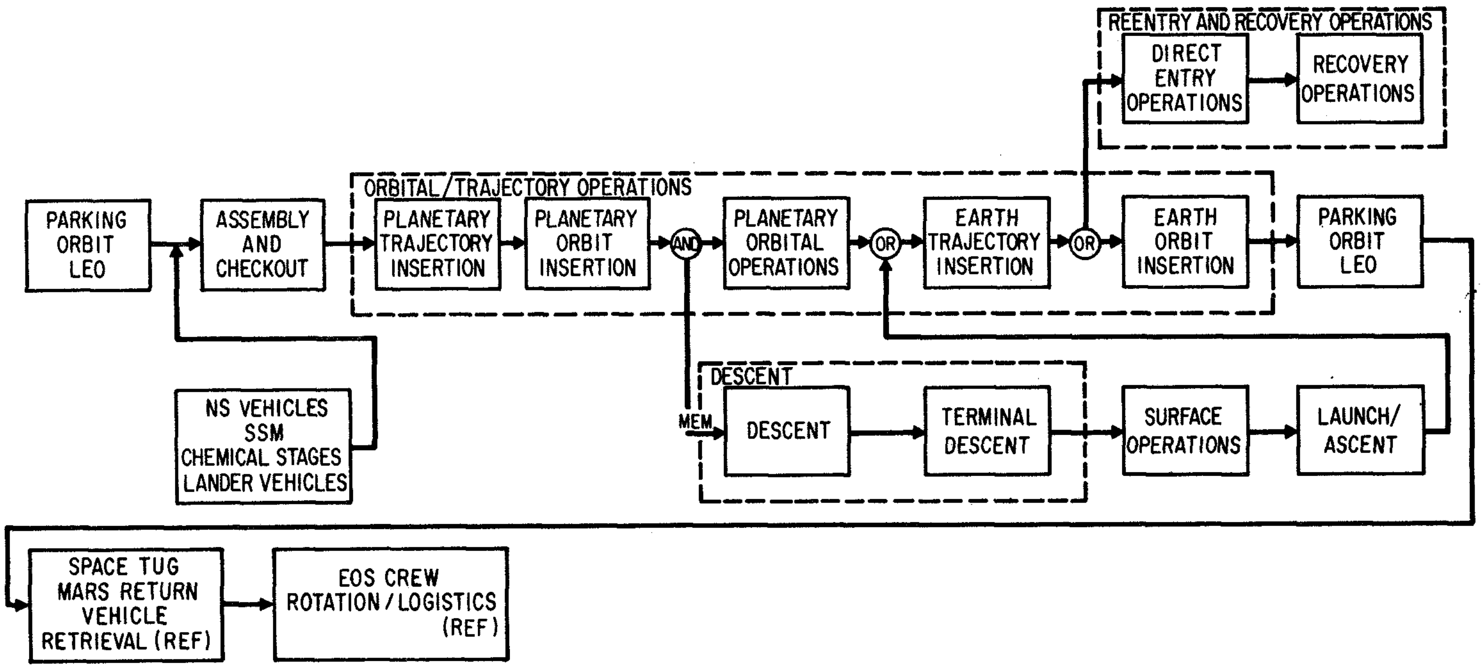


Figure B-13. Typical Planetary Mission

Table B-1. EOS Mission Operations/Phases

OPERATIONAL PHASES	ORBIT OPERATIONS
• ON-ORBIT	• CREW ROTATION/LOGISTICS (SPACE STATION/BASE)
• ORBIT CHANGE	• SATELLITE PLACEMENT/RETRIEVAL
• DOCKING	• SATELLITE SERVICE/MAINTENANCE
• TRANSFER CREW/CARGO/ETC.	• PROPELLANT DELIVERY
• DE-ORBIT	• DELIVERY OF PROPULSIVE STAGES AND PL TO/FROM PARKING ORBIT
	• SHORT DURATION ORBITAL MISSION
	• DOD MISSIONS
	• SPACE RESCUE

Table B-2. Space Tug: Earth Orbit Mission Operations/Phases

OPERATIONAL PHASES	ORBIT OPERATIONS
	• CREW TRANSFER, FUELING, PAYLOAD INTEGRATION AND PRELAUNCH OPERATIONS
• ON-ORBIT	• UNMANNED PLANETARY MISSION
	• MARS VEHICLE ASSEMBLY OPERATIONS
• ORBIT CHANGE	• PROPELLANT DEPOT SUPPORT OPERATIONS
	• SPACE STATION/BASE SUPPORT
• DOCKING	• PAYLOAD/CREW TRANSFER
	• EXPERIMENT TENDING
• TRANSFER CREW/CARGO/ETC.	• MARS RETURN VEHICLE RETRIEVAL
	• GEO SYNCH PAYLOAD DELIVERY/RETRIEVAL
• TUG DISPOSAL (AFTER USEFUL LIFE)	• SUN SYNCH PAYLOAD DELIVERY/RETRIEVAL
	• SPACE RESCUE
	• PAYLOAD DELIVERY TO LOW EARTH ORBIT

Table B-3. Space Tug: Lunar Mission Operations/Phases

OPERATIONAL PHASES	ORBIT OPERATIONS
• ON-ORBIT	• CREW TRANSFER , FUELING, PAYLOAD INTEGRATION AND PRELAUNCH OPERATIONS
• ORBIT CHANGE	• SPACE BASE DELIVERY TO LUNAR SURFACE
• DOCKING	• LOGISTICS/CREW DELIVERY TO/FROM LUNAR SURFACE
• TRANSFER CREW/CARGO/ETC.	• SATELLITE PLACEMENT/RETRIEVAL AND SERVICING
• DESCENT TO LUNAR SURFACE	• NS PAYLOAD/CREW TRANSFER
• ON SURFACE	• LUNAR PROPELLANT DEPOT SUPPORT
• ASCENT TO LUNAR PARKING ORBIT	• SPACE OR LUNAR SURFACE RESCUE
• TUG DISPOSAL (AFTER USEFUL LIFE)	

Table B-4. Nuclear Shuttle Mission Operations/Phases

OPERATIONAL PHASE		ORBIT OPERATIONS
LUNAR ORBIT	SYNCH ORBIT	
• ON-ORBIT (EARTH PARK ORBIT)	• ON-ORBIT (EARTH PARK ORBIT)	• CREW TRANSFER, FUELING, PAYLOAD INTEGRATION, AND PRELAUNCH OPERATIONS
• TRANSLUNAR TRAJECTORY INSERTION	• SYNCH TRAJECT. INSERTION	• PAYLOAD/CREW DELIVERY TO/FROM LUNAR PARKING ORBIT - STATION MODULES - COMPONENTS - LUNAR SURFACE VEHICLE - SPACE TUGS - PROPELLANT DEPOT - EXPENDABLES - PERSONNEL - EXPERIMENTS
• LUNAR ORBIT INSERTION	• SYNCH ORBIT INSERTION	• PAYLOAD/CREW DELIVERY TO/FROM SYNCH PARKING ORBIT - STATION MODULES - SPACE TUGS - PROPELLANT - EXPENDABLES - PERSONNEL - EXPERIMENTS
• ORBIT CHANGE	• ORBIT CHANGE	• SPACE RESCUE
• DOCKING	• DOCKING	
• TRANSFER CREW/CARGO/ETC.	• TRANSFER CREW/CARGO/ETC	
• TRANSEARTH TRAJECTORY INSERTION	• RETURN TRAJECTORY INSERTION	
• EARTH PARKING ORBIT INSERTION	• EARTH PARKING ORBIT INSERTION	
• NS DISPOSAL	• NS DISPOSAL	

Table B-5. Manned Mars Vehicle Mission Operations/Phases

OPERATIONAL PHASES	ORBIT OPERATIONS
• EARTH PARKING ORBIT	• CREW TRANSFER, FUELING, PAYLOAD INTEGRATION AND PRELAUNCH OPERATIONS
• ORBIT CHANGE	• EXPERIMENTS
• DOCKING	• SUSTAINING
• TRANSFER CREW/CARGO, ETC.	• EXPLORATION
• PLANETARY TRAJECTORY INSERTION	
• PLANETARY ORBIT INSERTION	
• ON PLANETARY ORBIT	
• DESCENT (TO SURFACE) (MEM)	
• ASCENT (TO PLANETARY ORBIT)	
• DOCKING	
• TRANSFER CREW	
• EARTH TRAJECTORY INSERTION	
• EARTH ORBIT INSERTION	
• RETURN VEHICLE RETRIEVAL/ RECOVERY	

- ON-ORBIT/ON-SURFACE
- ORBIT CHANGE (SHORT DURATION)
- DOCKING
- TRANSFER (CREW/CARGO/PROPELLANT/EXPERIMENTS/MODULES/ETC.)
- INSERTION INTO TRANSFER TRAJECTORY
- ARRIVING ORBIT INSERTION
- DESCENT TO SURFACE
- ASCENT FROM SURFACE
- DEORBIT (FROM LOW EARTH ORBIT)
- RETRIEVAL/RECOVERY
- DISPOSAL

Figure B-14. "Basic" Mission Operational Phases/Events

Table B-6. Summary of Vehicles and Mission Operational Phases

SPACE POSITION	LOW EARTH ORBIT						SYNCHRONOUS EARTH ORBIT								LUNAR ORBIT/SURFACE												PLANETARY ORBIT/SURFACE										
MISSION PHASE / MANNED VEHICLES	ON-ORBIT	ORBIT CHANGE	DOCKING	TRANSFER CREW/CARGO/ETC.	DE-ORBIT	DISPOSAL*	SYNC. TRAJ. INSERTION	SYNC. ORBIT INSERTION	ON-ORBIT	ORBIT CHANGE	DOCKING	TRANSFER CREW/CARGO/ETC.	TRANSEARTH TRAJ. INSERT.	EARTH P.O. INSERTION	TRANSLUNAR TRAJ. INSERT.	LUNAR ORBIT INSERTION	ON-ORBIT	ORBIT CHANGE	DOCKING	TRANSFER CREW/CARGO/ETC.	DESCENT TO LUNAR SURFACE	ON-SURFACE	SURFACE TRANSFER {CREW CARGO	ASCENT TO LUNAR ORBIT	TRANSEARTH TRAJ. INSERT.	EARTH P.O. INSERTION	PLANET TRAJ. INSERTION	PLANET ORB. INSERTION	ON PLANETARY ORBIT	DESCENT TO SURFACE	ON SURFACE	ASCENT TO PLANET. ORBIT	DOCKING	TRANSFER CREW/CARGO/ETC	E.O. TRAJ. INSERTION	E.O. INSERTION	RETRIEVAL/RECOVERY
• EOS	x	x	x	x	x																																
• SPACE TUGS	x	x	x	x		x	x	x	x	x	x	x	x	x			x	x	x	x	x	x		x													
• NUCLEAR SHUTTLE	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x					x	x											
• E.O. SPACE STATION/BASE	x	x	x	x					x	x	x	x																									
• L.O. SPACE STATION																	x	x	x	x																	
• LUNAR SURFACE BASE																						x	x														
• MARS MANNED VEHICLE	x	x	x	x																							x	x	x	x	x	x	x	x	x	x	x

*Disposal operations may be required for any hardware element at the conclusion of its useful life.

- Safety Catastrophic--Conditions such that environment, personnel error, design characteristics, procedural deficiencies, or subsystems or component malfunction will severely degrade system performance and cause subsequent system loss, death, or multiple injuries to personnel.
- Safety Critical--Conditions such that environment, personnel error, design characteristics, procedural deficiencies, or subsystem or component malfunction will cause equipment damage or personnel injury, or will result in a hazard requiring immediate corrective action for personnel or system survival.
- Safety Marginal--Conditions such that environment, personnel error, design characteristics, procedural deficiencies, or subsystem failure or component malfunction will degrade system performance but which can be counteracted or controlled without major damage or any injury to personnel.
- Safety Negligible--Conditions such that personnel error, design characteristics, procedural deficiencies, or subsystem failure or component malfunction will not result in major system degradation and will not produce system functional damage or personnel injury.

Current study limited to catastrophic and critical hazard categories. Marginal and negligible categories do not lead to requirement for escape or rescue.

Figure B-15. Hazard Categories (Safety Program Directive No. 1 - Rev. A, Dec. 12, 1969--Office of Manned Space Flight)

Table B-7. Data Sources for Hazard Analysis*

Company	Date of Study
Grumman Corporation Bethpage, N. Y.	1963
Douglas Aircraft Co. Long Beach, Calif.	1967
Rand Corporation Santa Monica, Calif.	1967
North American Rockwell Corp. Space Division Downey, Calif.	1967, 1970
Aerospace Corporation El Segundo, Calif.	1968, 1970
Bellcomm, Inc. Washington, D. C.	1968
Boeing Co. Aerospace Systems Division Seattle, Washington	1969
NASA Headquarters Washington, D. C.	1970
Lockheed Missiles and Space Co. Space Systems Division Sunnyvale, Calif.	1970
McDonnell Douglas Astronautics Co. Huntington Beach, Calif.	1970

*Twelve different hazard analyses were conducted by 10 different companies from 1963 to 1970.

- FIRE:
  - / ELECTRICAL
  - / CHEMICAL
  - / OTHER
- EXPLOSION:
  - / LIQUID
  - / GAS
  - / ORDNANCE
    - CHEMICAL
    - NONE
- DECOMPRESSION
- TOXIC CONTAMINATION
- TEMPERATURE
- POWER LOSS
- TUMBLING
- ORBIT DECAY
- SPACE RADIATION
- HOSTILE ACTION

Figure B-16. Emergency Situations (Grumman, Ref. B-2)

- PRESSURE LOSS
- ATMOSPHERE CONTAMINATION
- TEMPERATURE & HUMIDITY OUT OF LIMITS
- ELECTRICAL POWER LOSS
- TUMBLING
- ORBIT DECAY
- RADIATION SPACE ENVIRONMENT
- FOOD/WATER CONTAMINATION/LOSS
- BUILDUP OF DANGEROUS BACTERIA
- CREW INJURY
- FIRE
  - / ELECTRICAL
  - / CHEMICAL
  - / OTHER
- EXPLOSION
  - / LIQUID
  - / GAS

Figure B-17. EOSS Station Module Abort Situation (Douglas, Ref. B-3)

- DEPRIVATION OF METABOLIC NEEDS
  - / ANOXIA
  - / DEHYDRATION
  - / STARVATION
- EXCESSIVE PHYSIOLOGICAL STRESS
  - / EXPOSURE TO TUMBLING OR ROTATION
  - / EXPOSURE TO HEAT
  - / OTHER PHYSIOLOGICAL STRESSES
- INJURIES AND POISONINGS
  - / CHEMICAL INJURY
  - / RADIATION INJURY
  - / PHYSICAL INJURY
- DISEASE
  - / INFECTIVE AND PARASITIC
  - / OTHER
- MENTAL, PSYCHONEUROTIC, PERSONALITY DISORDERS

Figure B-18. Basic Hazard Threats (Rand, Ref. B-4)

Table B-8. Flight Hazards (Ref. B-5)

RESPONSE TIME	HAZARDS	EARTH ORBITAL	LUNAR	PLANETARY
IMMEDIATE (sec to min)	FIRE	X	X	X
	FRAGMENTATION DAMAGE	X	X	X
	TUMBLING	X	X	X
	CABIN RUPTURE OR DEPRESSURIZATION	X	X	X
	COLLISION	X	X	X
INTERMEDIATE (min to hr)	SMOKE	X	X	X
	PERSONNEL INJURY	X	X	X
	LOSS OF LIFE SUPPORT (oxygen supply failure, thermal control failure, atmosphere contamination)	X	X	X
LONG TERM (hr to days)	SPACE PROPULSION FAILURE		X	X
	UNSAFE OR UNABLE TO REENTER	X	X	X
	PERSONNEL ILLNESS	X	X	X
	INACCURATE COURSE CORRECTION		X	X
	LOSS OF LIFE SUPPORT (starvation, dehydration, trace contaminant buildup, oxygen depletion, loss of diluent gas)			X

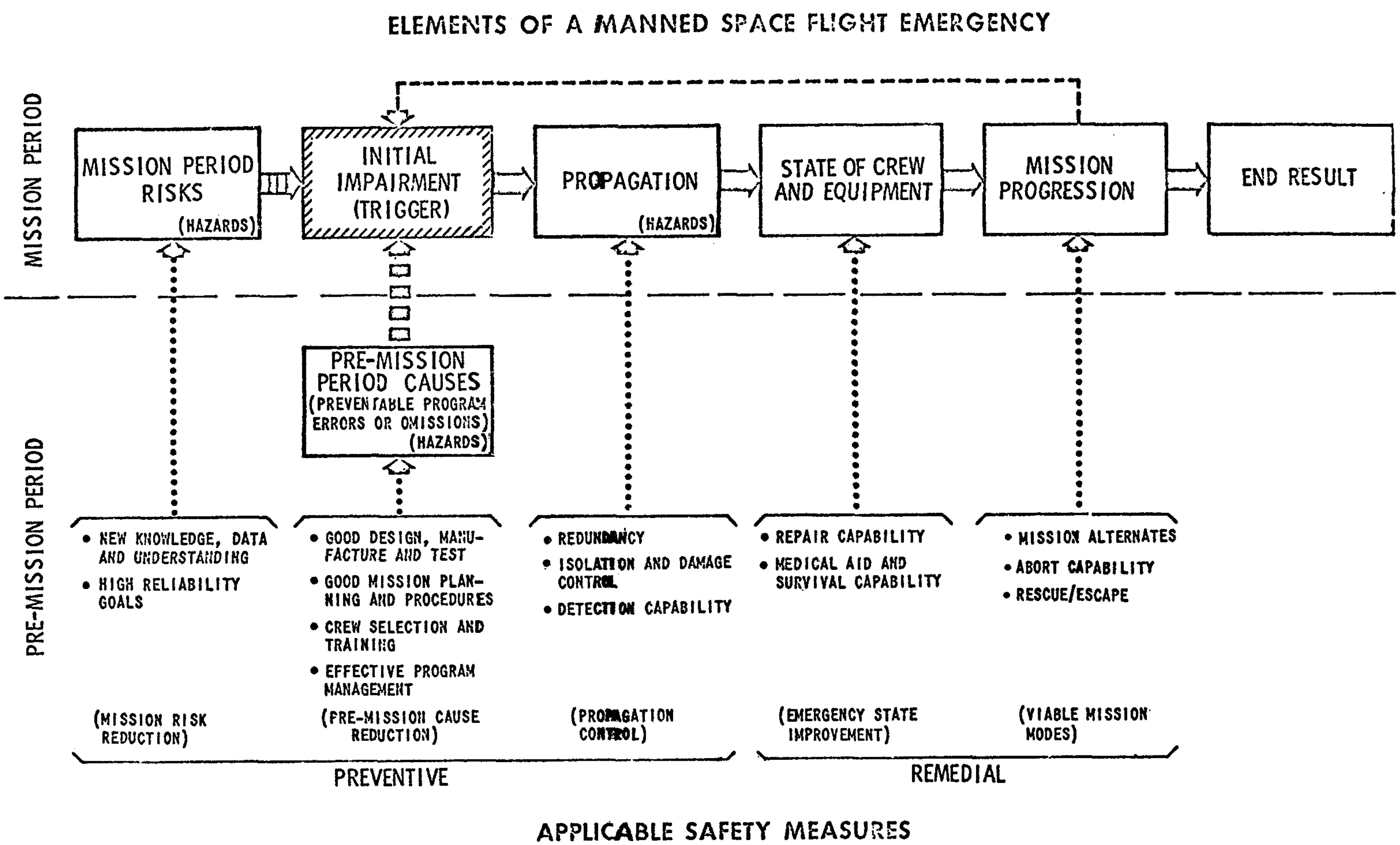


Figure B-19. Space Flight Emergencies and Safety Measures (Bellcomm, Ref. B-6)

USAF (AF)

ACCELERATION
CONTAMINATION
CORROSION
DISSOCIATION, CHEMICAL
ELECTRICAL
EXPLOSION
FIRE
HEAT & TEMPERATURE
LEAKAGE
MOISTURE
OXIDATION
PRESSURE
RADIATION
REPLACEMENT, CHEMICAL
SHOCK
STRESS CONCENTRATIONS
STRESS REVERSALS
STRUCTURAL DAMAGE OR FAILURE
TOXICITY
VIBRATION AND NOISE
WEATHER AND ENVIRONMENT

TEAGUE (T)

POWER FAILURE
LIFE SUPPORT FAILURE
CONTROL SYSTEM FAILURE
PROPULSION FAILURE
RCS FAILURE
EVA HAZARD
RADIATION
METEOROID
COLLISION
ACTIVITY INDUCED EMERGENCY
OPERATIONAL ERROR
ILLNESS
FIRE/EXPLOSION

GE

ACCELERATION
AERODYNAMIC LOADS
AERODYNAMIC HEATING
AEROEMBOLISM
ANOXIA
ATTITUDE CONTROL LOSS
BASE HEATING
CHEMICAL INJURY
COLLISION
CONTAMINATION
CORROSION
DEHYDRATION
DISSOCIATION, CHEMICAL
DROWNING
ELECTRICAL-INADVERTENT ACTIVATION
ELECTRICAL-POWER SOURCE FAILURE
ELECTRICAL-THERMAL
ELECTRICAL SHOCK
ELECTROMAGNETIC RADIATION
EXPLOSION
EXPOSURE
FIRE
HUMAN ERROR
LEAKAGE
MOISTURE
NAUSEA
OXIDATION (OTHER THAN AIR)
PRESSURE
PROPULSION FAILURE
RADIATION
REPLACEMENT, CHEMICAL
SHOCK AND IMPACT
SPACE DEBRIS
STARVATION
STRESS CONCENTRATION
STRESS REVERSAL
STRUCTURAL FAILURE
TEMPERATURE EXTREME
TOXICITY
TUMBLING
VIBRATION AND NOISE
WEATHER AND ENVIRONMENT
STAGING FAILURE

AEROSPACE (A)

FIRE
FRAGMENTATION
TUMBLING
CABIN RUPTURE
COLLISION
SMOKE
PERSONNEL INJURY
LOSS OF LIFE SUPPORT
PROPULSION FAILURE
CAN'T REENTER
ILLNESS
OFF-COURSE

RAND (R)

THREATS
- METABOLIC DEPRIVATION
- EXCESSIVE PHYS. STRESS
- INJURY

CAUSES
- IMPAIRED EQUIPMENT OR CREW
- EQUIPMENT FAILURE
- PERSONNEL ERROR
- ENVIRONMENTAL HAZARD (PERSONNEL BREAKDOWN)

Figure B-20. Hazard Identification by Sources

Table B-9. Hazard Categories and Sources (from Ref. B-6)

ITEM	CATEGORY AND IDENTIFIER				
	MISSION PERIOD RISKS	INITIAL IMPAIR-MENT	PRE-MISSION PERIOD CAUSES	PROPA-GATION	CREW AND EQUIPMENT
ACCELERATIONS			AF GE	AF GE	
ACTIVITY INDUCED EMERGENCY	T		T		
AERODYNAMIC LOADS			GE	GE	
AERODYNAMIC HEATING			GE		
AEROEMBOLISM				GE	
ANOXIA				GE	
ATTITUDE CONTROL LOSS					GE
BASE HEATING			GE	GE	
CAN'T TAKE OFF FROM LUNAR SURFACE*					
CAN'T REENTER EARTH ATMOSPHERE*					
CABIN RUPTURE				A	A
CHEMICAL INJURY				GE	
CONTAMINATION			GE	GE	
CONTROL SYSTEM FAILURE					T
COLLISION	GE A			GE A	
CORROSION			GE AF	GE AF	
DEHYDRATION				GE	
DISSOCIATION, CHEMICAL				GE AF	
DROWNING					GE
ELECTRICAL-INADVERTENT ACTIVATION		GE			

* CLASSIFIED AS MISSION PROGRESSION (IDENTIFIER R)

Table B-9. (Continued)

ITEM	CATEGORY AND IDENTIFIER				
	MISSION PERIOD RISKS	INITIAL IMPAIR-MENT	PRE-MISSION PERIOD CAUSES	PROPA-GATION	EFFECT ON CREW AND EQUIPMENT
ELECTRICAL-POWER SOURCE FAILURE					GE T
ELECTRICAL SHOCK			GE		
ELECTRICAL-THERMAL			GE		
ENVIRONMENTAL HAZARD	R AF GE		R AF GE		
EQUIPMENT FAILURE					R
EVA HAZARD	T		T		
EXPLOSION				AF GE T	
EXPOSURE				GE	
FIRE				AF GE T	
FRAGMENTATION				A	
HEAT & TEMPERATURE				AF	
IMPACT			GE	GE	
LEAKAGE				AF GE	
LIFE SUPPORT SYSTEM FAILURE					R T A
METABOLIC DEPRIVATION				R	R
METEOROID	T				
MOISTURE			AF GE		
NAUSEA				GE	
OXIDATION			AF GE		
OFF COURSE				A	
PERSONNEL ERROR		GE R T			
PERSONNEL ILLNESS	R T A			R T A	
PERSONNEL INJURY	R·A			R A	

Table B-9. (Continued)

ITEM	CATEGORY AND IDENTIFIER				
	MISSION PERIOD RISKS	INITIAL IMPAIR-MENT	PRE-MISSION PERIOD CAUSES	PROPA-GATION	EFFECT ON CREW AND EQUIPMENT
PRESSURE				AF GE	
PROPULSION FAILURE					GE T A
RADIATION	AF GE T		AF GE T	AF GE T	
REPLACEMENT, CHEMICAL			AF GE		
RCS FAILURE					T
SHOCK			AF GE	AF GE	
SMOKE				A	
SPACE DEBRIS	GE				
STAGING FAILURE				GE	GE
STARVATION				A	
STRESS CONCENTRATIONS			AF GE		
STRESS REVERSALS			AF GE		
STRUCTURAL FAILURE				AF GE R	
TEMPERATURE EXTREME				GE	
TOXICITY				AF GE	
TUMBLING*					
UNDESIRED PROLONGATIONS OF MISSION**					
VIBRATION AND NOISE			AF GE	AF GE	
WEATHER	AF GE		AF GE		

*CLASSIFIED AS MISSION PROGRESSION (IDENTIFIERS GE AND A)

**CLASSIFIED AS MISSION PROGRESSION (IDENTIFIER R)

- CONTAMINATION
- DEBRIS AND METEOROID IMPACT
- DECOMPRESSION/OVER-PRESSURE
- ELECTRICAL
- EQUIPMENT IMPACT
- EXPLOSION
- ILLNESS & INJURY
- LOSS OF VITAL SUPPLIES
- RADIATION
- TEMPERATURE EXTREMES
- SPACECRAFT ACCELERATIONS
- GENERAL

Figure B-21. General Hazard Groups (Boeing, Ref. B-7)

Table B-10. Hazard Summary: Communications and Data Management System (Ref. B-7)

POTENTIAL HAZARD	CAUSE	EFFECT
LOSS OF EXTERNAL VOICE COMMUNICATIONS	TRANSMITTER FAILURE RECEIVER FAILURE PREMODULATION PROCESSOR FAILURE ANTENNA FAILURE	CANNOT TALK TO GROUND CANNOT TALK TO EVA CREW CANNOT TALK TO LOGISTICS VEHICLES CANNOT TALK TO INDEPENDENT MODULES
LOSS OF INTERNAL VOICE COMMUNICATIONS	FAILURE OF ONE OR MORE AUDIO CENTERS MICROPHONE FAILURE HEADSET FAILURE	CANNOT TALK TO ALL CREW MEMBERS IN SPACE STATION
LOSS OF DATA COMMUNICATION WITH GROUND	UP-DATA RECEIVER-DECODER FAILURE PREMODULATION PROCESSOR FAILURE TELEMETRY FAILURE	LOSS OF AUTOMATIC UP-DATE INFORMATION LOSS OF GROUND COMMAND CAPABILITY CANNOT TRANSMIT DATA TO GROUND
LOSS OF TIME REFERENCE	TIMING UNIT FAILURE UP-DATA RECEIVER-DECODER FAILURE	DEGRADED PERFORMANCE OF ALL TIME-REFERENCED EQUIPMENT; E.G., COMPUTER FUNCTIONS, A.C. POWER REGULATION
LOSS OF COMPUTER FUNCTION	DATA ADAPTER FAILURE COMPUTER FAILURE POWER SUPPLY FAILURE	DEGRADED PERFORMANCE OF SPACECRAFT SYSTEMS AND EXPERIMENTS LOSS OF DATA

Table B-11. Hazard Summary: Crew System (Ref. B-7)

POTENTIAL HAZARD	CAUSE	EFFECT
EVA EQUIPMENT FAILURE	PRESSURE SUIT LEAKAGE COOLING CIRCUIT FAILURE CO_2 REMOVAL FAILURE	CREW INJURY OR LOSS
FOOD CONTAMINATION	COOLING SYSTEM FAILURE WATER CONTAMINATION INADEQUATE STORAGE	CREW ILLNESS FOOD SHORTAGE
RADIATION	INADEQUATE PROTECTION EXCESSIVE TIME IN ORBIT RF RADIATION	CREW INJURY OR LOSS
CREW INJURY OR ILLNESS	INADEQUATE INTERIOR DESIGN INADEQUATE RESTRAINT PROVISIONS INADEQUATE CREW OPERATING PROCEDURES INADEQUATE CREW WARNING SYSTEM	INCREASED WORKLOAD ON REMAINING CREW POSSIBLE EMERGENCY TREATMENT
INADEQUATE MAINTENANCE CAPABILITY	LACK OF REPLACEMENT PARTS LACK OF MAINTENANCE INSTRUCTIONS FAILURE OR LACK OF MAINTENANCE EQUIPMENT	DEGRADED SYSTEM OPERATION LIMITED MISSION DURATION EMERGENCY SUPPORT REQUIRED

Table B-12. Hazard Summary: Electrical Power System (Ref. B-7)

POTENTIAL HAZARD	CAUSE	EFFECT
FIRE, SMOKE, TOXIC PRODUCTS	SHORT CIRCUITS ELECTRICAL OVERLOAD ARCING BATTERY OVERPRESSURE OVERHEATING	ATMOSPHERE CONTAMINATION CREW INJURY OR ILLNESS EQUIPMENT DAMAGE
LOSS OF ELECTRICAL POWER	POWER SOURCE FAILURE CHARGING SYSTEM FAILURE DISTRIBUTION SYSTEM FAILURE POWER CONVERSION SYSTEM FAILURE THERMAL CONTROL FAILURE SOLAR PANEL DAMAGE	LOSS OF A. C. POWER LOSS OF D. C. POWER LOSS OF ELECTRICAL EQUIPMENT OPERATION
POWER SOURCE RADIATION	THERMAL CONTROL FAILURE SHIELDING FAILURE INADEQUATE SHIELDING	CREW ILLNESS OR INJURY ELECTRONIC EQUIPMENT MALFUNCTION SEAL DAMAGE PROPELLANT DAMAGE

Table B-13. Hazard Summary: Environmental Control/ Life Support System (Ref. B-7)

POTENTIAL HAZARD	CAUSE	EFFECT
LOSS OF O_2	REGULATOR FAILURE TANK LEAKAGE VALVE FAILURE PLUMBING FAILURE THERMAL CONTROL FAILURE	CREW ILLNESS DECREASED MISSION DURATION DANGER OF FIRE O_2 SHORTAGE
LOSS OF CABIN PRESSURE	CABIN LEAKAGE STRUCTURAL DAMAGE REGULATION FAILURE SEAL FAILURE	CREW INJURY LOSS OF CABIN AIR SUPPLY
EXCESSIVE CO_2	CO_2 REMOVAL FAILURE EXCESSIVE CO_2 GENERATION EXCESSIVE HUMIDITY	CREW ILLNESS
FLUID LEAKAGE	PLUMBING FAILURE COMPONENT FAILURE SEAL FAILURE	CONTAMINATION FIRE DAMAGE EQUIPMENT DAMAGE
ATMOSPHERE CONTAMINATION	FILTER CLOGGED OR FAILED FLUID LEAKAGE FIRE, SMOKE CONTAMINANT REMOVAL FAILURE AIR CIRCULATION FAILURE	CREW ILLNESS EQUIPMENT DAMAGE
LOSS OF THERMAL CONTROL	COMPONENT FAILURE RADIATOR FAILURE CONTROL FAILURE AIR CIRCULATION FAILURE HEATER FAILURE	TOO HOT OR COLD FREEZING FLUID LINES EQUIPMENT DAMAGE UNUSABLE O_2 SUPPLY

Table B-13. (Continued)

POTENTIAL HAZARD	CAUSE	EFFECT
WATER CONTAMINATION	PURIFICATION FAILURE VALVE FAILURE IMPROPER CLEANING TANK FAILURE	CREW ILLNESS WATER SHORTAGE
LOSS OF SUIT LOOP	VALVE FAILURE COMPONENT FAILURE PURIFICATION FAILURE REGULATION FAILURE	NOT AVAILABLE IN EMERGENCY

Table B-14. Hazard Summary: Stability and Control System (Ref. B-7)

POTENTIAL HAZARD	CAUSE	EFFECT
LOSS OF ATTITUDE CONTROL	PROPELLANT SUPPLY FAILURE THRUSTER ASSEMBLY FAILURE SHUTOFF VALVE FAILURE CMG FAILURE ELECTRONICS FAILURE MANUAL ATTITUDE CONTROL FAILURE EXCESSIVE DOCKING LOADS BMAG FAILURE	SPACECRAFT TUMBLING LOSS OF SOLAR PANEL ORIENTATION CREW DISABLED LOSS OF EXPERIMENT DATA
PROPELLANT LEAKAGE	SHUTOFF VALVE FAILURE PLUMBING FAILURE RELIEF VALVE FAILURE TANK FAILURE	LOSS OF PROPELLANT CONTAMINATION OF OTHER EQUIPMENT POSSIBLE FIRE
PROPELLANT TANK RUPTURE	METEOROID PENETRATION COLLISION WITH OTHER OBJECTS TANK OVERPRESSURE	DAMAGE TO SPACECRAFT OR OTHER EQUIPMENT INJURY TO PERSONNEL POSSIBLE FIRE
EXHAUST PLUME	INHERENT TO SPACECRAFT SYSTEMS	DAMAGE TO EQUIPMENT OR EVA PERSONNEL
FIRE	SEE "PROPELLANT LEAKAGE" AND "PROPELLANT TANK RUPTURE" ABOVE	DAMAGE TO EQUIPMENT INJURY TO PERSONNEL

Table B-15. Hazard Summary: Structures/Mechanical Systems (Ref. B-7)

POTENTIAL HAZARD	CAUSE	EFFECT
NO AIRLOCK CAPABILITY	SEAL FAILURE PRESSURIZATION FAILURE HATCH FAILURE PUMPDOWN FAILURE	RESTRICTS EVA RESTRICTS CREW TRANSFER LOSS OF ATMOSPHERE CREW INJURY
DOCKING ACCIDENT	CONTROL SYSTEM FAILURE DOCKING EQUIPMENT FAILURE LIGHTING FAILURE	SPACE VEHICLE STRUCTURAL DAMAGE DAMAGE TO EXTERIOR EQUIPMENT DAMAGED DOCKING PORT CREW INJURY CANNOT ACCOMPLISH DOCKING CABIN PRESSURE LOSS
CANNOT TRANSFER RESUPPLY CARGO	DOCKING PORT DAMAGE TRANSFER EQUIPMENT FAILURE	RESTRICTED MISSION DURATION
STRUCTURAL DAMAGE	MICROMETEOROID PENETRATION FAULTY HANDLING AND MOVEMENT OF EQUIPMENT LONG-TERM MICROMETEOROID BOMBARDMENT SPACE DEBRIS COLLISION	CABIN PRESSURE LOSS EQUIPMENT DAMAGE CREW INJURY OR LOSS

- MOST PROBABLE CAUSES OF VEHICLE/CREW LOSS DURING POST APOLLO SPACE PROGRAM WILL RESULT FROM:
  - / NONHABITABLE ENVIRONMENT
  - / LOSS OF:
    - PROPULSION
    - ATTITUDE CONTROL
    - GUIDANCE AND NAVIGATION
    - ATMOSPHERIC MANEUVERING CAPABILITY
  - / FIRE
  - / EXPLOSION
  - / COLLISION
  - / INABILITY TO PERFORM RESCUE/ABORT AFTER FAILURE
  - / LACK OF GROUND ASSISTANCE
- ABOVE CAUSE FACTORS REQUIRE SPECIAL EMPHASIS DURING FUTURE STUDIES/DESIGN EFFORT

Figure B-22. Vehicle/Crew Loss Contingency Analysis (Aerospace, Ref. B-8)

HAZARDS GROUPS (FROM PRELIMINARY HAZARD ANALYSIS)

1. RADIATION
2. EXPLOSION
3. TEMPERATURE EXTREMES
4. IMPACT
5. ELECTRICAL SHOCK
6. ILLNESS
7. METABOLIC DEPRIVATION
8. TOXICITY

HAZARD GROUPS (FROM GROSS HAZARDS ANALYSIS)

1. FIRE
2. COLLISION
3. EXPLOSION
4. DECOMPRESSION
5. PROCESS FLUIDS LEAKAGE
6. GRAZING COLLISION
7. INJURY/ILLNESS
8. TOXIC CONTAMINATION
9. LOSS OF ACCESS
10. PHYSIOLOGICAL LOSS OF CONTROL
11. RADIATION MATERIALS LEAKAGE
12. METEOROID PENETRATION
13. ABANDONMENT OF STATION

*REF: PAPER BY R. ALLER AND M. SHAW (AAS NO. 70-056)

Figure B-23. Hazard Groups (NASA Headquarters, Ref. B-9)

1. UNINHABITABLE ENVIRONMENT
2. AGING/WEAROUT
3. EXPLOSION
4. FIRE/EXPLOSION
5. HUMAN ERROR
6. INADEQUATE COMMUNICATION & LIGHTING
7. INADEQUATE HUMAN ENG. /POOR WORKMANSHIP
8. CRASH
9. CORROSION
10. STANDARD FAILURE/DAMAGE
11. EXPLOSION/IMPLOSION
12. PRESSURE DIF. /FIRE/CONTAMINATION
13. SABOTAGE
14. SICK OR DISABLED PERSONNEL OR ANIMALS
15. IMPACT ACCELERATION
16. FIRE/EQUIPMENT DAMAGE
17. OVER-PRESSURE
18. STRESS
19. PERSONNEL INJURY
20. LIGHTNING STRIKE/STATIC DISCHARGE

Figure B-24. Hazard Descriptive Groups (Lockheed, Ref. B-10)

21. GUIDANCE SYSTEM MALFUNCTION
22. LOSS OF ROLL CONTROL
23. RADIATION
24. EQUIPMENT DAMAGE
25. COLLISION
26. GLARE/SHADOWING/VEILING/COLLISION
27. ACCELERATION
28. PASSAGEWAY OBSTRUCTIONS
29. RAPID PRESSURE CHANGE
30. HIGH TEMPERATURE
31. CONTAMINATION & ACCELERATION
32. LACK OF VISIBILITY/EQUIPMENT DAMAGE
33. LANDING SHORT/CRASH
34. STRESS DAMAGE
35. INADVERTENT ACTUATION
36. SHOCK/ACCELERATION/BAD WEATHER/CRASH
37. FLAMEOUT/CRASH
38. BAD WEATHER/CRASH
39. INADEQUATE COMMUNICATIONS
40. IMPACT ACCELERATION

Figure B-24. (Continued)

- FIRE
- MECHANICAL DAMAGE
- EXPLOSION
- DE-PRESSURIZATION
- FLUID LEAKAGE
- COLLISION
- PERSONNEL LOSS
- FOOD OR WATER CONTAMINATION
- ACCIDENT IN A HATCH
- INCAPACITATED EVA OR IVA MAN
- RADIO-ACTIVE LEAKAGE
- METEOROID PENETRATION
- VEHICLE ABANDONMENT

Figure B-25. Credible Accidents (North American Rockwell, Ref. B-11)

- BODILY TRAUMA RESULT FROM IMPACT DUE TO HIGH-MOMENTUM PROJECTILES
- CREW ASPHYXIATION FROM FIRE IN SPACE STATION
- MERCURY TOXICOSIS (POISONING) IN SPACE STATION
- CREW ASPHYXIATION RESULTS FROM INSUFFICIENT O_2
- CREW ASPHYXIATION RESULTS FROM EXCESS CO_2 IN SPACE STATION
- BODILY TRAUMA RESULT FROM ELECTRICAL SHOCK
- MAJOR LEAKAGE FROM WATER SUPPLY MAY CONTRIBUTE TO POSSIBILITY OF "SHORT CIRCUIT FIRE"
- HYPOXIA FROM SPACE STATION DECOMPRESSION
- TOXICOSIS RESULTS FROM INGESTION OF CRITICAL DOSAGE OF TOXIC AGENTS
- MICROBIAL CONTAMINATION OF POTABLE WATER SUBSYSTEM RESULTS IN CREW ILLNESS
- FOOD LOSS OCCURS IN SPACE STATION
- PARTICULATE MATTER IS RELEASED INTO SPACE STATION ATMOSPHERE
- UNABLE TO MAINTAIN SPACE STATION TEMPERATURE WITHIN CREW TOLERANCE LIMITS

Figure B-26. Potential Hazard Events (McDonnell Douglas, Ref. B-12)

- LIFE SUPPORT - PARTIAL OR TOTAL LOSS OF PRESSURE, OXYGEN, FOOD, WATER
  - / FAILURE TO RESUPPLY
  - / LOSS OF ITEM
  - / UNUSABILITY OF ITEM BY CONTAMINATION
- RADIATION - ALPHA PARTICLES, BETA PARTICLES, GAMMA RAYS, X-RAYS, COSMIC RAYS, NEUTRONS, HIGH-SPEED ELECTRONS, HIGH-SPEED PROTONS, ETC., INCLUDES HAZARDS ASSOCIATED WITH ELECTROMAGNETIC RADIATION
- EXPLOSION - VIOLENT DESCRIPTION OF STATION, COMPARTMENTS WITHIN STATION, OR COMPONENTS WITHIN OR ATTACHED TO STATION
  - / OVERPRESSURE
  - / CHEMICAL
  - / PHYSICAL REACTIONS
  - / OTHER MEANS
- TEMPERATURE EXTREMES - EXTREME HEAT (SUCH AS FIRE) AND EXTREME COLD (SUCH AS CRYOGENICS)
- TOXICITY - RELATED TO OR CAUSED BY CHEMICAL COMPONENTS OR ELEMENTS
  - / HUMAN METABOLISM BY PRODUCTS
  - / OUTGASSING
  - / BROUGHT ON BOARD (EXPERIMENTS, ETC.)
  - / PRODUCED BY INTERREACTIONS (CHEMICALS AND/OR HARDWARE)

---

* REPRESENT PRIMARY METHODS BY WHICH PERSONNEL CASUALTY/INJURY CAN BE EFFECTED BY AND/OR IN THE SPACE STATION AND ITS ASSOCIATED ENVIRONMENT AND EQUIPMENT

Figure B-27. Hazard Groupings for Logic Diagram Analysis (Ref. B-12)

- ILLNESS - CREW DISABILITY
  - / BACTERIOLOGICAL CAUSES (SUCH AS COLDS)
  - / NATURAL CAUSES (SUCH AS HEART FAILURE)
  - / CONTAMINATION OF LIFE SUPPORT ITEMS (BACTERIOLOGICAL OR BIOLOGICAL)
  - / LONG TERM EFFECTS OF WEIGHTLESSNESS

- IMPACT
  - / WITH INTERNAL STATION EQUIPMENT, SUPPLIES, CARGO
  - / WITH STATION-RELATED EQUIPMENT EXTERNAL TO STATION (LOGISTICS SUPPORT SYSTEM, FREE-FLYING OR ATTACHED EXPERIMENT MODULES, SUBSATELLITES, TUGS, ETC.)
  - / WITH ITEMS EXTERNAL TO STATION AND PROGRAM (OTHER SATELLITES, SPENT STAGES, DEBRIS, ETC.)

- ELECTRICAL SHOCK - INJURY OR FATALITY CAUSED BY ELECTRIC CURRENT PASSING THROUGH BODY OF A CREW MEMBER

Figure B-27. (Continued)

1. Unprogrammed vehicular motion
   - RCS extended firing
   - RCS inadvertent firing
   - Axial engine inadvertent and/or extended firing
   - Axial engine hard-over
   - Axial engine burn-through
   - Control moment gyro seizure
   - Hole in pressurized compartment

2. Nonhabitable spacecraft environment
   - Loss of atmospheric temperature control
   - Loss of humidity control
   - Pressure loss
   - Atmospheric contamination
   - Variations in O_2 content
   - Loss of helium
   - Nuclear radiation

3. Loss of electrical power

4. Mechanical systems malfunctions
   - Inability to separate as planned
   - Premature separation
   - Inoperative hatch

5. Loss of attitude control capability

6. Loss of retro ΔV capability

7. Explosion

8. Structural damage

9. Fire

10. Loss of guidance and control capability

11. Personnel malfunctions

Figure B-28. Classification of Emergencies (USAF, Ref. B-13)

Table B-16. Hazard Identification Comparison

GRUMMAN ASD-TDR-63-778 (Ref. B-2)	RAND RM-5200 (Ref. B-4)	DOUGLAS DAC-56550 (Ref. B-3)	AEROSPACE CORP. ATR-68(7080)-2 (Ref. B-5)	BOEING D2-113070-5 (Ref. B-7)	AEROSPACE CORP. Contingency Analysis (Ref. B-8)	NASA Aller & Shaw (Ref. B-9)	LMSC Current Study (Ref. B-10)	NAR Space Station Phase B (Ref. B-11)	MDAC Space Station Phase B (Ref. B-12)
● Fire ● Explosion ◐ Decompression		○ Fire ◐ Explosion ◐ Press. Loss	○ Fire ○ Fragment Damage ◐ Rupture/Decomp. ○ Collision	○ Explosion ○ Decom/Overpress ◐ Debris/Meteroid Impact ○ Equipment Impact	● Fire ◐ Explosion ◐ Non-habit. Envir. ● Collision	◐ Fire ● Explosion ● Decompression ◐ Int Collision ◐ Grazing Ext. Collision ◐ Meteroid Impact	○ Fire ○ Explosion ○ Press-Excur. ◐ Collisions - Int. - Ext.	● Fire ◐ Explosion ◐ Depressurization ● Mechanical Damage ● Collisions ◐ Meteoroid Penetration	● Explosion ● Impact - Internal - External
◐ Toxic Contamination		● Atmos. Contami. ◐ Bacteria Buildup ◐ Food/Water Contamination	◐ Smoke	○ Contamination	◐ Non-habitable Environment	◐ Toxic Contamn. - Food/Water	● Contamination - Toxic/Non-Toxic	● Fluid Leakage ● Food/Water Contam.	● Contaminated Life Support ● Toxicity
	◐ Physiological Stresses ● Chemical Injury ◐ Physical Injury ○ Disease ◐ Mental Disorders	◐ Injury	○ Injury/Illness	○ Injury/Illness		◐ Injury/Illness	◐ Injury/Illness		● Illness/Injury - Bacteria - Natural Causes - Electrical Shock
			○ Unsafe to Reenter			◐ Loss of Access ◐ Fluid Leakage	◐ Personnel Isolation - Stranding - Entrapment	● Accident in Hatch ● Incapacitated in EVA	
● Space Radiation	● Radiation Injury	◐ Space Radiation		○ Radiation	◐ Non-habitable Environment	◐ Radiation Leakage	● Radiation - All sources	● Radioactive Leakage	● Radiation
							◐ Personnel Errors		
◐ Power Loss- ● Tumbling/Orbit Decay ◐ Temperature	◐ Tumbling/Rotation ◐ Heat Exposure ◐ Anoxia/Dehy./Starvation	◐ Electrical Pwr Loss ○ Tumbling/Orbit Decay ◐ Temp./Humidity Extremes ○ Food/Water Loss	◐ Tumbling/Prop. Failure ◐ Loss of Life Support ◐ Inaccurate course corr.	○ Electrical ◐ S/C Acceleration ◐ Temperature Extremes ◐ Loss of vital supplies	● Loss of Propulsion ◐ Non-habitable Environment ● Loss of G & N ◐ Loss of Ground Assistance		● Power Failure ● Loss of Propulsion ◐ Loss of Environ Control ◐ Loss of Life Support ● Communication Loss		● Temp. Extremes ● Loss of Life Support
◐ Hostile Action									
					◐ Loss of Atmospheric Maneuvering Capability				
							● Motion/Tumbl.		
						○ Abandonment		● Abandonment	
				◐ General					
								● Personnel Loss	
									● Failure to Resupply

- FIRE
- EXPLOSION/IMPLOSION
- DECOMPRESSION/OVERPRESSURE
- COLLISIONS BETWEEN INTERNAL OBJECTS
- CONTAMINATION (TOXIC/NON-TOXIC)
- INJURY/ILLNESS
- MECHANICAL/STRUCTURAL FAILURES (NON-COLLISION-ORIENTED)
- RADIATION (FROM SOURCES INTERNAL OR ATTACHED TO VEHICLE)
- PERSONNEL ERRORS
- BASIC SUBSYSTEM MALFUNCTIONS (CAN ALSO BE CAUSED BY OR RESULT IN OTHER BASIC HAZARDS)
    - POWER (ELECT, HYD., MECH.)
    - PROPULSION (MANEUVERING, RCS, LOCOMOTIVE)
    - ENVIRONMENTAL CONTROL (TEMP., HUMIDITY)
    - LIFE SUPPORT (FOOD, WATER, OXYGEN)
    - G&N FUNCTION
    - COMMUNICATIONS
    - ETC.

Figure B-29. Basic Internal Hazards

- COLLISION WITH ANOTHER OBJECT (METEROIDS, SATELLITES, SPACE DEBRIS, SPENT STAGES, SHUTTLES, TUGS, ETC.)
- EXTERNAL RADIATION (SPACE, NUCLEAR POWER SOURCE)
- INABILITY TO RETURN FROM EVA (BROKEN TETHER, LOSS OF MANEUVERING PROPULSION, INJURED/INCAPACITATED)
- LACK OF RESUPPLY/ROTATION (LOSS OF SCHEDULED RESUPPLY VEHICLE)
- SURFACE CONTAMINATION

Figure B-30. Basic External Hazards

- FIRE
- EXPLOSION / IMPLOSION
- DECOMPRESSION / OVERPRESSURE
- COLLISIONS (INTERNAL / EXTERNAL OBJECTS)
- CONTAMINATION (TOXIC / NON-TOXIC)
- INJURY / ILLNESS
- MECHANICAL / STRUCTURAL FAILURES (NON-COLLISION-ORIENTED)
- RADIATION (INTERNAL / EXTERNAL)
- PERSONNEL ERRORS
- BASIC SUBSYSTEM MALFUNCTIONS
- INABILITY TO RETURN FROM EVA
- LACK OF RESUPPLY / ROTATION

Figure B-31. Combined Hazards Listing

Table B-17. Summary of Gross Hazards and Resulting Emergency Situations

GROSS HAZARD EVENT (A NON-CATASTROPHIC DISCRETE EVENT---NO CHAIN REACTIONS)	GROSS EMERGENCY SITUATIONS RESULTING FROM OCCURRENCE OF HAZARD EVENT: ILLNESS/INJURY				METABOLIC DEPRIVATION			STRANDED/ ENTRAPPED		INABILITY TO COMMUNICATE			OUT-OF-CONTROL S/C			DEBRIS IN VICINITY OF S/C	RADI-ATION IN VICINITY OF S/C	NONHABITABLE ENVIRON. IN S/C			INABILITY TO REENTER	BAILOUT (Abandon-ment Necessary)
	Physical	Chemical	Disease	Mental	Anoxia	Dehyd.	Starv.	In S/C	In EVA	With Earth	With Other S/C	With EVA Crew	Tumb-ling	Decay Orbit	Unsafe Traj.			Lack of Environ. Control	(Surf.) Contam. (Atm.)	Radi-ation		
o FIRE	X				X			X		X	X	X							X			X
o EXPLOSION/IMPLOSION	X	X			X			X					X			X			X			X
o DECOMPRESSION/OVERPRESSURE	X				X								X					X				
o COLLISIONS																						
- INTERNAL OBJECTS	X																					
- EXTERNAL OBJECTS	X							X					X			X		X				
o CONTAMINATION (TOXIC/ NON-TOXIC)		X			X	X	X												X			X
o INJURY/ILLNESS	X	X	X	X																		
o MECHANICAL/STRUCTURE FAILURE								X	X												X	
o RADIATION (INCL. LEAKAGE)	X	X															X		X	X		X
o PERSONNEL ERRORS[1]																						
o BASIC SUBSYSTEM MALFUNCTIONS[2]																						
- POWER[1]																						
- PROPULSION													X	X	X						X	
- ENV. CONTROL																		X				X
- LIFE SUPPORT					X	X	X															
- G&N FUNCTION															X						X	
- COMM.										X	X	X										
o INABILITY TO RETURN FROM EVA																						
- BROKEN TETHER					X				X													
- LOSS OF PROPUL. FUNCTION					X				X													
- INJURED/INCAPACITATED	X				X				X													
o LACK OF RESUPPLY/ROTATION																						
- LOSS OF SCHEDULED RESUPPLY VEHICLE					X	X	X											X				

[1] COULD LEAD TO ANY OF INDICATED SITUATIONS DEPENDING UPON EXTENT.

[2] CAN BE CAUSED BY OR RESULT IN OTHER BASIC HAZARDS.

- 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 B-32. Summary of Emergency Situations

Table B-18. Summary: Emergency Situation/Mission Phase Matrix

GROSS EMERGENCY SITUATIONS (RESULTING FROM OCCURRENCE OF A HAZARD)	LOW EARTH ORBIT				SYNCH. ORBIT			LUNAR ORBIT			LUN. SURF.		PLANETARY DISTANCES		
	STATION/ BASE	EOS	TUG	RNS	STATION	TUG	RNS	STATION	TUG	RNS	BASE	TUG	MMV		
O ILLNESS/INJURY	X	X	X	X	X	X	X	X	X	X	X	X	X		
/ Physical															
/ Chemical															
/ Disease															
/ Mental															
O METABOLIC DEPRIVATION	X	X	X	X	X	X	X	X	X	X	X	X	X		
/ Anoxia															
/ Dehydration															
/ Starvation															
O STRANDED/ENTRAPPED	X	X	X	X	X	X	X	X	X	X	X	X	X		
/ In S/C															
/ In EVA															
O INABILITY TO COMMUNICATE	X	X	X	X	X	X	X	X	X	X	X	X	X		
/ With Earth															
/ With Another S/C															
/ With EVA Crew															
O OUT OF CONTROL SPACECRAFT															
/ Tumbling	X	X	X	X	X	X	X	X	X	X	NA	NA	X		
/ Decaying Orbit	X	X	X	X	-	-	-	-	-	-	NA	NA	X		
/ Unsafe Trajectory	X	X	X	X	X	X	X	-	X	X	NA	NA	X		
O DEBRIS IN VICINITY OF S/C (NON-RADIOACTIVE)	X	X	X	X	X	X	X	X	X	X	X	X	X		
O RADIATION IN VICINITY OF S/C	X	X	X	X	X	X	X	X	X	X	X	X	X		
/ Incl. Particles, Objects															
O NONHABITABLE ENVIRONMENT IN S/C	X	X	X	X	X	X	X	X	X	X	X	X	X		
/ Lack of Environ. Control (Press., Temp., Humid.)															
/ Contamination (Atmos., Surface)															
/ Radiation (Internal)															
O UNABLE TO REENTER (EARTH'S ATMOS.)	NA	X	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	X		
O BAILOUT (ABANDONMENT NECESSARY)	X	X	X	X	X	X	X	X	X	X	X	X	X		
/ Crew in EVA															
/ Crew in Other Shelter															

APPENDIX C

NASA CONTINGENCY PLANNING

APPENDIX C

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APPENDIX C

NASA CONTINGENCY PLANNING

C.1 GENERAL*

There is, as yet, no separately-documented, overall safety plan for the manned phases of the Integrated Program. There are, however, numerous references to safety and safety-related guidelines offered in both NASA and contractor documents concerned with the various missions and hardware elements of the Integrated Program. The objective of this portion of the study was to review the available pertinent documents and provide a general summarization of the existing contingency and preventive/remedial plans.

C.2 DATA SOURCES

The primary sources of data were those NASA documents which define either the missions or the hardware elements of the Integrated Program. This category included project description documents, work statements, and specific guideline documents. In addition, contractor reports concerned with current hardware studies related to the Earth Orbit Shuttle, the Space Station program and the Reusable Nuclear Shuttle program were reviewed.

A listing of the specific documents reviewed (Ref. C-1 through C-16) is given at the end of this appendix.

C.3 DISCUSSION OF RESULTS

C.3.1 Specific Contingency Plans

C.3.1.1 Earth Orbit Missions

It is proposed that rescue capability will be provided for the Space Station and Base in low earth orbit. Both the Space Tug and the Earth Orbit Shuttle (EOS) are mentioned as rescue vehicles.

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*This appendix is based on the work of M. Hinton.

Several tugs are proposed for use in the vicinity of the station, with a standby tug always available.

In the case of the EOS, it is currently defined as having a 24-hour rendezvous capability (from notice of station emergency to rendezvous with the station) and, further, to be able to complete any required rescue operations (including personnel transfer) within an additional 24 hours.

There are no escape or rescue provisions proposed as yet for the case where either the EOS or the manned tug becomes a distressed vehicle.

C.3.1.2 Lunar Missions

It is also proposed that rescue capability will be provided for the lunar missions. In this case, the two major elements--Orbiting Lunar Station (OLS) and the Lunar Surface Base (LSB)--are each designated as a rescue operations base for the other.

Various configurations of a basic space tug are proposed in lunar mission operations, with one "ready status" tug always available for rescue missions. Such tugs are defined to have extensive lunar orbit maneuvering capability. It is suggested that a tug always be available at the OLS for descent and a tug available on the lunar surface (at the LSB) for ascent to implement any required escape/rescue mission from either haven. It is further suggested that a tug in lunar orbit have the capability to return to low earth orbit.

If the Space Shuttle (either nuclear or chemically fueled) is available in lunar orbit it could provide the return-to-earth function also.

C.3.1.3 Mars Mission

The currently-defined manned Mars exploration program relies totally on a pre-planned self-help capability in the event of emergencies. This self-help capability is provided by configuring the manned Mars vehicle system as a buddy system with redundant spacecraft, mission modules, and landers.

In the case of spacecraft elements, each is manned by a separate crew, with each spacecraft capable of sustaining both crews.

A spare mission module is provided but the entire crew is in the primary mission module under non-emergency conditions.

With regard to planetary landers, two are deployed with a 2-man crew in each lander. Each lander has the capacity to return four men in its ascent module.

These provisions for self-help via the buddy approach are in consonance with previous safety studies concerned with advanced planetary missions.

C.3.2 Preventive Planning

Considerable emphasis has always been given preventive planning in the NASA manned space programs. The procedures and experience gained in previous programs are being applied to the Integrated Program. Crew training and capability and vehicle design provisions have been emphasized. Redundancy, back-up, in-flight maintenance, repair or replacement, safety-oriented system design and component location are among suggested features. More specific examples are delineated below.

C.3.2.1 Operational Provisions

Examples in the general area of operational provisions to prevent the occurrence of emergencies are:

a. Trajectory shaping (to permit free-return paths to low earth orbit)

b. Crew override capability for critical automated controls

c. Buddy-system EVA

d. Crew training and capability

   (1) EOS flown by single crewman

   (2) Duplicate crew capability to perform required tasks.

With regard to nuclear systems, planned operations are prescribed for the disposal of used systems and components. The nuclear space shuttle is required to stand off from other manned spacecraft.

C.3.2.2 Vehicle Design Provisions

In the general area of vehicle design provisions to prevent the occurrence of emergencies, numerous approaches have been specified. The more significant examples are:

a. Redundancy--included in this area are not only the fail-operation/fail-operational/fail-safe system design requirements for critical functions but also items such as backup lighting for docking and excess or spare consumables, etc.

b. Maintenance/repair/replacement

c. Safety-oriented systems and subsystems--including malfunction detection systems, self-validating avionics systems, radiation protection provisions, micrometeoroid penetration detection and location, shielded pyrotechnics, materials compatibility, atmosphere consistent with fire protection, deactivated "one-time-use" items, and design to avoid accidental damage or inadvertent operation

d. Equipment location--including separate, isolated compartments for redundant elements as well as the isolation of high-energy-release equipment from each other and crew/passenger quarters

e. Remote shutoff for hazard isolation

f. Fluid/gas venting and containment provisions

g. Multiple viewing ports

C.3.3 Remedial Planning

NASA and industry references recognize that in spite of all precautions, emergencies can and will occur. Both self-help and rescue possibilities are considered. Limited emergency supplies and equipment are identified and recommendations are made for spacecraft design features to facilitate escape and rescue.

C.3.3.1 Operational Provisions

The specific operational provisions for rescue and self-help were described in Section C.3.1. In addition, provisions for abort operations are specified wherever applicable.

C.3.3.2 Vehicle Design Provisions

In the area of spacecraft design, features to facilitate escape/rescue include such examples as common atmospheres, common docking mechanisms, multiple access/egress routes, separate pressure-isolated volumes, hazard containment and control, hatches operable from either side, and compartment exterior pressure indication devices.

Also identified is emergency equipment to be carried, such as medical facilities, EVA/IVA suits, full-face O_2 masks, and portable lights.

Backup emergency life support and power have also been suggested, as well as EVA support items (pre-breathing O_2 facilities, provision for return of incapacitated EVA crewman, and 2-man air locks).

C.4 SUMMARY AND CONCLUSIONS

Although there is no separately documented overall safety plan for the Integrated Program, it is clear that a "de-facto" plan exists. It encompasses all aspects of the safety problem, from preventive measures to action in response to an emergency.

It is proposed that rescue capability be provided for both earth orbit and lunar missions. Missions will be designed to allow EOS, Tug, and Space Shuttles to be available for this purpose. For Mars mission emergencies, self-help appears to be the only solution. Buddy system concepts are being proposed for this latter mission, including redundant spacecraft, mission modules, and landers.

The plan is, as yet, incomplete and must remain dynamic, changing as the missions and hardware elements become more clearly defined. At present, certain equipment capabilities and operations are assumed without considering their technical feasibility. Also assumed is the availability, when needed, of specialized escape and rescue equipment. Furthermore, there is little indication of coordinated planning between interfacing major hardware elements.

There are no escape or rescue provisions specified, as yet, for either the Earth Orbit Shuttle or the manned Tug.

References*

EOSS

C-1. Space Station Program Description Document (March 1970).

C-2. Space Station Program Definition - Phase B (24 April 1970).

C-3. Space Station Statement of Work - Phase B (14 April 1970).

C-4. Modular Space Station - Guidelines and Constraints (7 October 1970).

C-5. Space Station Program - 8th Technical Review (MDAC, October 1970).

C-6. Space Station Preliminary System Design Data. Vol. III: Book 4, McDonnell Douglas Aircraft Co. (July 1970).

C-7. Space Station Program - Phase B Definition - 3rd Quarterly Report, North American Rockwell Corp. (June 1970).

EOS

C-8. Space Shuttle Program Requirements Document (1 July 1970).

TUG

C-9. Space Tug Program Description Document (24 April 1970).

*NASA Documents unless otherwise specified.

OLS

C-10. Orbiting Lunar Station Program Description Document (April 1970).

LSB

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APPENDIX D

REENTRY DELAY DUE TO LANDING SITE LOCATION

APPENDIX D

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APPENDIX D

REENTRY DELAY DUE TO LANDING SITE LOCATION

D.1 INTRODUCTION*

The nature of space emergencies may require a rapid return to earth because of crew injury or equipment failure. Irrespective of the mission, the last leg of a return to earth is from low earth orbit and is currently planned to be via the Orbiter stage of the Earth Orbit Shuttle (EOS). Rapid Orbiter return is, however, not always possible, and waiting periods in space may be required before an appropriate return opportunity occurs. This waiting time is determined by the Orbiter position in space, its operational characteristics, and the location of available landing sites.

The Orbiter horizontal landing feature implies a landing capability at most commercial airports. However, its landing must, in fact, be restricted to prepared sites where appropriate ground support has been provided. Although the landing need not necessarily be made at the launch site, a single launch and landing site may be operationally preferred. No final selection has, as yet, been made. One of the candidate sites is ETR. An analysis was therefore made, using ETR as the launch site, to assess the effect of Orbiter crossrange and the number and location of available alternate landing sites on the re-entry waiting time.

D.2 SCOPE OF ANALYSIS

The return opportunities from two low earth orbits were examined in detail. One corresponded to the orbit of the Space Station, namely 270 n mi altitude and 55° inclination. The other corresponds to the orbit of the Orbiting Propellant Depot (OPD) which provides propellant storage for vehicles operating between earth orbit and lunar orbit, namely 260 n mi altitude and 31.5° inclination. Both of these orbits are subsynchronized with the earth

*This appendix is based on the work of R. Nagy.

rotation to assure at least one in-plane and in-phase EOS launch opportunity every day. The resulting ground tracks repeat after 15 orbital revolutions; i. e., the tracks for the first and sixteenth revolutions coincide. The OPD orbit has an additional property in that the regression rate of the orbital plane is synchronized with lunar orbital rates and provides periodic departure opportunities for transfer to the moon.

It is assumed that the Orbiter is in one of these orbits and, following its participation in a rescue mission or an emergency of its own, seeks to return to earth as rapidly as possible. Three versions of the Orbiter were considered, each having a different crossrange capability. Although the nominal crossrange value is currently 1100 n mi, a lower value of 200 n mi and a higher value of 1500 n mi were also examined. The ability of each version of the Orbiter to reach selected landing sites from each of the 15 different ground tracks was then determined. In addition to ETR, eight other landing sites were considered. All alternate sites have 10,000 ft runways and except for Ramey AFB, Bermuda, are either within the continental United States (CONUS) or at U. S. possessions. Included as alternate landing sites are:

Edwards, Calif.	Hawaii	Puerto Rico
Wendover, Utah	Wake	Bermuda
El Paso, Texas	Guam	

D. 3 RESULTS AND DISCUSSION

D. 3. 1 270 n mi, 55° Inclination Orbit

The return opportunities at each of the nine landing sites considered are tabulated according to the orbit number in Tables D-1, D-2, and D-3 for crossranges of 200, 1100, and 1500 n mi, respectively. An "X" indicates the orbits from which the designated site can be reached for a landing. Although individual site availability improves as the crossrange is increased, worst case delays for a single site of at least five orbits (~8 hours) occur even at 1500 n mi. These data have been plotted in Figures D-1, D-2, and

D-3 to show the effect of having more than one landing site available. Two curves are presented on each figure, one an optimum combination of sites and the other a random selection with Edwards as the second available site. Both represent worst case situations for the combinations of sites involved.

The effect of crossrange on the worst case waiting orbits for the optimum selection of landing sites is summarized in Figure D-4. If ETR is the only landing site used, substantial orbital loiter could be required. In the worst case, an 1100 n mi crossrange could require an 8-orbit (~13 hours) landing delay. The minimum delay for this crossrange is one orbit, in the worst case, and requires five alternate landing sites in addition to ETR. They are Edwards, Hawaii, Wake, Guam, and Puerto Rico. With Edwards as the only alternate, a 7-orbit (~11 hour) reentry delay can be encountered.

D.3.2 260 n mi, 31.5° Inclination Orbit

Results for the OPD orbit are tabulated in Tables D-4, D-5, and D-6 and and plotted in Figures D-5, D-6, and D-7. For these latter figures, the number of waiting orbits is again the worst case. A summary of the optimum grouping of landing sites for the three crossranges considered is given in Figure D-8. For this orbit as well, an ETR-only landing site can require a substantial orbital loiter delay. With an 1100 n mi crossrange capability this delay can be as long as nine orbital revolutions (~14 hours). If ETR is augmented by Puerto Rico and Guam as alternate landing sites, then one of these sites is available from every orbit and no orbital loiter is required. It is interesting to note that with an 1100 n mi crossrange capability, a commonality of landing sites occurs for both orbits considered.

D.4 CONCLUSIONS

For an ETR launch and an 1100 n mi crossrange, no single continental United States (CONUS) site offers a shorter landing delay than ETR. Multiple CONUS sites offer a 1-orbit reduction in orbital loiter over the single site case but still require a half-day delay in the worst case, which in the case of a medical emergency may prove to be intolerable. Only by adding landing sites outside the CONUS can a significant reduction be made in this landing delay.

Table D-1. Return Opportunities from 270 n mi 55° Orbit -- 200 n mi Crossrange

REV	ETR	EDWARDS	WENDOVER	HAWAII	EL PASO	WAKE	GUAM	PUERTO RICO	BERMUDA
1		X	X						
2				X					
3									
4								X	
5			X						
6									
7									
8				X					
9									
10									
11									
12									
13								X	
14	X								
15									

Table D-2. Return Opportunities from 270 n mi 55° Orbit -- 1100 n mi Crossrange

REV	ETR	EDWARDS	WENDOVER	HAWAII	EL PASO	WAKE	GUAM	PUERTO RICO	BERMUDA
1		X	X		X				
2		X	X	X					
3			X	X		X			X
4	X	X	X		X	X	X	X	X
5	X	X	X				X	X	
6		X	X						
7				X					
8				X					
9						X			
10						X	X		
11							X		
12									
13								X	X
14	X							X	X
15	X	X	X		X				X

Table D-3. Return Opportunities from 270 n mi 55° Orbit -- 1500 n mi Crossrange

REV	ETR	EDWARDS	WENDOVER	HAWAII	EL PASO	WAKE	GUAM	PUERTO RICO	BERMUDA
1	X	X	X	X	X				X
2		X	X	X	X				X
3	X	X	X	X	X	X		X	X
4	X	X	X		X	X	X	X	X
5	X	X	X		X		X	X	
6		X	X		X				
7		X		X					
8				X		X			
9				X		X			
10						X	X		
11							X	X	
12								X	
13	X							X	X
14	X				X			X	X
15	X	X	X	X	X				X

Table D-4. Return Opportunities from 260 n mi
31.5° Orbit -- 200 n mi Crossrange

REV	ETR	EDWARDS	WENDOVER	HAWAII	EL PASO	WAKE	GUAM	PUERTO RICO	BERMUDA
1	X				X				
2					X			X	
3						X	X		
4									
5									
6									
7						X			
8									
9									
10									
11									
12								X	
13									
14	X								X
15	X								X

Table D-5. Return Opportunities from 260 n mi 31.5° Orbit -- 1100 n mi Crossrange

REV	ETR	EDWARDS	WENDOVER	HAWAII	EL PASO	WAKE	GUAM	PUERTO RICO	BERMUDA
1	X	X	X	X	X		X	X	X
2	X	X	X	X	X	X	X	X	X
3	X	X	X	X	X	X	X	X	
4		X		X	X	X	X		
5				X		X	X		
6				X		X	X		
7						X	X		
8						X	X		
9							X		
10								X	
11								X	
12								X	X
13	X							X	X
14	X			X	X			X	X
15	X	X	X	X	X			X	X

Table D-6. Return Opportunities from 260 n mi 31.5° Orbit -- 1500 n mi Crossrange

REV	ETR	EDWARDS	WENDOVER	HAWAII	EL PASO	WAKE	GUAM	PUERTO RICO	BERMUDA
1	X	X	X	X	X	X	X	X	X
2	X	X	X	X	X	X	X	X	X
3	X	X	X	X	X	X	X	X	
4		X		X	X	X	X		
5				X		X	X		
6				X		X	X		
7				X		X	X		
8						X	X		
9						X	X		
10							X	X	
11								X	
12	X							X	X
13	X				X			X	X
14	X	X	X	X	X			X	X
15	X	X	X	X	X	X		X	X

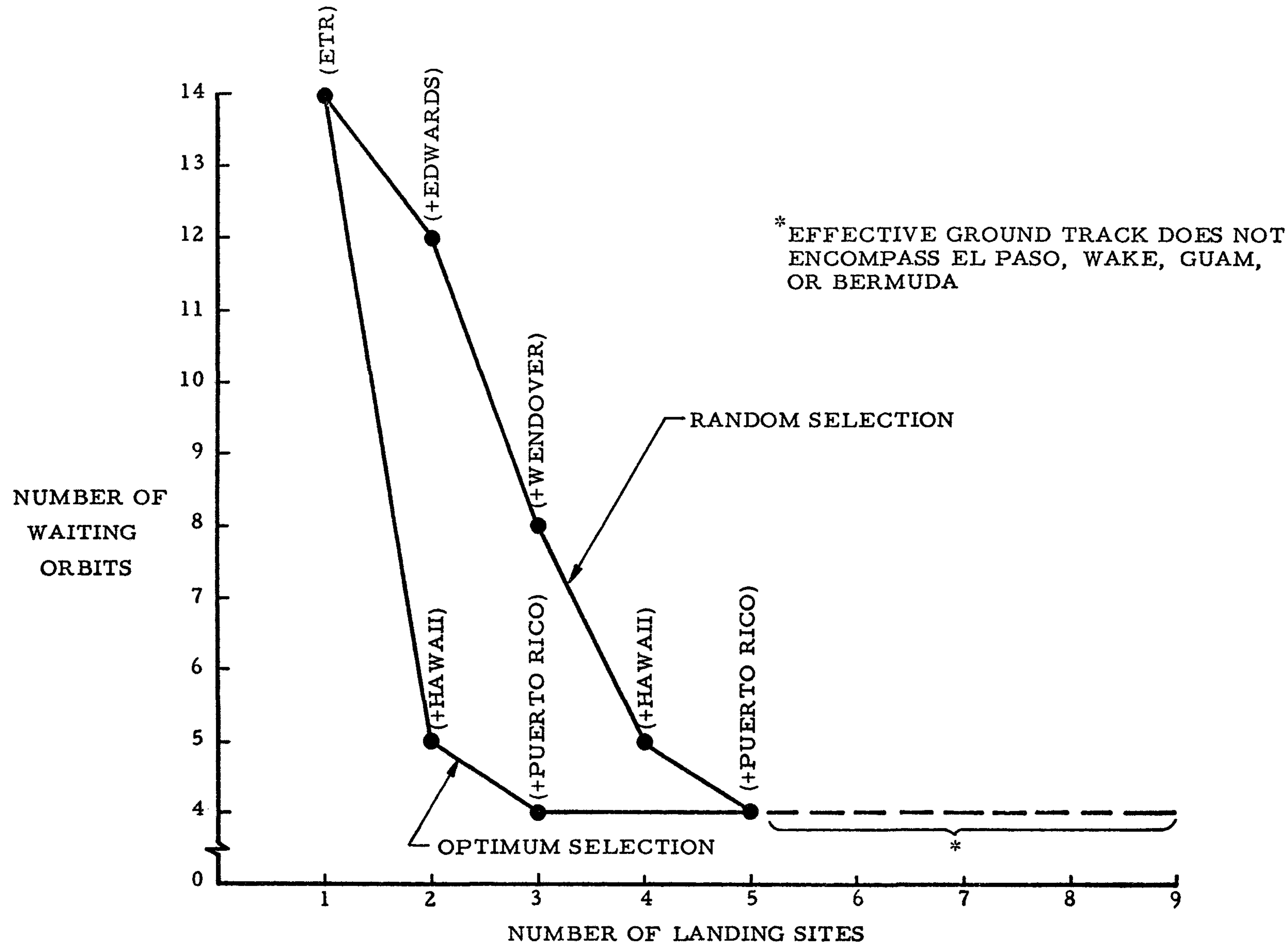

Figure D-1. Return Opportunities from 270 n mi, 55° Orbit -- 200 n mi Crossrange

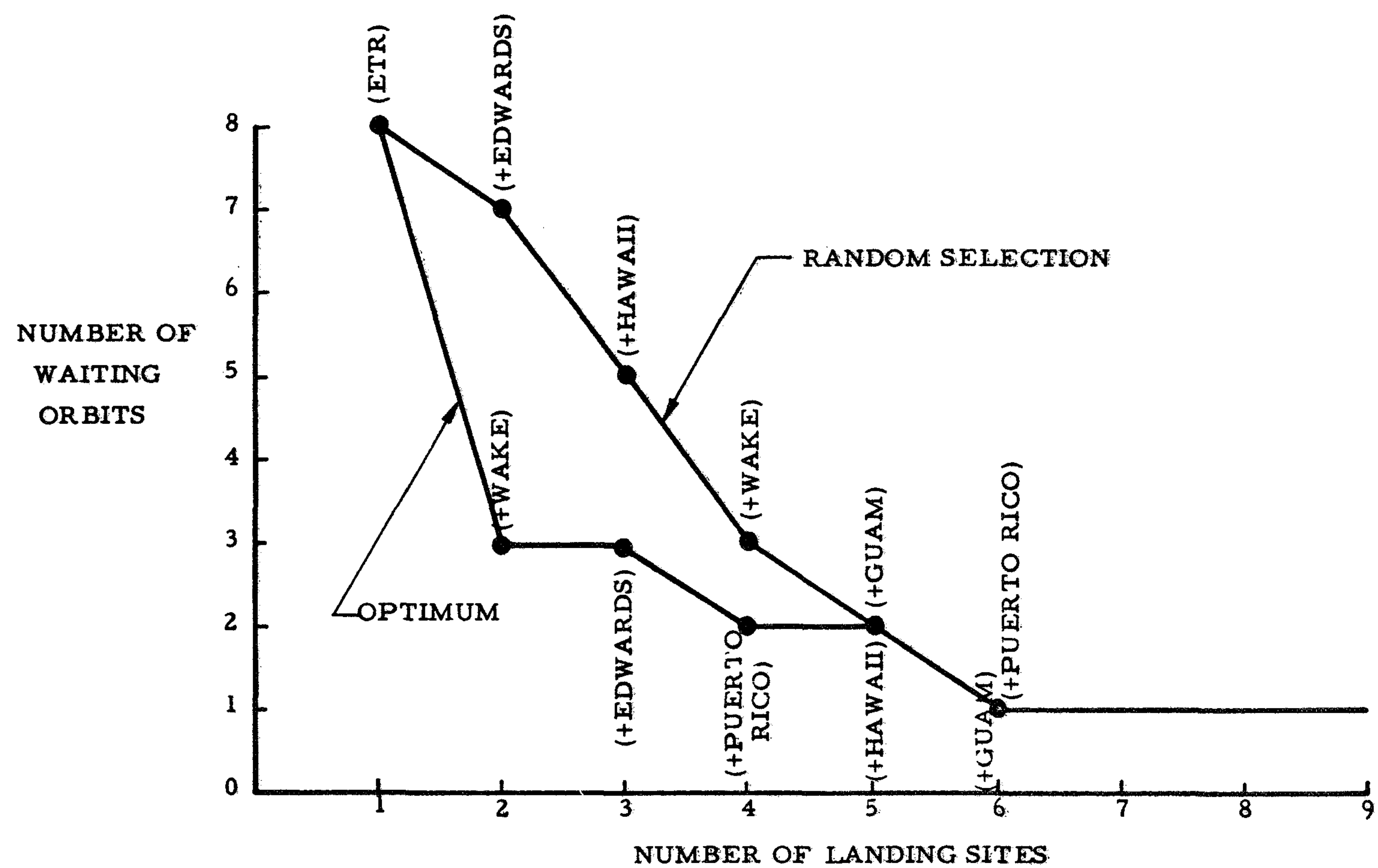

Figure D-2. Return Opportunities from 270 n mi, 55° Orbit -- 1100 n mi Crossrange

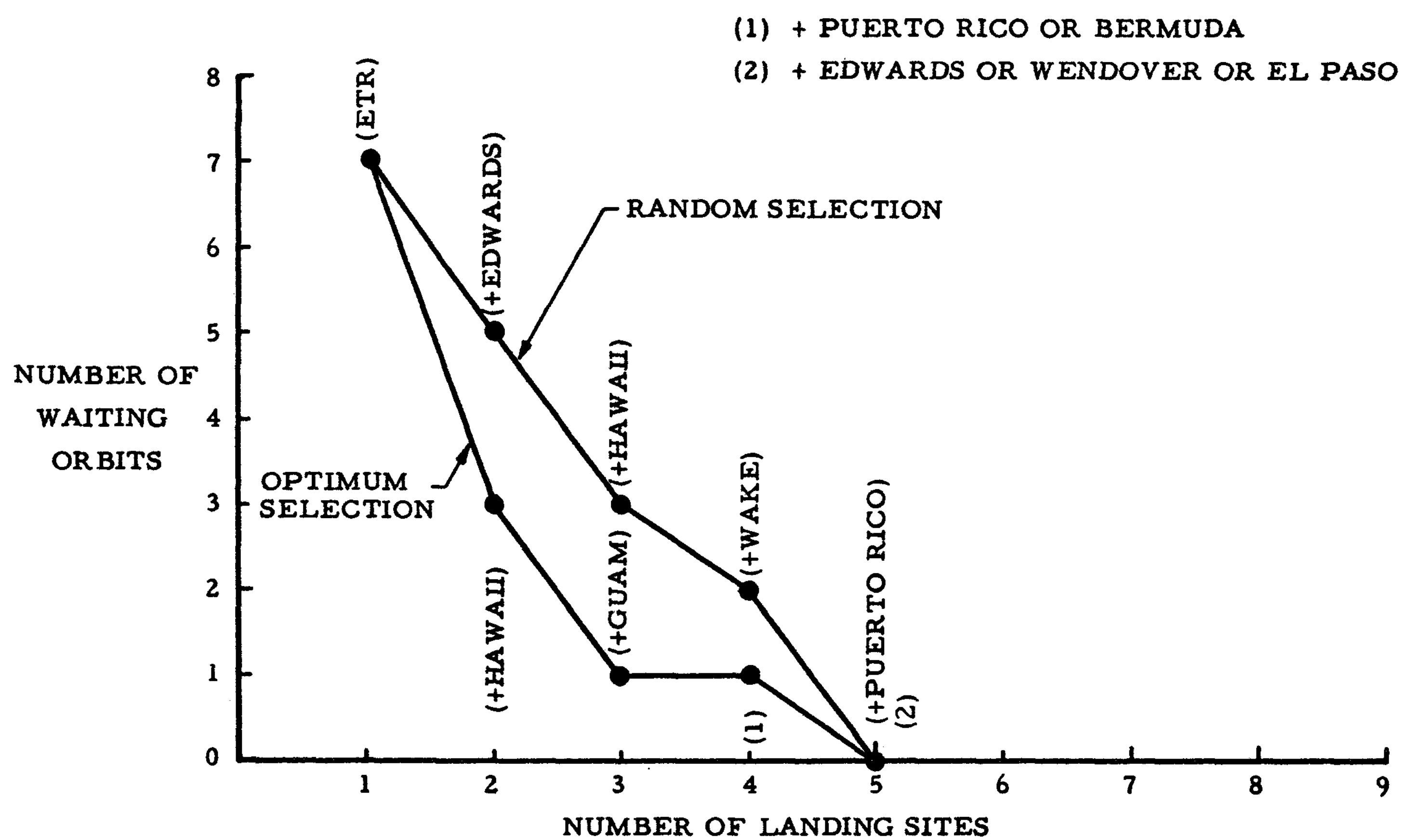

Figure D-3. Return Opportunities from 270 n mi, 55° Orbit -- 1500 n mi Crossrange

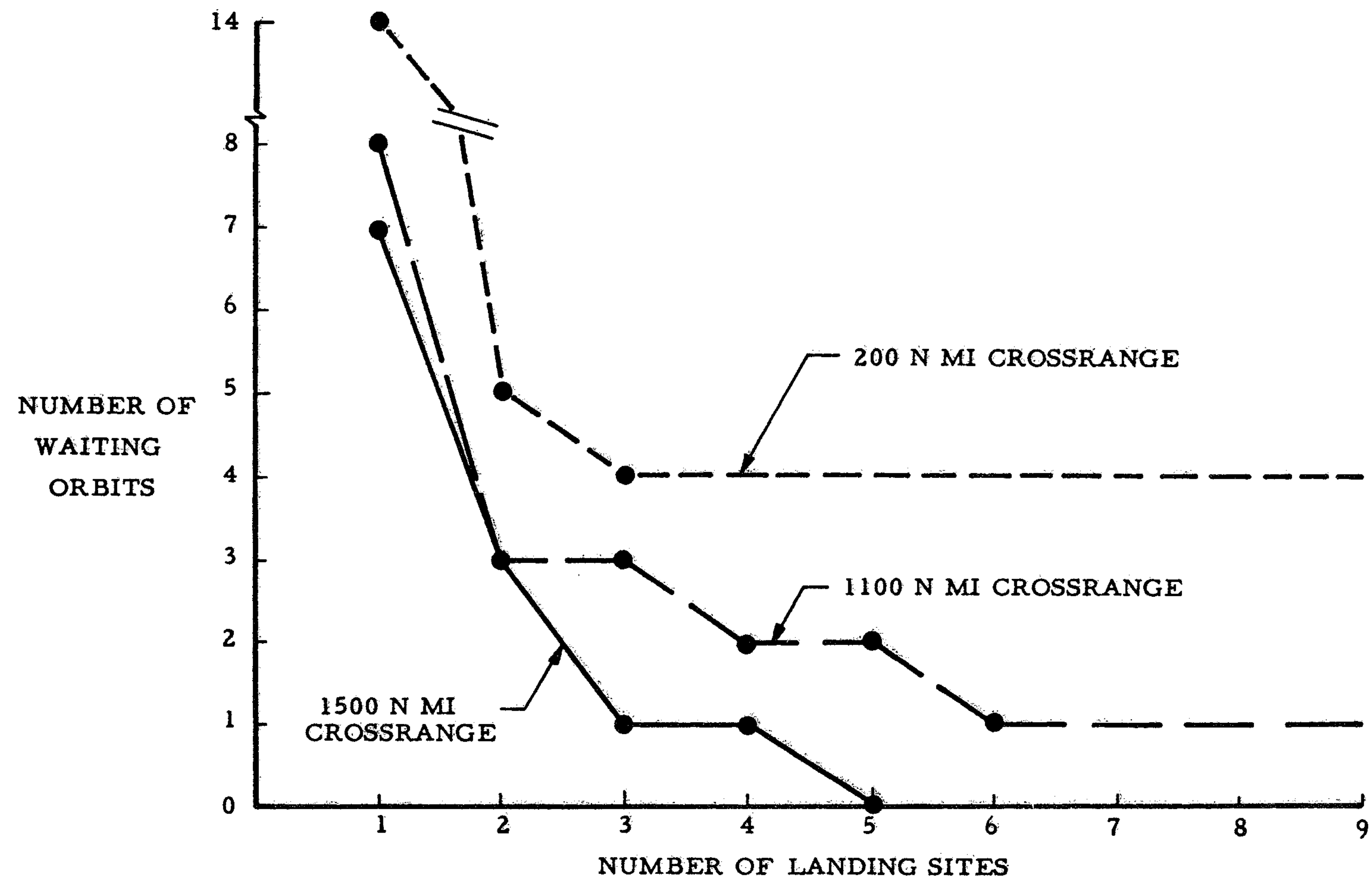

Figure D-4. Maximum Return Delay from 270 n mi, 55° Orbit with Optimum Site Selection (ETR -- Site No. 1)

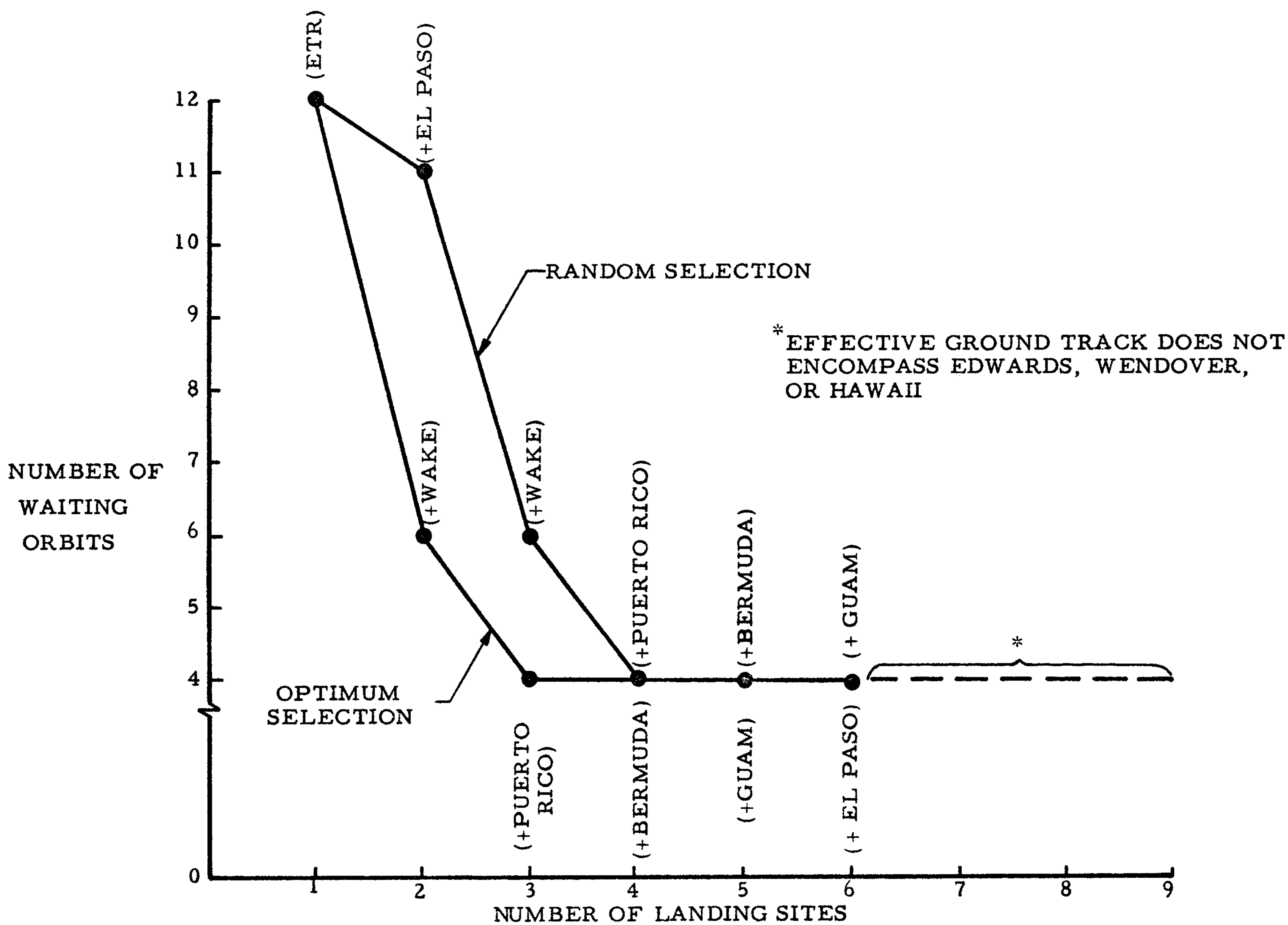

Figure D-5. Return Opportunities from 260 n mi, 31.5° Orbit -- 200 n mi Crossrange

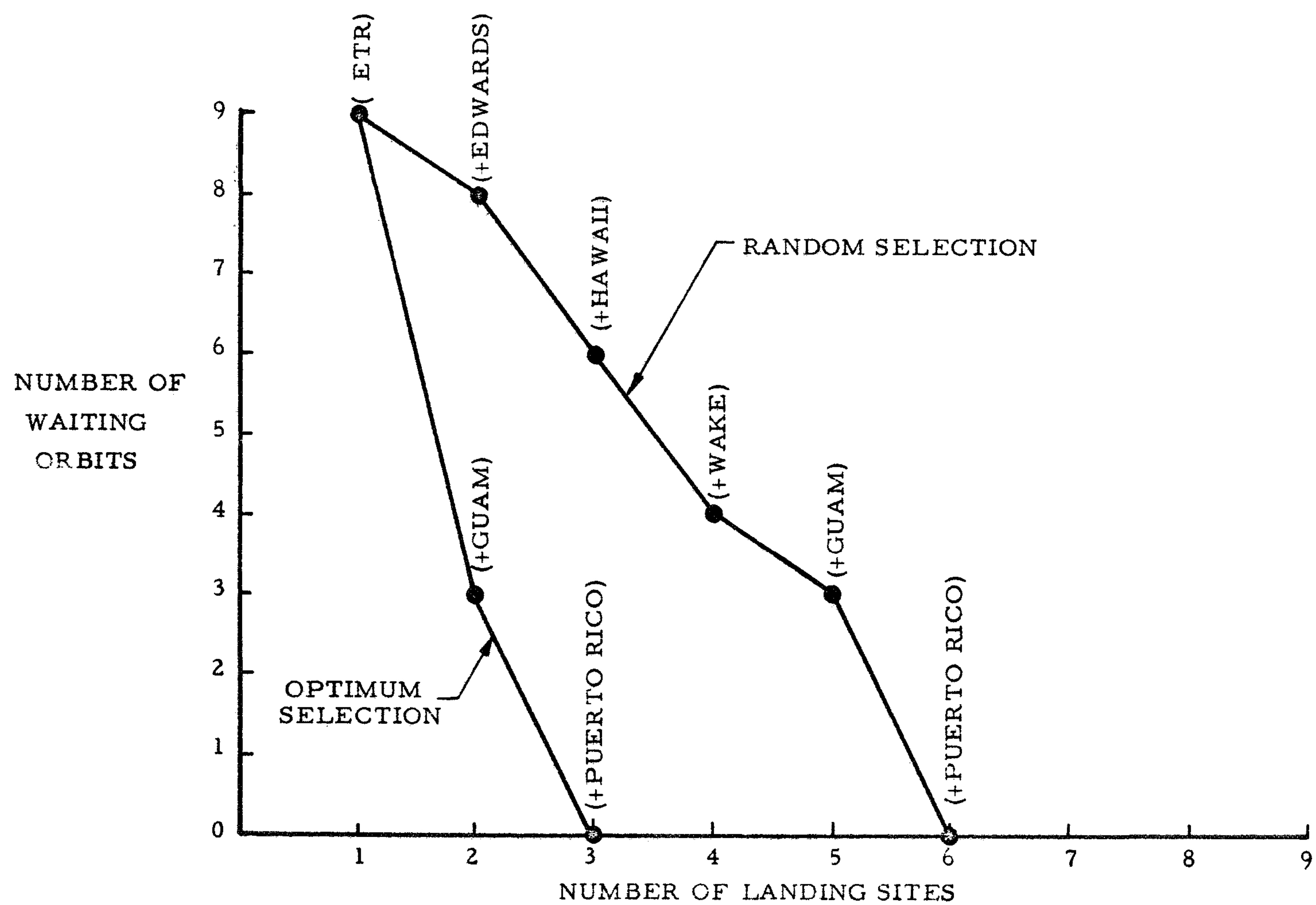

Figure D-6. Return Opportunities from 260 n mi, 31.5° Orbit -- 1100 n mi Crossrange

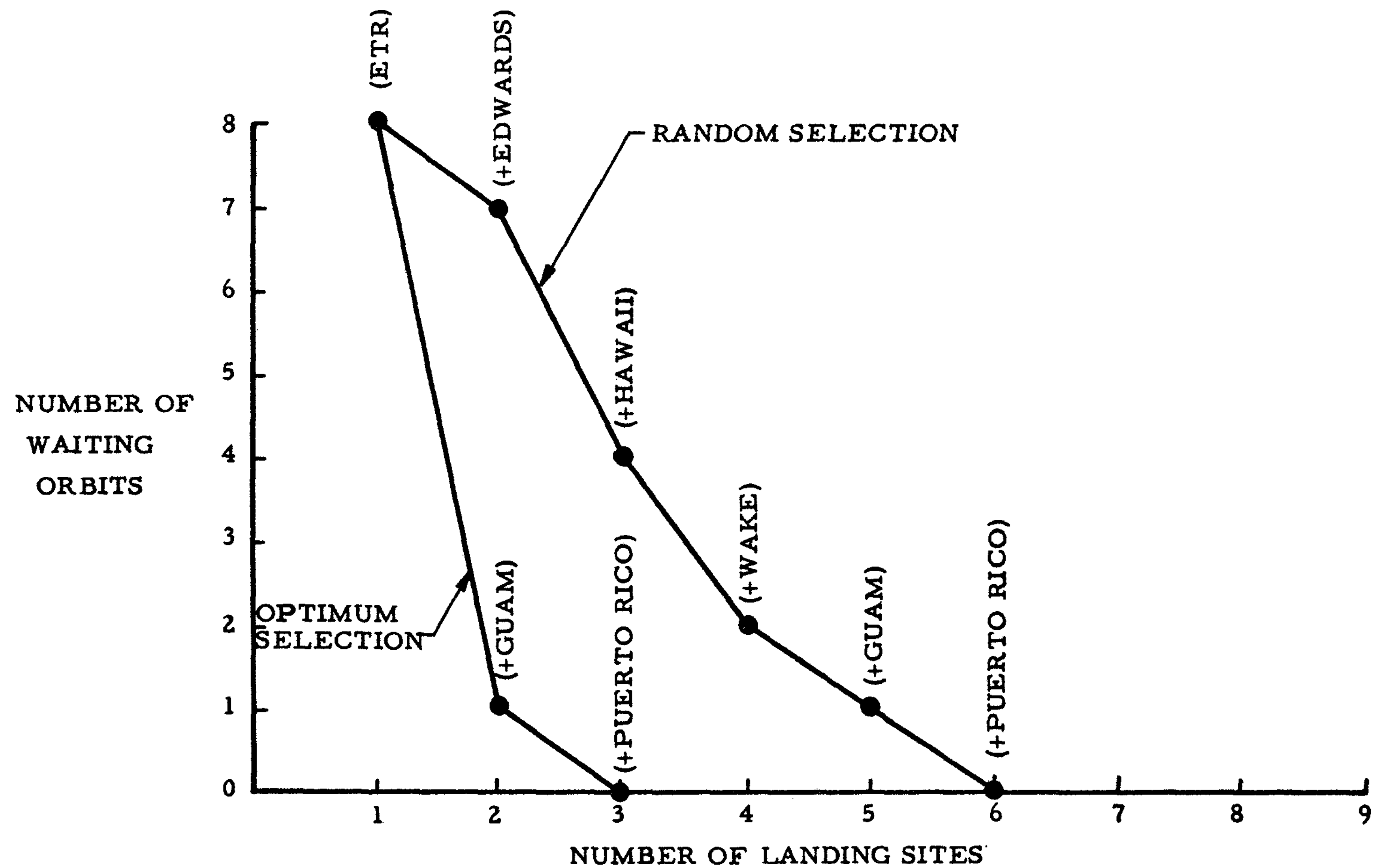

Figure D-7. Return Opportunities from 260 n mi, 31.5° Orbit -- 1500 n mi Crossrange

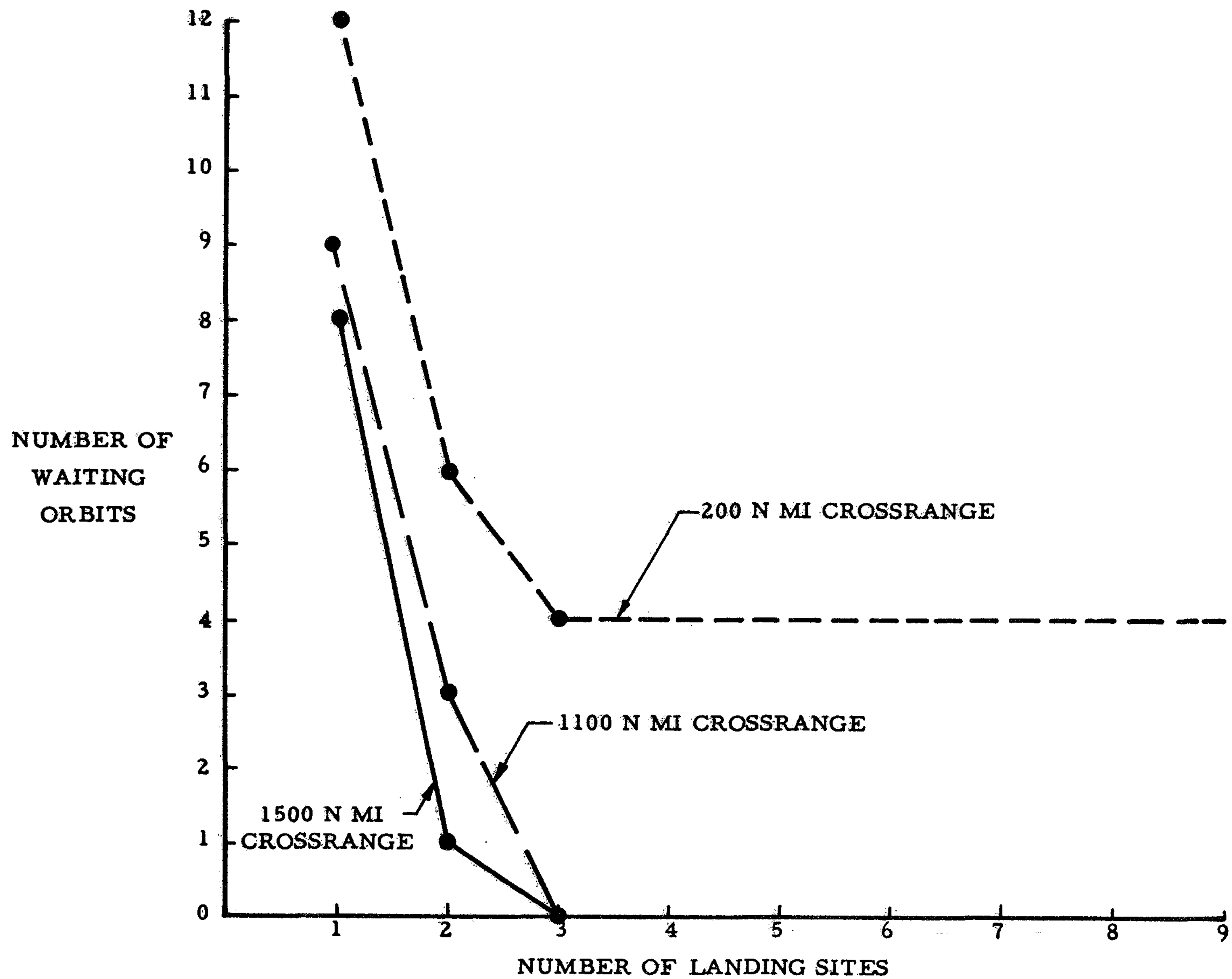

Figure D-8. Maximum Return Delay from 260 n mi, 31.5° Orbit with Optimum Site Selection (ETR -- Site No. 1)

APPENDIX E

EMERGENCY ΔV REQUIREMENTS

APPENDIX E

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APPENDIX E

EMERGENCY ΔV REQUIREMENTS

E.1 GENERAL*

In order to help determine the applicability of IP elements to an escape or rescue operation, it is necessary to establish the performance requirements imposed by the various IP missions. Should IP elements be unable to meet such requirements, new vehicles would be required to meet these ΔV requirements. A review of earth and lunar missions was therefore conducted to determine the range of emergency situations which might require assistance from a Space Rescue Vehicle (SRV), and to derive the maximum performance requirements which each mission class would impose upon an SRV. This review of emergency situations was also used to establish performance requirements which abort of the basic mission would impose. The inherent performance capability of the mission vehicle was then compared to the abort requirements to determine its adequacy.

This review covered both low earth and geosynchronous missions. It assumed that emergency situations could occur in low earth orbit (LEO), in geosynchronous orbit (GEO) and in transit between these orbits. The review was not concerned with vehicles in transit between the ground and low earth orbit.

The lunar mission spectrum was similarly examined. Both starting and final destination orbits were treated, as well as the transit phases between them.

The emergency spectrum considered included such situations as medical emergencies requiring earliest possible return either to earth or to an intermediate haven with appropriate medical facilities. Also considered was failure of the main propulsion system resulting in the inability to perform orbit injection or orbit circularization, an impact upon either lunar or

*This Appendix is based on the work of E. J. Rattin and others as indicated.

earth surface, or in escape into the solar system without return to low earth orbit. The SRV might have to travel considerable distances to make rendezvous with a distressed vehicle (DV) suffering a propulsion failure.

Another objective of this review was to determine where the SRV should be based. In the case of lunar missions, basing could be assumed in low earth orbit, in lunar orbit, and on the lunar surface. In the instance of earth orbits, basing could again be in low earth orbit or in geosynchronous orbit. Figures E-1 and E-2 summarize all the emergency ΔV requirements examined.

A fundamental assumption underlying the results reported in succeeding sections of this appendix was that all of the emergency situations treated had an equal probability of occurring. The selection of the maximum ΔV requirement for a particular mission regime, based on a particular emergency situation and rescue mode, does not imply a judgment that the causative emergency situation had a high probability of occurring and that a rescue vehicle should be available to meet this requirement.

E.2 ANALYSIS

E.2.1 DV Emergency ΔV Requirements

The emergency situations considered for self-help by the DV involved abort of the mission or a faster than nominal return from either lunar orbit or fly-by for reasons such as medical emergencies or subsystem failures. The discussion of lunar missions will precede that of geosynchronous missions.

E.2.1.1 Lunar Missions

E.2.1.1.1 Midcourse Abort*

Figure E-3 shows a typical abort situation for a translunar flight phase. After translunar injection, about 17,000 fps is typically available to complete

*This subsection is based on the work of V. Chobotov, Ref. E-1.

a lunar mission. This remaining ΔV must cover not only the abort ΔV but the earth orbit injection ΔV as well. This latter maneuver requires a ΔV in the order of 10,000 fps.

Two return times, representing near extremes are given in Figure E-3. The shorter time of 11 hours requires more total ΔV (14,000 fps for the abort maneuver alone) than remains in the DV. Since the DV could not inject itself into low earth orbit, a fly-by rendezvous with an SRV would have to be arranged. The longer 52-hour return represents a near upper limit since it is not much shorter than a free return after a swingby of the moon.

If the entire 17,000 fps is utilized, the return time to low earth orbit is about 35 hours after translunar injection. Adding ΔV to the mission vehicle in excess of that needed to perform the nominal lunar mission would reduce this time.

The point along the flight path at which abort becomes ineffective in reducing time of return, is a function of the remaining velocity capability of the DV. This in turn may be a function of the emergency situation itself and of the ability of the DV to jettison payload. Beyond that point it is only feasible to assure that the vehicle is in a free-return trajectory as discussed in the following section. Very little ΔV is required to steer the vehicle into such a trajectory, and the secondary propulsion system should be designed with such a capability as a backup to the main propulsion system.

E.2.1.1.2 Return to Earth without Lunar Injection

If midcourse abort is impractical or if the emergency requiring mission abort does not occur until after the "point of no midcourse abort," the moon's gravitational attraction will produce a return trajectory. This situation is shown on Figure E-4. If the DV is still on the nominal trans-lunar flight path, i.e., the emergency has not brought about major trajectory perturbations, only small amounts of ΔV (in the order of 50 fps) are required to produce a so called "free return" trajectory. Such a return trajectory would require about 72 hours after translunar injection (TLI) to reach LEO. If this is considered too slow and if the main propulsion system is functioning, the 6000 fps of ΔV available from a nominal mission budget can be used to speed this return. If the return time is to be cut in half, to about 36 hours, only about 5300 fps are required. An even faster return would therefore be feasible with a functioning main propulsion system.

E.2.1.1.3 Fast Return to Earth from Lunar Orbit

As already stated, the nominal lunar return flight time would be about three days if velocity requirements were to be minimized and if the emergency did not require a faster return. With the DV in orbit around the moon as shown on Figure E-5, a ΔV of about 3000 fps (no plane change) would be required to insert the DV into a nominal return trajectory. A 50% reduction in flight time could be accomplished by the expenditure of an additional 5000 fps, but at the cost of leaving insufficient ΔV to perform low earth orbit insertion (LEOI) for a nominal mission budget. This in turn would require rendezvous with a SRV during fly-by of the earth to rescue the crew.

E.2.1.2 Earth Missions

E.2.1.2.1 Midcourse Abort*

Because of the emphasis on orbital vehicles and emergencies occurring during orbital operations, only the abort from a Hohmann Transfer to geosynchronous orbit was treated in this analysis. It is obvious that mission abort may also be required for the EOS during its ascent from the ground and that the requirements for such an abort should be studied.

As already discussed for the lunar mission, medical problems, malfunction of the EC/LS, or other causes may make it desirable or necessary to return to low earth orbit and to transfer to a permanent haven more rapidly than

*This subsection is based on the work of V. Chobotov, Ref. E-2.

feasible by completion of the Hohmann Transfer ellipse into apogee and return therefrom. A complete round trip from Hohmann Transfer Injection (HTI) to LEOI on a minimum energy trajectory would require about 10.5 hours. It might, in some cases be desirable to abort the mission by the application of retro impulse along a velocity vector optimized for shortest return time. In the example shown on Figure E-6, the retro impulse was applied at an altitude of about 2000 n mi; that is, shortly after completion of HTI. The reduced velocity of approach to LEO from that normally occurring when returning from GEO, brings about a reduced EOI velocity requirement. As shown on Figure E-7, about 8200 fps are nominally required for a normal Hohmann transfer return including a small plane change at perigee. In the abort case, the same plane change requirement exists, since the ascent portion of the transfer trajectory is performed at an inclination about two degrees different from that of the starting orbit. If time is not critical, then the nominal return (10.5 hours) can be used without expenditures of any additional ΔV other than that for LEOI.

E.2.1.2.2 Fast Return to Low Earth Orbit

Although nominal return from geosynchronous orbit is only about 5.25 hours, the need for faster return may arise. As indicated on Figure E-8, the transfer time reductions are not impressive and require considerable additional ΔV. Approximately 1000 fps would be available out of the nominal mission budget if the return to low earth orbit were made without plane change, and LEOI would result in an equatorial orbit. This would require rendezvous with an SRV for crew removal and transfer to a space station or to an EOS orbiter for earth reentry. Any really effective total trip time reduction requires an increase in mission vehicle ΔV so that plane change capability is not sacrificed and more rapid rendezvous with a safe haven can be achieved.

An optimally fast return from GEO requires that the plane change and retro impulse be applied along the circular orbit track beyond the location on the major axis of the Hohmann Transfer ellipse (line of apsides) at which the nominal, minimum energy transfer retro firing would have occurred. The degree of overshoot at this fast return injection burn is a function of the desired return speed and corresponds to about 20 degrees for a ΔV of 1800 fps. The return trajectory is designed to result in a perigee at the same point of tangency with LEO at which the nominal transfer perigee would occur, i.e., on the major axis of the transfer ellipse.

E.2.2 Space Rescue Vehicle ΔV Requirements*

Table E-1 shows the variety of situations in which aid from an SRV might be required and which were considered in this study. References E-1, E-3, and E-4 provided the basic information presented in the following sections.

E.2.2.1 Lunar Missions

E.2.2.1.1 SRV in Lunar Orbit or at Lunar Surface Base

E.2.2.1.1.1 Rescue from DV in Approach to the Moon

The emergency situations considered under this heading include those in which the DV has performed a nominal translunar injection, and perhaps also a nominal midcourse correction, but where the main propulsion system has failed prior to or at the time of lunar orbit injection. The DV in this case would return to earth vicinity if in a free return trajectory, or it could be injected into a free return trajectory with use of secondary propulsion. However, since low earth orbit injection could not be achieved it might be desirable for an SRV to rendezvous with the DV near the moon. An SRV based at the Orbiting Lunar Station (OLS) would require considerably less ΔV for such a rendezvous than an SRV based in LEO, Figure E-9.

*This subsection is based in part on the work of V. Chobotov and R. D. Sugar, Refs. E-1 and E-3.

The ΔV requirements for descent/ascent between a 60 n mi lunar orbit and a lunar surface base vary from about 6000 fps for the coplanar case to about 12,000 fps for a 90 degree plane change in low lunar orbit, Figure E-10. To rendezvous with a DV in a fly-by orbit tangent to and in the plane of the lunar orbit requires about 3000 fps when starting from the lunar orbit. An approximately equal ΔV is required to return to lunar orbit. This requirement increases to a maximum of 12,000 fps if the rendezvous point is not at the point of tangency with the lunar orbit but is along the fly-by hyperbola either prior to arrival at the point of tangency or past this point. The highest rescue ΔV requirement in lunar orbit thus exists when an SRV based on the lunar surface must intercept an incoming DV far from its point of closest moon approach and must perform 90-degree plane changes during both departure from the ground and return to the ground. This corresponds to the 39,000 fps ΔV requirement shown on Figure E-9. Plane change requirements would also add to the ΔV needed for SRV departure from lunar orbit.

It should also be noted that plane changes at high altitudes impose lower ΔV requirements. If allowable rescue mission reaction time permits injection into elliptical lunar orbits for the purpose of performing plane changes at the apogee of such orbits, a considerable reduction in velocity requirements can be achieved. This technique is discussed later in this section.

Figure E-9 shows that the minimum ΔV requirement for the case of nominal approach to the moon calls for lunar orbit basing for the SRV and return to a safe haven in lunar orbit. Even the return to low earth orbit (LEO) after rendezvous with the DV, instead of return to lunar orbit, would require little more of the SRV than the case of an intercept of the DV near earth by an LEO-based SRV which, in the best case, expends about 20,000 fps.

Another requirement for rescue would occur in the situations depicted on Figure E-11 where a three-burn lunar injection maneuver is only partially successful. The velocity requirements shown here are based on the assumption of three-burn rendezvous trajectories taking full advantage of the lowered plane change velocity requirement if that maneuver is performed at altitude. The emergency situation depicted here assumes that the planned lunar insertion maneuver involved three burns since the encounter geometry requires a plane change in excess of about 10 degrees. In such missions it becomes more economical to first inject into a lunar ellipse, perform the plane change burn at apolune, and circularize with the Orbiting Lunar Station (OLS) orbit at perilune. If propulsion should fail after the first injection burn, the DV orbit will not be coplanar with the OLS orbit and the SRV from that orbit will have to perform the plane change for rendezvous. If the second burn were performed before propulsion failure, then the SRV would only need to perform phase matching and inject into the DV orbit at perilune, since the orbits would be coplanar.

The most optimum elliptic orbit for minimum plane change velocity and total minimum injection velocity is one with an apolune of about 10,000 n mi, requiring an injection velocity at perigee of about 2000 fps from an SRV in a 60 n mi circular orbit. The same ΔV would be required to return the SRV to the OLS orbit. Here again the minimum rescue ΔV is attained with lunar orbital basing for the SRV, and with the safe haven also in lunar orbit. However, even the return to earth by the SRV is feasible, since it requires about 16,000 fps of ΔV, which can be obtained from planned Space Tugs.

The final group of emergency situations under this heading are shown on Figure E-12 and assume that the approaching DV is either going to impact the moon or is on a trajectory that does not return it to earth. The ΔV requirements for rescue are comparable to some of the situations discussed for the nominal approach to the moon because approach velocities are assumed essentially nominal.

The off-nominal conditions assumed here involve primarily guidance errors combined with the inability to perform LOI or course correction to avoid impact or escape. The velocity of arrival is assumed to be essentially nominal. Disastrous overspeed conditions could exist, of course, but since no rational limit can at this time be set to such conditions, no consideration was given to them.

In a worst case of impact the SRV would have to intercept the DV prior to its arrival on the moon, with a consequent maximum rendezvous velocity requirement of about 12,000 fps from lunar orbit. If the SRV were based on the lunar surface, as much as 12,000 fps more might have to be expended for ascent and plane change. Return to lunar orbit would require another 3000 fps, and a final return to the LSB with maximum plane change would cost an additional 12,000 fps, totalling 39,000 fps.

The minimum ΔV requirement is represented by a rendezvous with the DV in a fly-by (escape) orbit and with the SRV starting from lunar orbit (LO). In this instance, only 3000 fps are required to rendezvous with the DV and another 3000 fps to return to LO. These ΔV's are similar to those quoted for the free return case, but assume that the approach trajectory lies in the plane of the lunar orbit. Plane change would add to these ΔV requirements.

E.2.2.1.1.2 Rescue from DV in OLS Orbit

Figure E-13 shows two of the situations considered under this heading. The safe haven to which the SRV brings the DV crew can be on the lunar surface or back at earth. The third alternative, that of the safe haven being the Orbiting Lunar Station, is also valid but requires so little ΔV from the SRV that it was not shown or analyzed here.

As discussed earlier, if the SRV is based on the lunar surface and if a return to the LSB is required, the ΔV requirements might reach 22,000 fps. Here again, orbital basing of the SRV represents minimal velocity requirements. If the OLS is not available for a safe haven, direct return of the SRV to earth after rescue would appear feasible in the sense of not imposing impossible ΔV requirements.

E.2.2.1.2 Space Rescue Vehicle in Low Earth Orbit

E.2.2.1.2.1 Rescue from DV in Approach to Earth

An SRV in LEO can react to a DV which is unable to perform LEOI after returning from the moon and which therefore is on an escape trajectory or headed for an impact on the earth surface. Nominally, LEOI from a lunar mission requires about 10,000 fps of ΔV. As a consequence, a SRV starting from LEO would require at least twice that much, or 20,000 fps, to match velocities with the incoming DV on a nominal trajectory and then to return to LEO. If, however, the DV approach trajectory is off-nominal, caused by overspeed at trans-earth injection, and is leading to either an impact or a fly-by trajectory the ΔV requirement on the SRV might increase to very large values, well beyond the likelihood of SRV capability. For this reason no quantitative analysis was performed.

E.2.2.1.2.2 Rescue from DV in Lunar Orbit

Sending an SRV to the moon would involve, as a minimum, a ΔV budget identical to that of the basic lunar mission and might exceed it, depending on the lunar approach geometry at the time of rescue. Nominal lunar missions are planned around departure and arrival dates requiring minimum plane changes on both earth departure and arrival, and lunar arrival and departure. Under such optimal conditions, a lunar mission requires about 27,600 fps. Since it is unlikely that a rescue mission could be dispatched under such optimal conditions, an SRV in standby at LEO for dispatch to lunar orbit will probably need at least an additional 1500 fps if a three-impulse insertion maneuver is performed to complete a maximum 90 degree plane change at LOI. Since this maneuver may take as long as 36 hours to perform, other insertion maneuvers involving only a double or a single impulse may be desirable to accomplish rescue in shorter time periods. In that event, as much as 6000 fps of additional ΔV may be required for situations needing maximum plane change capability.

More study effort is needed to determine the optimum combination of SRV performance with speed of rescue, since additional ΔV above the nominal would also be required to return to an earth orbit accessible to an EOS, without excessive waiting time prior to trans-earth injection.

E.2.2.1.2.3 Rescue from DV in LEO

If the DV has been able to inject itself into low earth orbit according to the nominal mission plan, it will be in an orbit accessible to a space station or an Orbital Propellant Depot (OPD) from which SRV's may be dispatched at ΔV expenditures in the order of a few hundred feet per second. If a more rapid mission abort from lunar orbit resulted in an off-nominal lunar departure date, the earth arrival orbit may differ considerably from the station or OPD orbit in inclination and ascending node. Some of these possible arrival orbits may be accessible to a ground-launched SRV. Most may not, if the lunar departure were entirely random. The ΔV capability of the SRV will permit it to perform some on-orbit plane change. However, since plane change in LEO is very expensive in terms of ΔV, it is not reasonable to assume that totally random arrival orbits will always be accessible to an SRV either based in a nominal station orbit or ground launched. It is desirable, therefore, that lunar aborts not be random in time but rather that TEI be performed at times that permit earth arrival orbits accessible to an SRV in low earth orbit or ground launched. No quantitative analysis of this problem has been performed during this study, nor were references to outside analyses uncovered.

E.2.2.2 Earth Missions

E.2.2.2.1 SRV in GEO

E.2.2.2.1.1 Rescue from DV in Approach to GEO

Figure E-14 shows the problem of an off-nominal DV approach to geosynchronous orbit; it is off-nominal in the sense that overspeed has occurred at Hohmann Transfer injection (HTI) in LEO and the disability of the DV main propulsion system prevents correction of the condition. As a consequence, the DV is on an escape trajectory and an SRV may be required to remove its crew and return it to LEO. This type of emergency is the only potentially difficult performance requirement imposed on an SRV by the geosynchronous mission.

Underspeed at HTI would return the DV to LEO automatically, while inability to perform GEOI would also return the DV to LEO. In the first instance, an SRV in LEO could rendezvous with the DV at perigee at a total ΔV requirement of less than 16,000 fps. In the second instance, the LEO based SRV ΔV requirement would be about 16,000. If the SRV is GEO based, the requirement would be decreased by about 2000 fps for return to earth orbit haven.

In the instance of the problem shown in Figure E-14, the ΔV requirement could be large. An overspeed condition at HTI of about 1000 fps, for example, would result in a one-way rendezvous ΔV requirement of approximately 5000 fps for the SRV. Since the DV could have a maximum overspeed of 14,000 fps at HTI, based on its nominal mission budget, the SRV requirements could reach unachievable values. Such an extreme overspeed condition is very unlikely, however. Further study is required to determine rational values of off-nominal conditions during approach to GEO, if it is desired to size an SRV stationed in GEO.

E.2.2.2.1.2 Rescue from DV in GEO

As shown in Figure E-15, it may be required to rescue a crew from a DV trapped in GEO. Unless a fast return is desired, the SRV ΔV requirements are identical to those of the basic mission, i.e., about 6000 fps to retro and perform plane change, and about 8000 to 8200 fps to perform EOI. The problem of fast return was already discussed in Section E.2.1.2.2. An additional 1800 fps during retro would provide a rather minor reduction in flight time. In addition, LEOI would also be slightly more demanding in ΔV.

E.2.2.2.2 SRV in LEO

E.2.2.2.2.1 Rescue from DV in Approach to LEO

If the DV is in a nominal approach to LEO, the SRV ΔV requirements for rendezvous with the DV and to return to the LEO are between 16,000 and 16,400 fps, depending upon the plane change to be performed at LEO.

The case of the off-nominal approach is shown on Figure E-16. If a retro maneuver were performed at GEO with an overshoot of about 1000 fps, the additional ΔV required of the SRV in LEO in order to rendezvous with the DV during fly-by would be about the same amount. Return to LEO is equal in ΔV requirement to that for rendezvous.

E.2.2.2.2.2 Rescue from DV in GEO

As Figure E-17 shows, the ΔV requirement for rescue from DV in geosynchronous orbit is identical to that for the basic geosynchronous mission, except for the addition of small amounts of ΔV for phasing with the DV and for rendezvous and docking.

E.3 SUMMARY

E.3.1 ΔV Needs of DV to Assist in Rescue

Figure E-18 provides an overview of the results detailed in previous sections for both earth and lunar mission regimes. When these requirements are compared to the ΔV available, one finds that, if DV propulsion systems are functioning, mission abort may be a feasible means of self-help. This applies to those emergency situations where the crew is functioning and where the critical DV subsystems allow the crew to remain with the vehicle until safe haven is reached. Table E-2 shows that abort to a safe haven can be accomplished relatively rapidly for either lunar or earth mission regimes with available performance margins, and that additional ΔV augmentation will only be marginally useful in reducing return times.

E. 3. 2 ΔV Needs of SRV to Perform Rescue Mission

Figures E-19 and E-20 summarize the SRV emergency ΔV analysis as a function of DV emergency, SRV basing, and location of final haven. The salient characteristics of these figures have been extracted and presented in Table E-3 for lunar missions. This table shows that lunar orbit basing leads to the smallest SRV ΔV requirement, particularly if the safe haven can also be located in lunar orbit. This holds true only for emergencies occurring in transit to the moon or while in lunar orbit. Emergencies occurring during the return trip to earth must be dealt with by an SRV based in LEO.

Table E-4 shows that for emergencies occurring on the way to geosynchronous orbit or in GEO, SRV basing in GEO imposes the minimum ΔV requirement. SRV basing in LEO in addition to GEO appears unnecessary. The Hohmann Transfer orbit is a repeating orbit; i.e., if LEOI is not performed, the DV returns to GEO in the original transfer ellipse which repeats until orbit degradation at perigee alters the trajectory. The total orbit ellipse requires about 10.5 hours of travel; therefore, ascent to GEO or return from GEO requires about 5.25 hours. If, therefore, main propulsion failure of the DV prevents its insertion into LEO when returning from GEO, it may receive aid from the SRV based in GEO by waiting about 5.25 hours, or some multiple thereof, until the trajectory returns the DV to GEO at a longitude accessible to the SRV. The longer waiting periods may be needed because, if the SRV is in a true synchronous orbit, its period is 24 hours and it will have moved a considerable distance from the apogee of the repeating Hohmann Transfer orbit by the time the DV returns to GEO 10.5 hours after leaving. The SRV will therefore have to enter a phasing orbit such that it can rendezvous with the DV on the latter's second or third return to GEO.

E. 3. 3 Concluding Remarks

The data presented in this appendix represent only an overview of the main classes of emergency ΔV requirements. A great variety of situations must be considered in sizing the propulsion capability of an SRV, and in determining preferred basing concepts. Such decisions must also consider access time and the relative capabilities of available safe havens. Not the least of the considerations involved in basing the SRV will be the relative probability of events requiring rescue, i. e., the probabilities of main propulsion failure, guidance failure, etc.

Additional study recommendations include the search for repeating lunar orbits which would return the DV to the vicinity of the moon in the event LEOI could not be performed. This would be useful since rescue from lunar orbit would be considerably less demanding of SRV performance capability than rescue near earth.

Further detailed attention should also be given to the problem of accidental overspeed at HTI, or retro from GEO, and the likely values of ΔV required of the rescue vehicle in those instances.

References

E-1. V. A. Chobotov, Orbital Mechanics of Space Rescue Operations, Report No. TOR-0059(6759-05)-1, Vol V, Aerospace Corp. (1 July 1970).

E-2. V. A. Chobotov, "Velocity Requirements for Abort from Hohmann Transfer Orbit to Synchronous Altitude," ATM-71(7212-04)-3, Aerospace Corp. (12 February 1971). (Aerospace Technical Memoranda cannot be distributed outside The Aerospace Corporation.)

E-3. R. D. Sugar, Velocity Requirements for Operations Between the Lunar Surface and a Lunar Orbit Space Station, Report No. TOR-0059(6758-01)-4, Aerospace Corp. (16 July 1970).

E-4. Midterm Briefing: Lunar Mission Safety and Rescue, Report No. MA-138T-1, Lockheed Missiles and Space Co. (November 1970).

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Lunar Mission Safety and Rescue Study, Final Report No. A984262, Lockheed Missiles and Space Co. (June 1970).

Schreiber, A. L., "Plane Change Penalty for Unscheduled Abort from the Lunar Surface -- Case 105-4," Memorandum for File, No. B 70-10002, Bellcomm, Inc. (1 October 1970).

Table E-1. Emergency Situations Considered Candidates for SRV Aid

DV in Lunar Mission		DV in Earth Mission	
SRV in OLS or at LSB	SRV in LEO	SRV in GEO	SRV in LEO
o <u>Rescue from DV in Approach to Moon</u> No LOI (fly-by) Partial LOI (elliptic orbit) Impact Trajectory Escape Trajectory o <u>Rescue from DV in OLS Orbit</u> No TEI	o <u>Rescue from DV in Approach to Earth</u> No EOI Partial EOI Impact Trajectory Escape Trajectory o Rescue from DV in LO	o <u>Rescue from DV in Approach to GEO</u> No GEOI (fly-by) Escape o <u>Rescue from DV in GEO</u> No TEI	o <u>Rescue from DV in Approach to Earth</u> No EOI Partial EOI Impact Escape o <u>Rescue from DV in GEO</u> No TEI o <u>Rescue from DV in LEO</u>

Table E-2. Distressed Vehicle ΔV Needs

	ΔV, fps		Time to LEO, Hr.
<u>Lunar Mission</u>			
Midcourse Abort After TLI	Available*	~17,000	~35 (After TLI)
	Augmented	By 8000	~20
Return Without LOI	Available*	~17,000	~48 (After TEI)
	Augmented	By 2000	~36
<u>Geosynchronous Mission</u>			
Fast Return From GEO	Available**	~14,000	5.25
	Augmented	By 2200	3.5
Midcourse Abort From ~2000 n mi Alt.	Available**	~20,000 (Only 15,000 Req.)	~1.5 (After HTI)

*Based on nominal mission budget of ~27,000 fps

**Based on nominal mission budget of ~28,000 fps

Table E-3. Space Rescue Vehicle ΔV Needs* -- Lunar Mission

DV Situation	SRV Origin	Haven	ΔV Range (fps)	
			Max	Min
Impact Trajectory with Moon	LSB	LSB	39,000	
Incomplete Lunar Orbit Injection		OLS		11,000
Impact Trajectory with Moon	OLS	LEO	22,000	
Incomplete Lunar Orbit Injection		OLS		4,400
Trapped in Lunar Orbit	LEO	LEO	27,000	
Unable to Perform LEO Injection		LEO		20,000

*Trajectory changes only.

Table E-4. Space Rescue Vehicle ΔV Needs* -- Geosynchronous Mission

DV Situation	SRV Origin	ΔV Range (fps)	
		Max	Min
In Escape Trajectory Unable to Depart GEO	GEO	14,000 +f(X)**	14,000
Unable to Depart GEO In Midcourse Abort and No LEO Injection Capability	LEO	28,000	16,000

*Notes: Trajectory changes only; SRV returns to LEO in all cases.

**"X" is overspeed imparted at Hohmann Transfer injection.

DISTRESSED VEHICLE

- MIDCOURSE ABORT FROM EARTH-TO-LUNAR ASCENT
- FAST RETURN WITHOUT LUNAR ORBIT INJECTION

SPACE RESCUE VEHICLE

- RESPONSE TO DV (LUNAR REGION)*
  - INCOMPLETE LUNAR ORBIT INJECTION
  - UNABLE TO PERFORM LOI
  - TRAPPED IN LUNAR ORBIT
  - TRAPPED ON LUNAR SURFACE
  - DV ON ESCAPE / IMPACT TRAJECTORY
- RESPONSE TO DV (EARTH REGION)**
  - UNABLE TO PERFORM LEOI
  - DV ON ESCAPE / IMPACT TRAJECTORY

* SRV BASED LO/LS **SRV BASED LEO

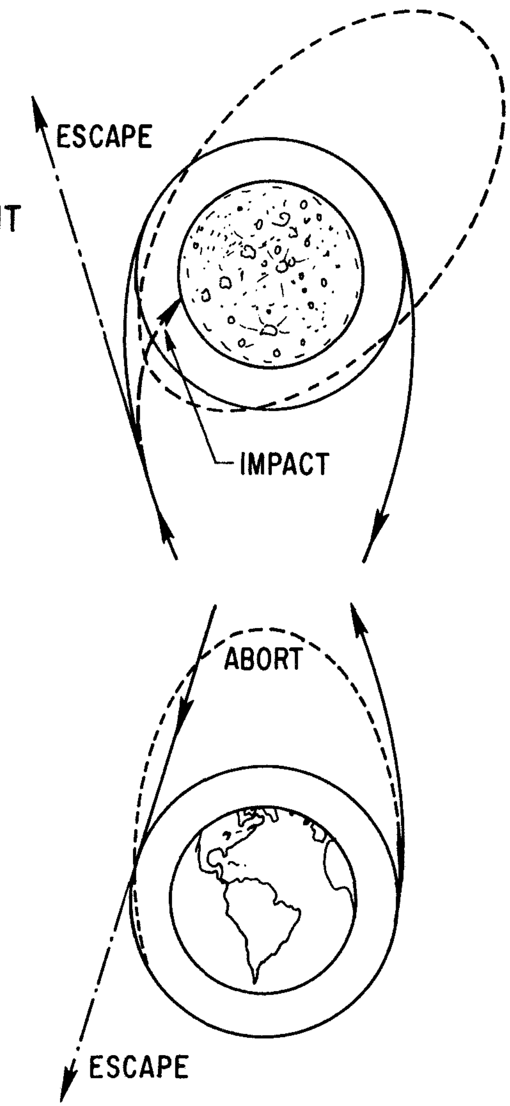


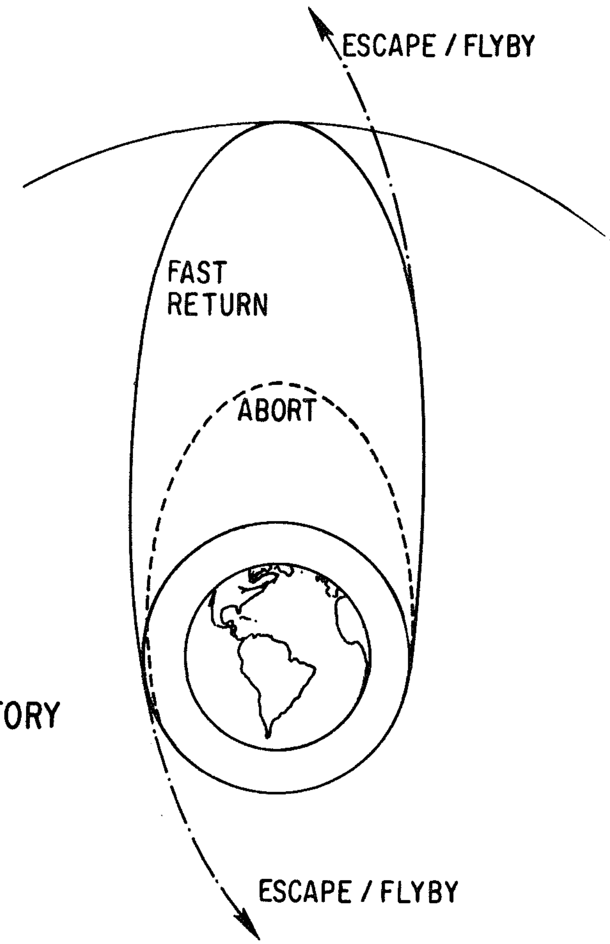
Figure E-1. Mission Situations Examined--Lunar

DISTRESSED VEHICLE

- MIDCOURSE ABORT FROM GEOSYNCHRONOUS ASCENT
- FAST RETURN FROM GEO

SPACE RESCUE VEHICLE *

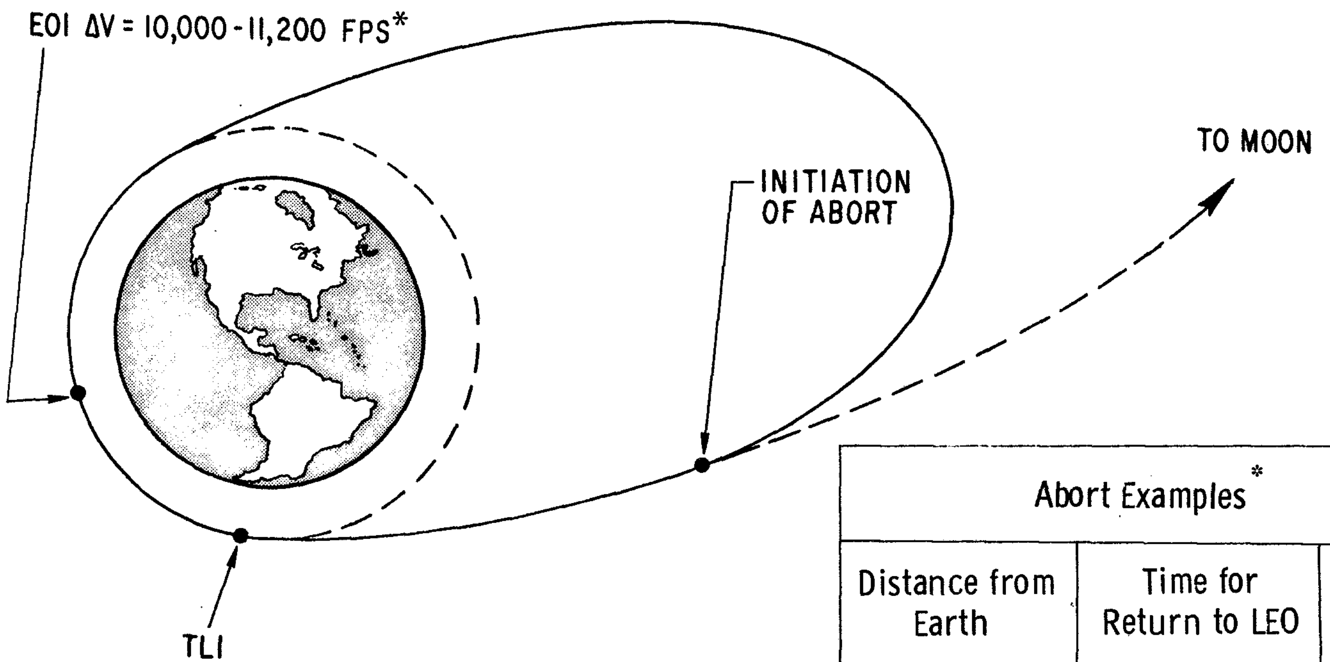
- RESPONSE TO DV
  - TRAPPED IN LEO
  - TRAPPED IN GEO
- RESPONSE TO DV ON ESCAPE / FLYBY TRAJECTORY
- UNABLE TO PERFORM LEO INJECTION



* BASED IN LEO / GEO

Figure E-2. Mission Situations Examined--Earth Orbit

● Lunar Mission: Abort from Lunar Transit Phase

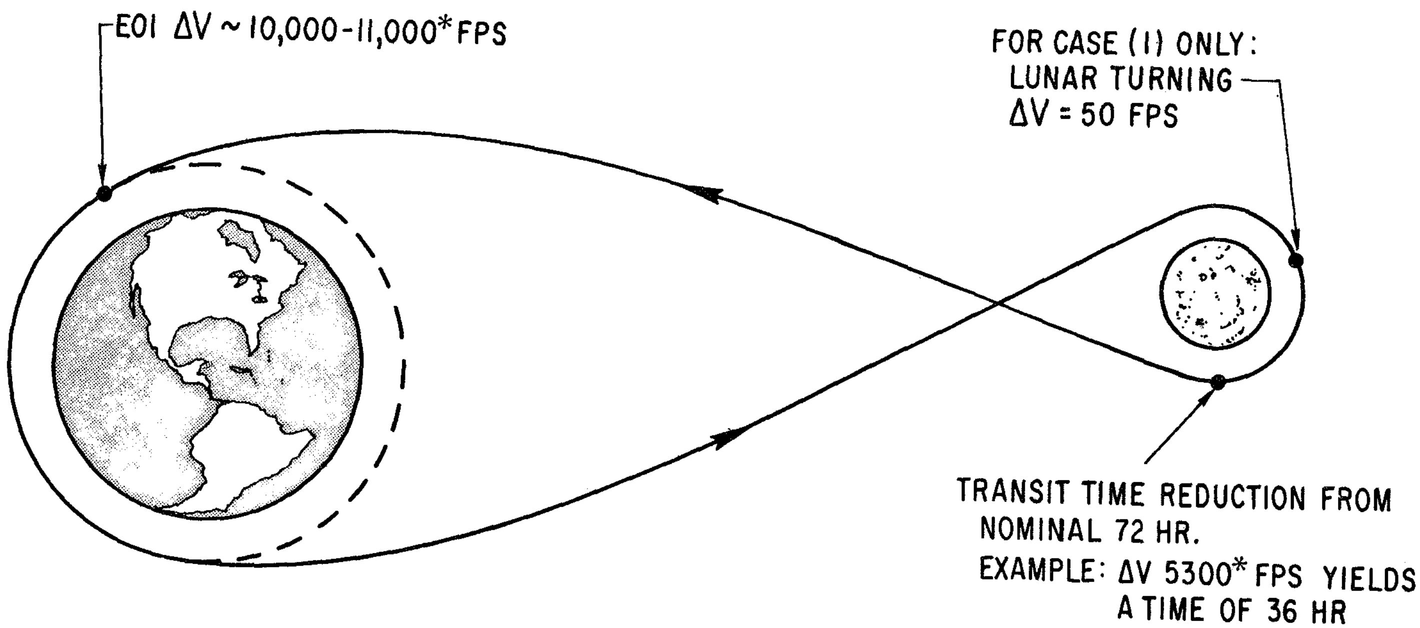


Abort Examples*		
Distance from Earth n. mi.	Time for Return to LEO hr.	ΔV of Abort FPS
60,000	11	14,000
	52	4,000

Reasonable Total DV ΔV Requirements Range after TLI ~14,000 to 25,200 FPS*

Figure E-3. DV Emergency ΔV Needs for Abort from Lunar Transit Phase

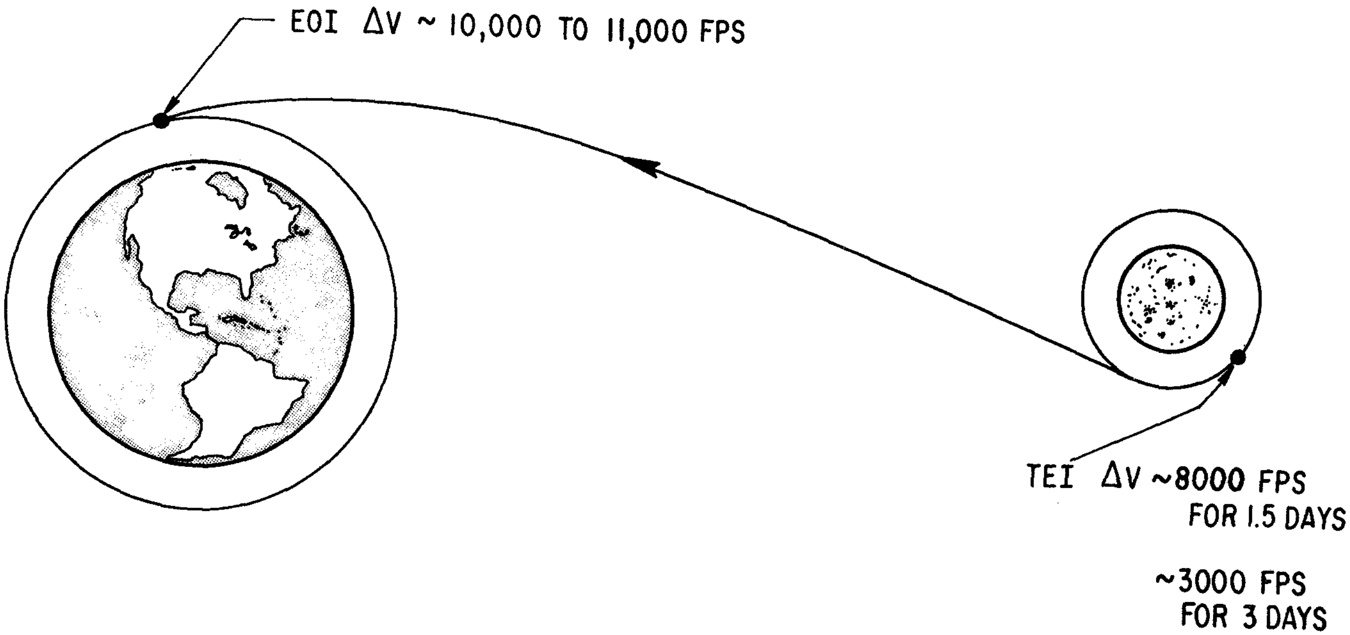
- Lunar Mission: Fast Return to Earth - No LOI: (1) No Free Return
  (2) Free Return



Total DV ΔV Requirement after TLI (either case) ~ 10,000 to 16,300* FPS

Figure E-4. DV Emergency ΔV Needs for Fast Return to Earth from Lunar Mission--No LOI

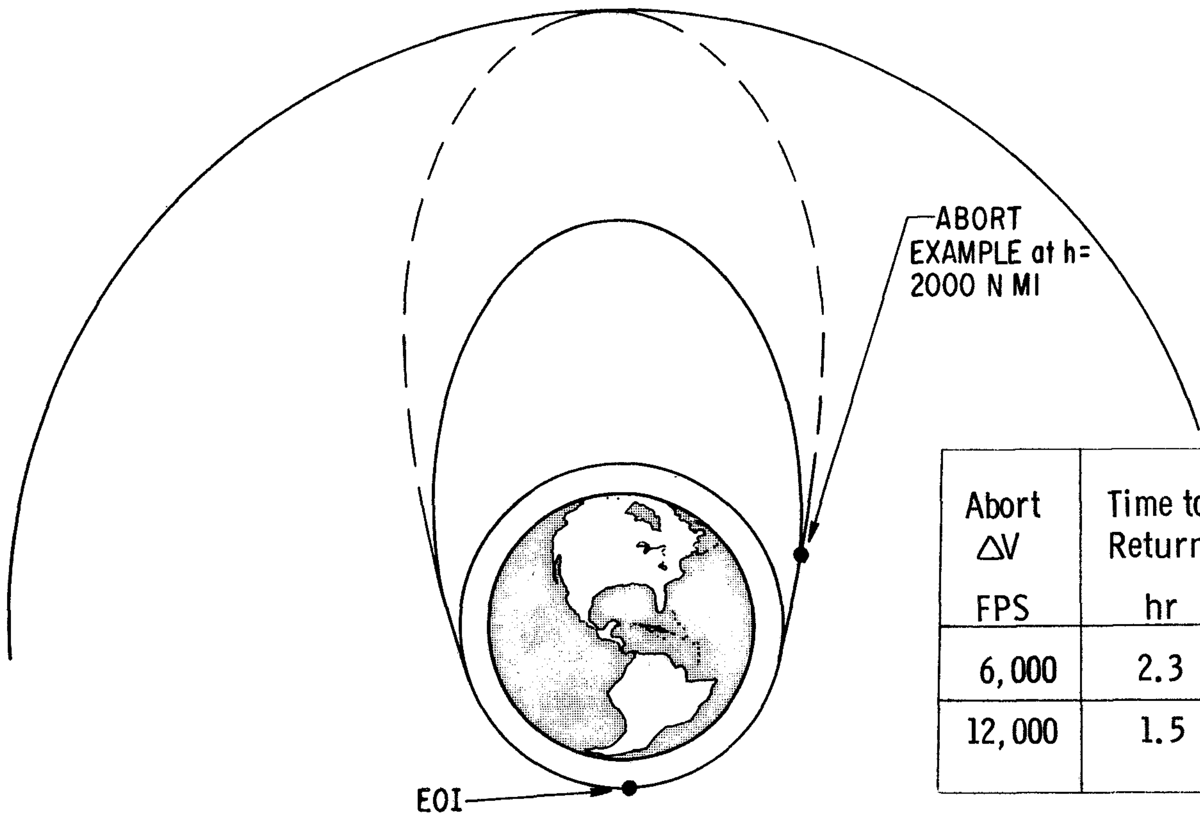
- Lunar Mission: Fast Return to Earth - From LO



Total DV ΔV Requirement out of LO ~13,000 FPS (3 days)
~19,000 FPS (1.5 days)

Figure E-5. DV Emergency ΔV Needs for Fast Return to Earth from Lunar Orbit

• Geosynchronous Mission: Abort from Hohmann Transfer Phase



Abort ΔV FPS	Time to Return hr	EOI ΔV FPS
6,000	2.3	4600
12,000	1.5	3200

Total DV ΔV Requirement after Hohmann Transfer Injection (HTI) ~ 10,000 to 15,000 FPS

Figure E-6. DV Emergency ΔV Needs for Abort from Hohmann Transfer Phase --Geosynchronous Mission

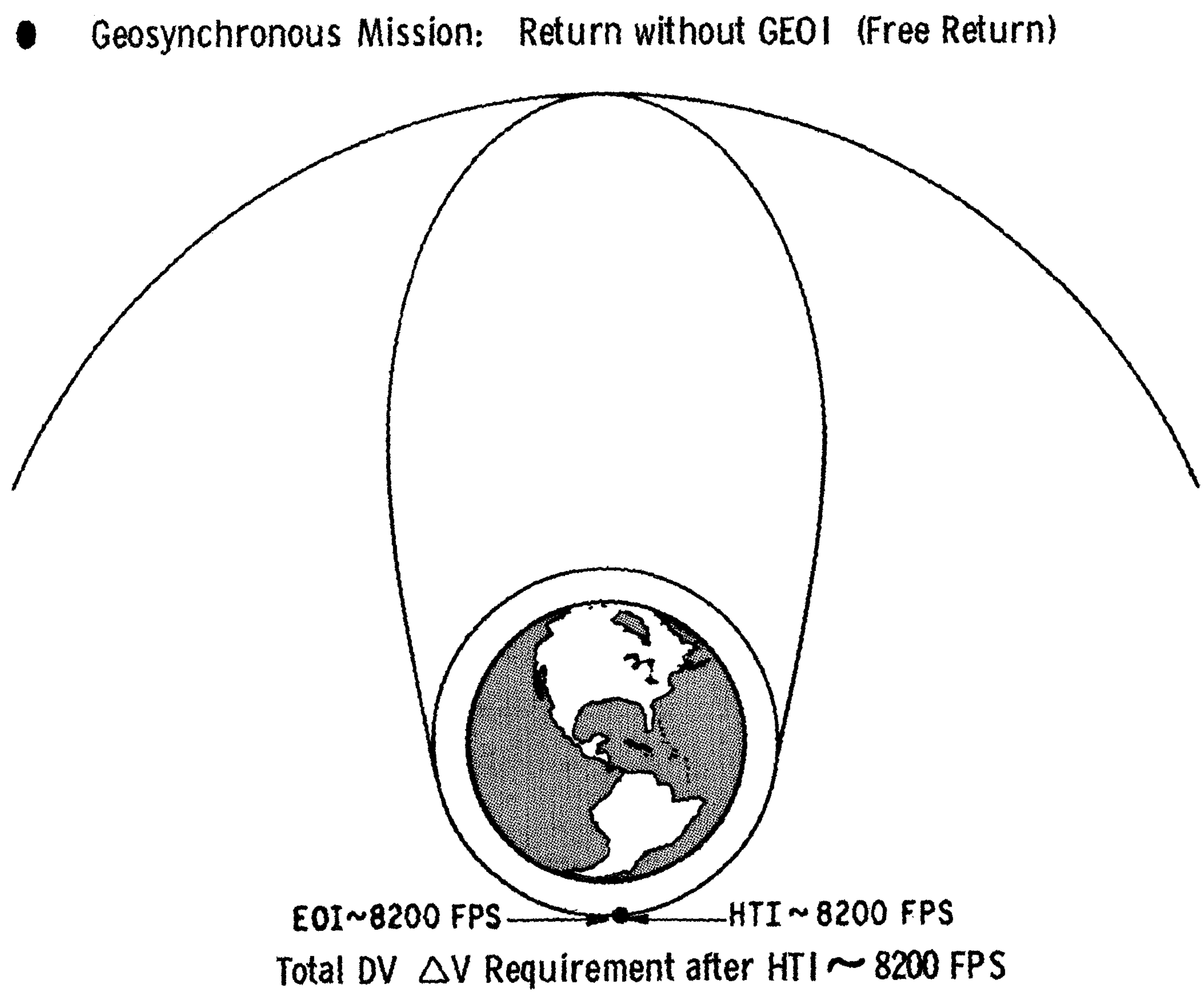
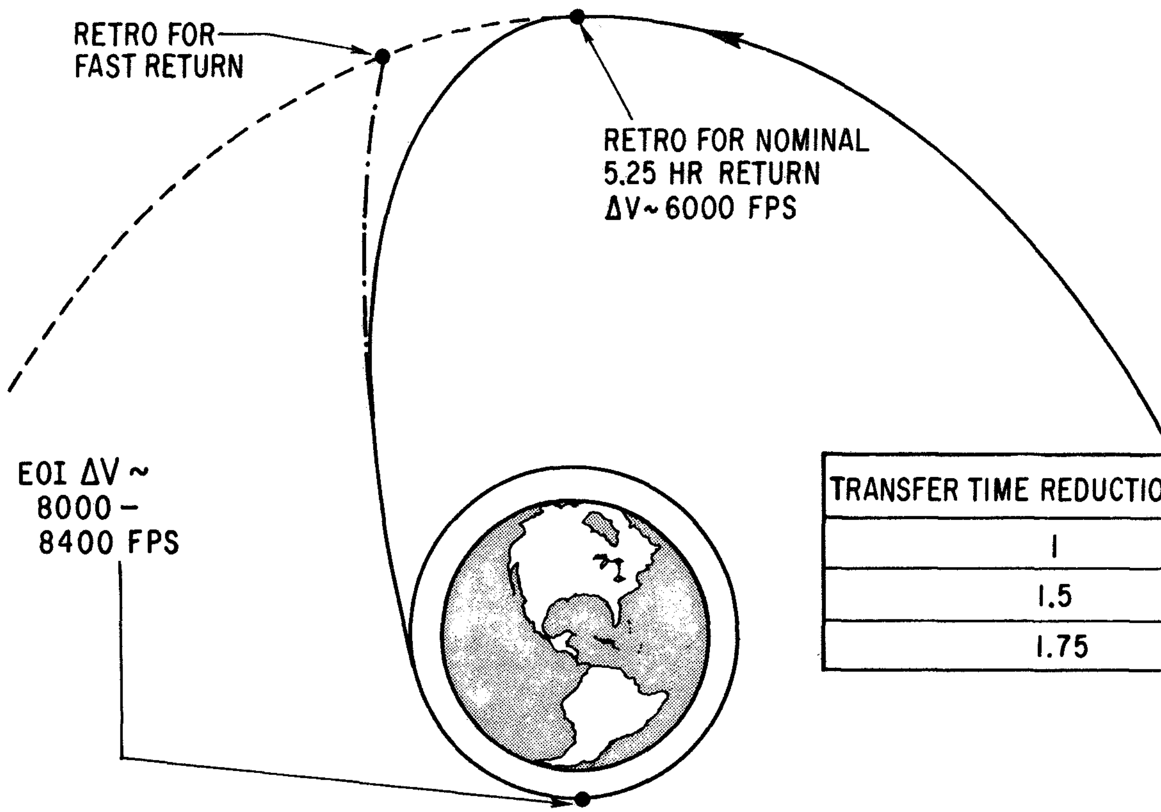


Figure E-7. DV Emergency ΔV Needs for Return from Geosynchronous Mission without GEOI (Free Return)

- Geosynchronous Mission: Fast Return from GEO

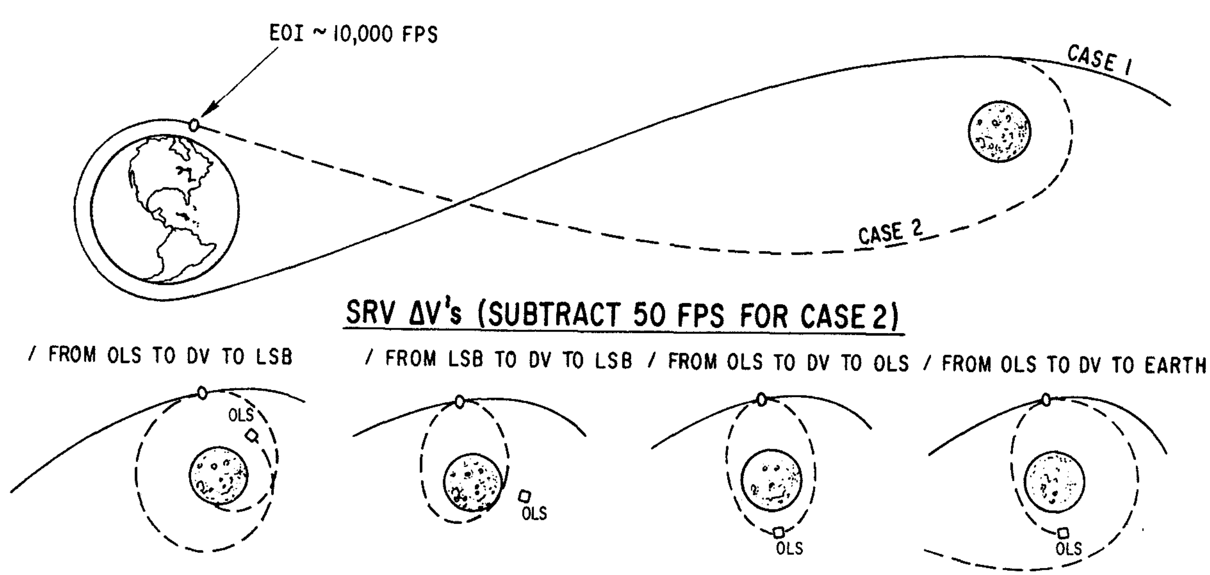


TRANSFER TIME REDUCTION, HR	ΔV, FPS
1	~ 500
1.5	~ 1200
1.75	~ 1800

Total DV ΔV Requirement after GEOI ~ 14,000 to 16,200 FPS

Figure E-8. DV Emergency ΔV Needs for Fast Return from GEO--Geosynchronous Mission

- DV in Nominal Approach Trajectory - No LOI - Case 1: No Free Return
  Case 2: Free Return



Rescue ΔV	9000 - 24,000 FPS	18,000 - 39,000 FPS	6000 - 15,000 FPS	13,000 - 22,000 FPS
Transfer to Earth Required	Yes	Yes	Yes	No

Figure E-9. SRV ΔV Needs for Lunar Mission Rescue with SRV in Lunar Space--No DV LOI

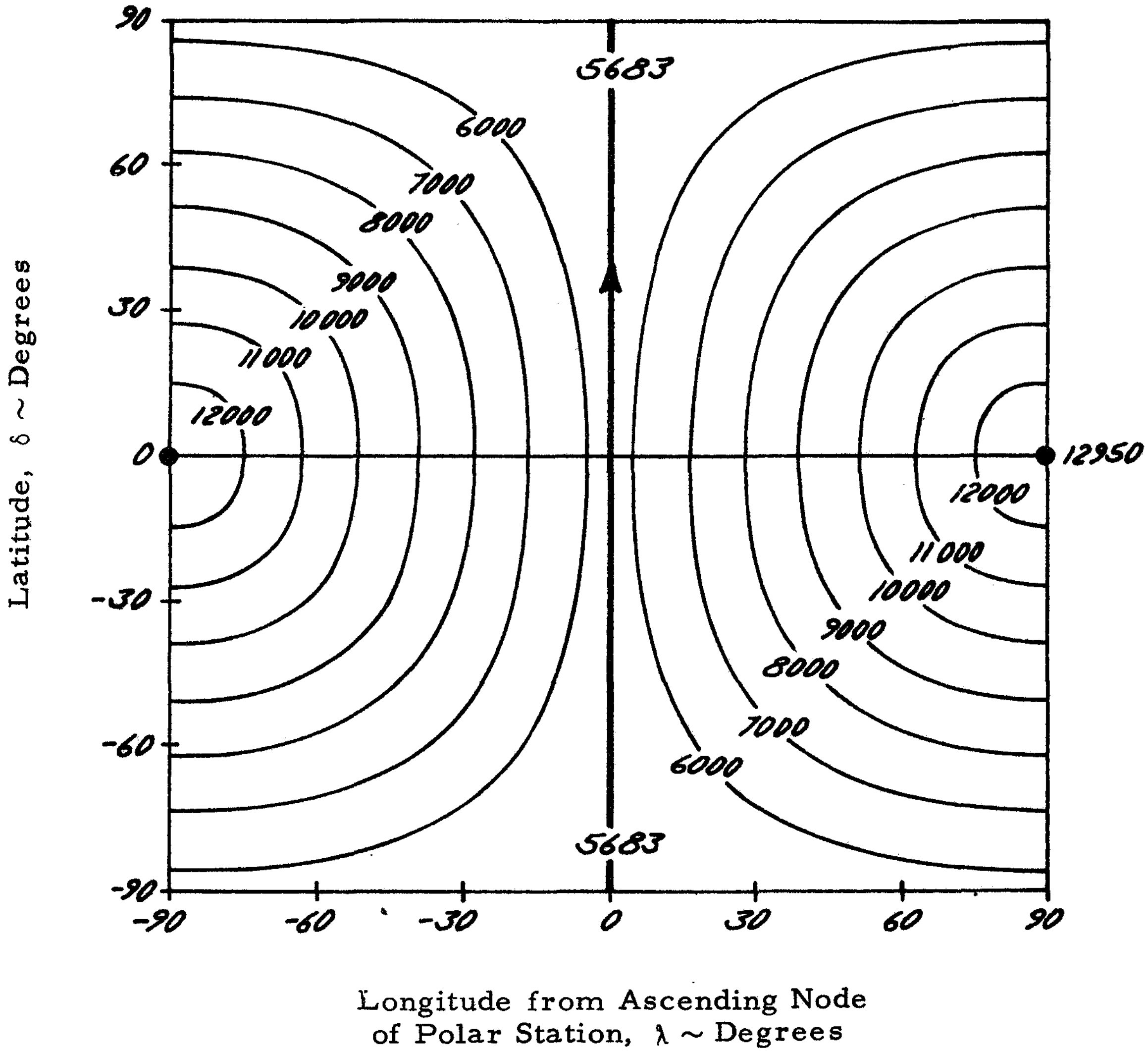
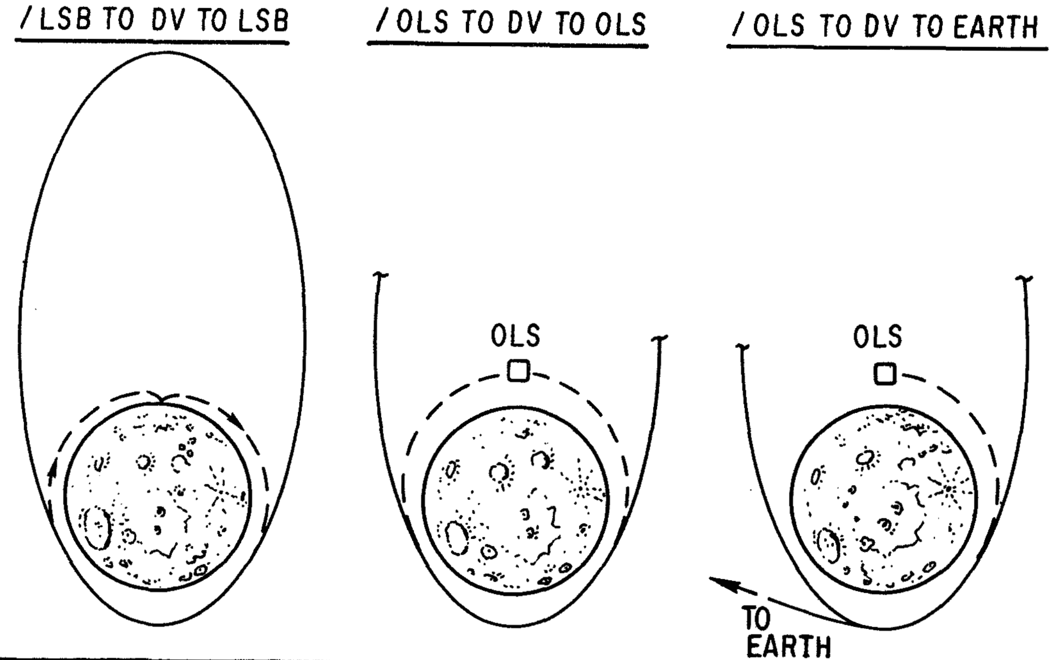


Figure E-10. Curves of Constant ΔV for Descent and Ascent from 60 n mi Lunar Polar Orbit (Ref. E-3)

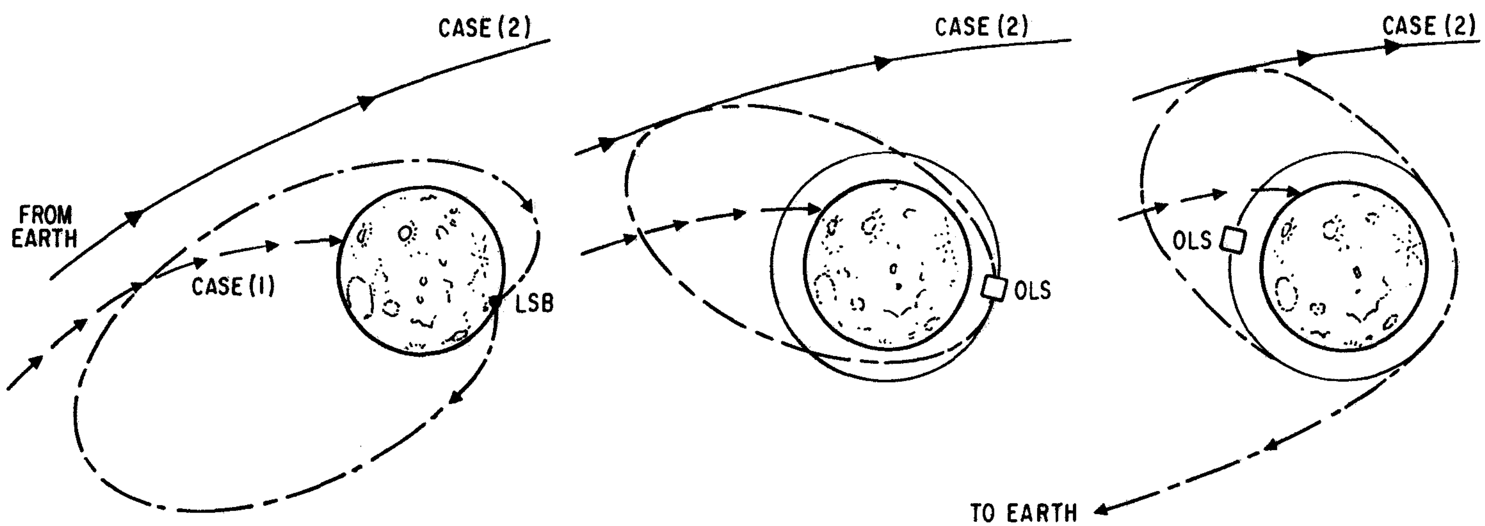
- DV in Nominal Approach Trajectory – LOI Attempted: 1st Burn Only, or 1st & 2nd Burn Only



Rescue ΔV	16,000 - 18,700 FPS	5,000 FPS	16,000 FPS
Transfer to Earth Required	Yes	Yes	No

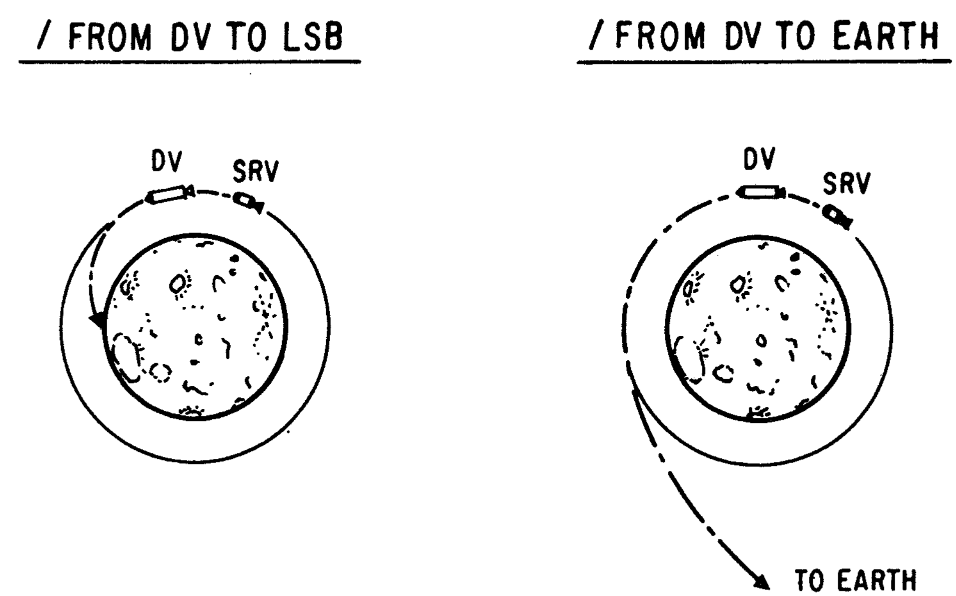
Figure E-11. SRV ΔV Needs for Lunar Mission Rescue with SRV in Lunar Space--LOI Attempted

- DV in Off-Nominal Trajectory - No LOI, Case 1: Impact
  - No Free Return, Case 2: Escape



Rescue ΔV	18,000 - 39,000 FPS	6,000 - 15,000 FPS	13,000 - 22,000 FPS
Transfer to Earth Required	Yes	Yes	No

Figure E-12. SRV ΔV Needs to Rescue DV That Will Miss or Impact on Moon-- SRV in Lunar Space



Rescue ΔV	6000 to 12,000 FPS	13,000 FPS
Transfer to Earth Required	Yes	No

Figure E-13. SRV ΔV Needs to Rescue DV in Lunar Orbit--SRV in Lunar Space

- SRV in GEO
  - / DV in Off-nominal Approach to GEO (Escape)

    ΔV for Rendezvous ~ 6000 FPS + X
    and return to Earth

    ΔV for EOI ~ 8000 FPS + X'

    where X and X' are functions of the abnormality

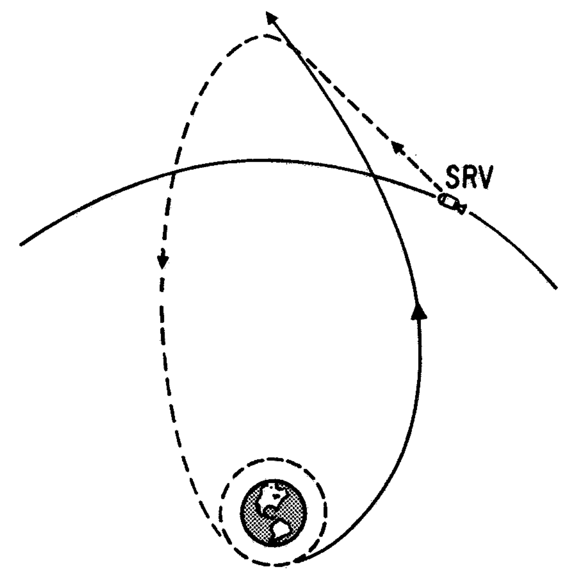
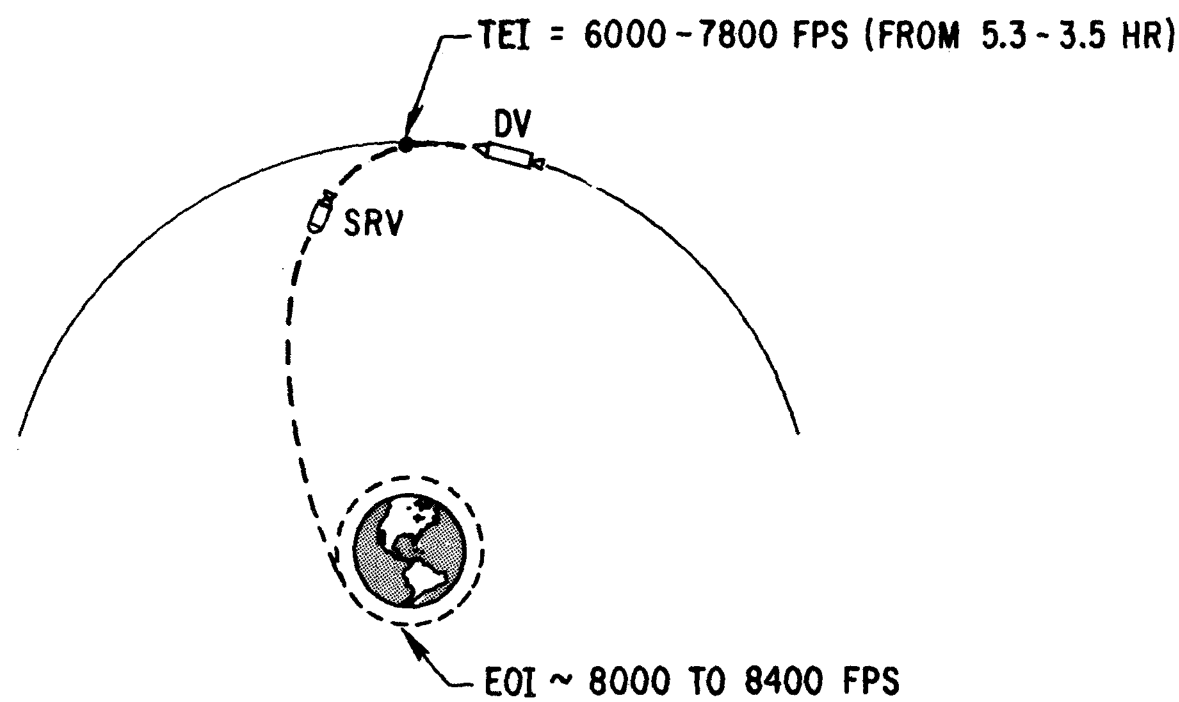


Figure E-14. SRV ΔV Needs to Rescue DV from Escape Trajectory Resulting from Failure to Achieve HT to Geosynchronous Orbit--SRV in GEO

- DV in Geosynchronous Orbit: Fast Return



Total SRV ΔV Required ~ 14,000 to 16,200 FPS

Figure E-15. SRV ΔV Needs to Rescue DV Trapped in Geosynchronous Orbit--SRV in GEO

SRV in LEO

DV in Off-nominal Approach:

- to LEO from GEO

  ΔV for Rendezvous and EOI ~16,000 FPS + X

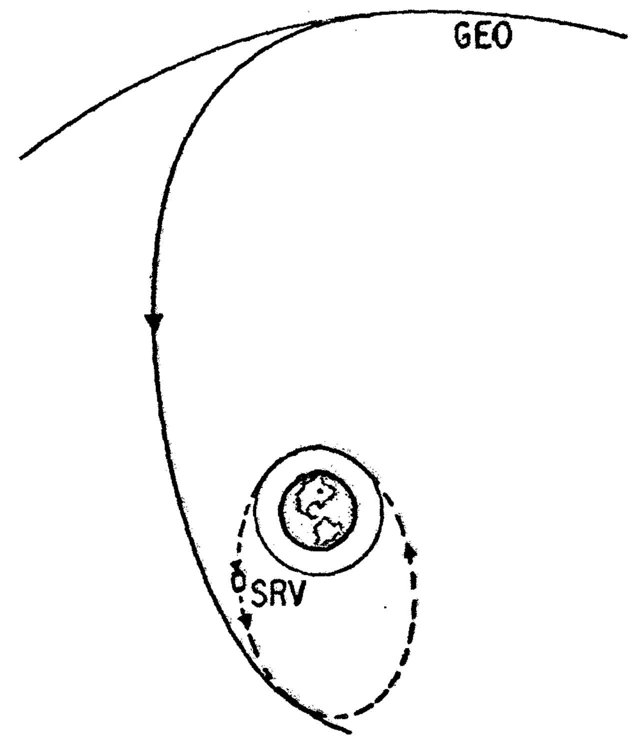
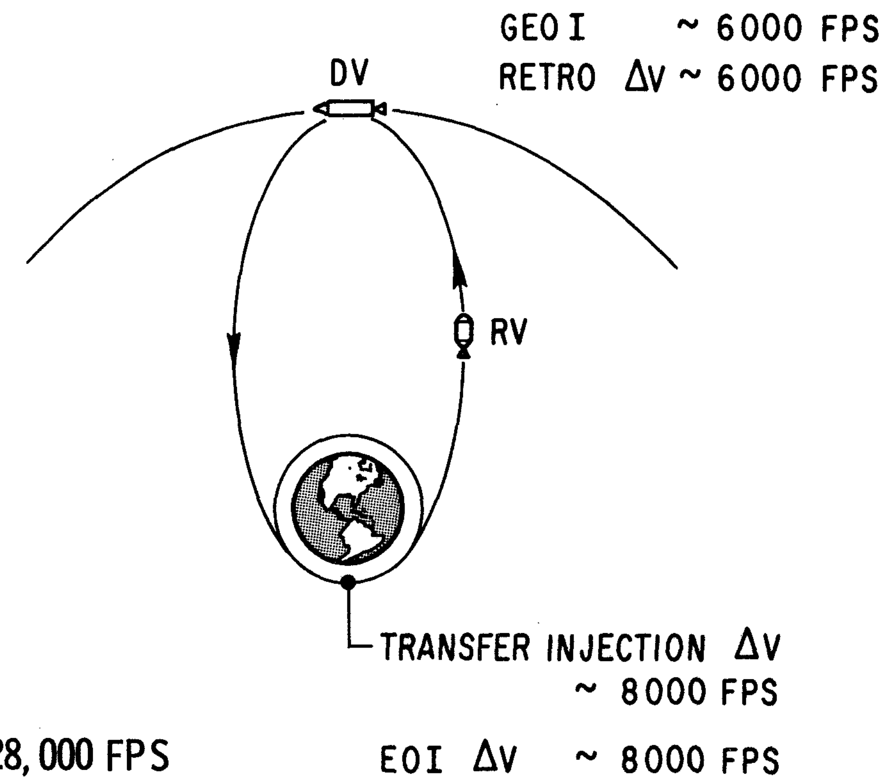


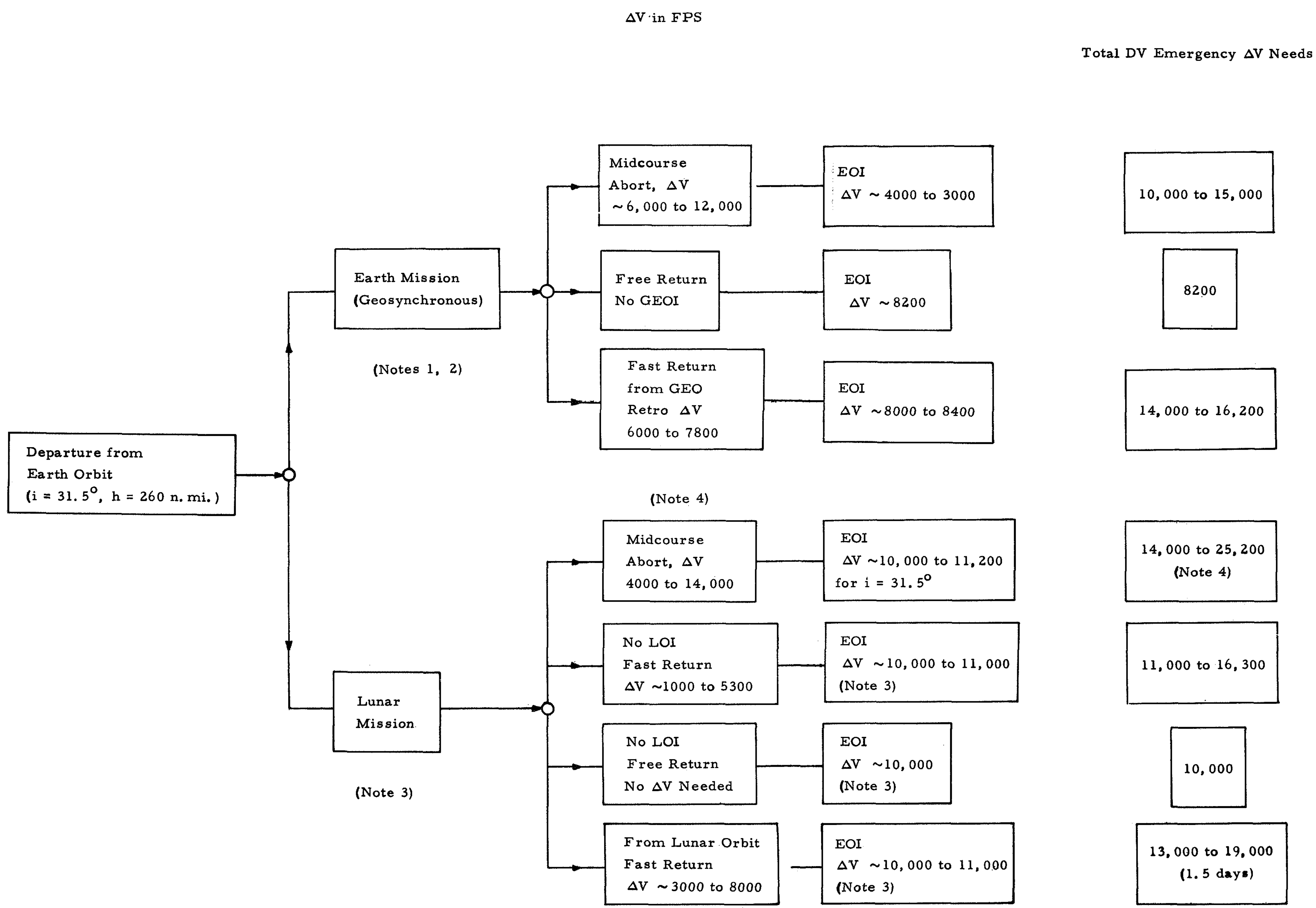
Figure E-16. SRV ΔV Needs for Rescuing DV in Off-Nominal Approach to Low Earth Orbit--SRV in LEO

- DV in Geosynchronous Orbit



Total SRV ΔV Required ~28,000 FPS

Figure E-17. SRV ΔV Needs for Rescuing DV in Geosynchronous Orbit--SRV in LEO



Notes:

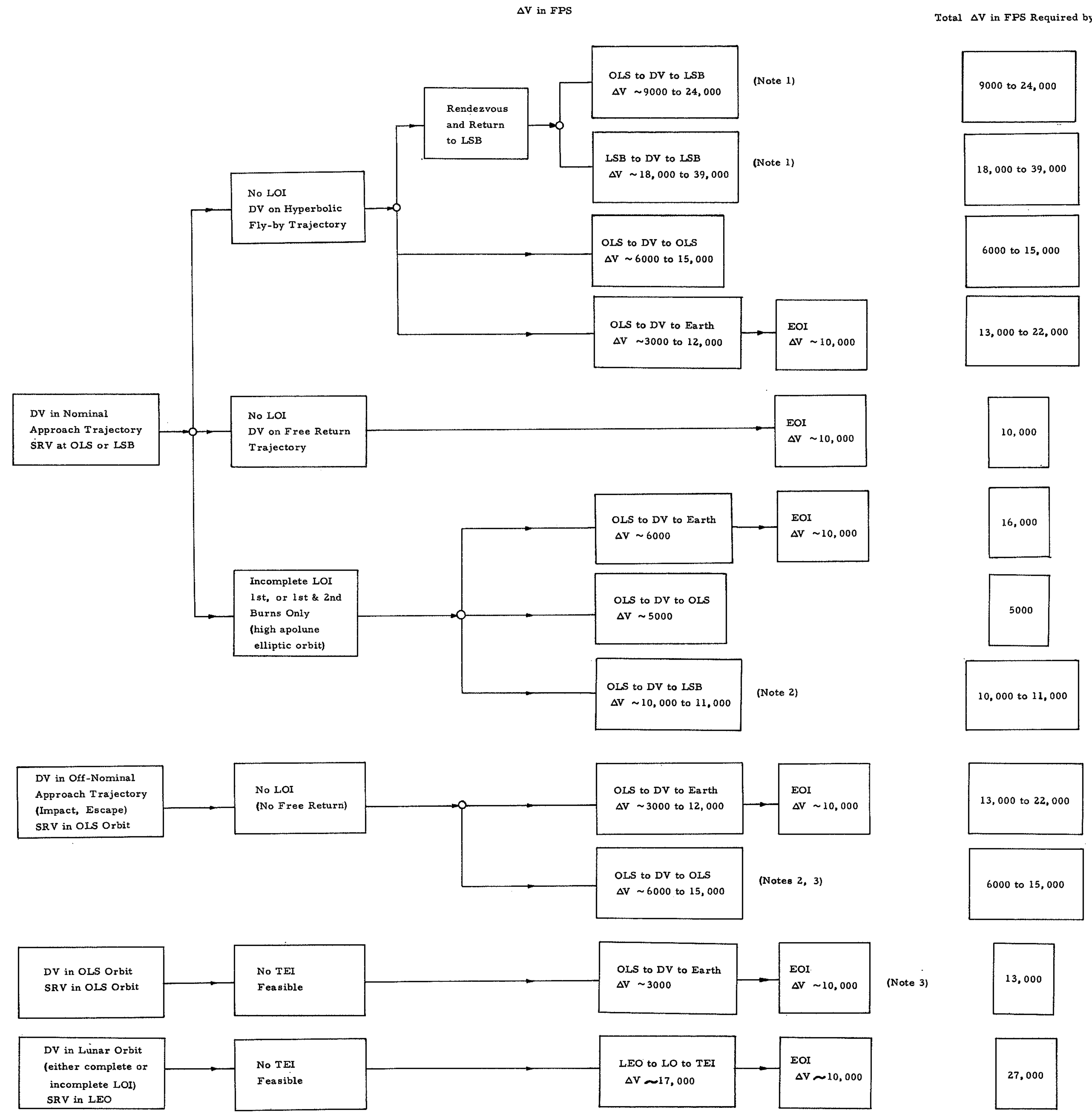
(1) Plane change of ~29.5° at geosynchronous altitude.
In emergencies all 31.5° of plane change performed at altitude (when feasible).

(2) Hohmann type transfers assumed except when "Fast Return" indicated.

(3) No restrictions are placed on the inclination of the return orbit.

(4) Will permit return within 55 to 16 hours as far out as 90,000 n. mi. along earth radius.

Figure E-18. Emergency ΔV Needs of Distressed Vehicle to Assist in Rescue



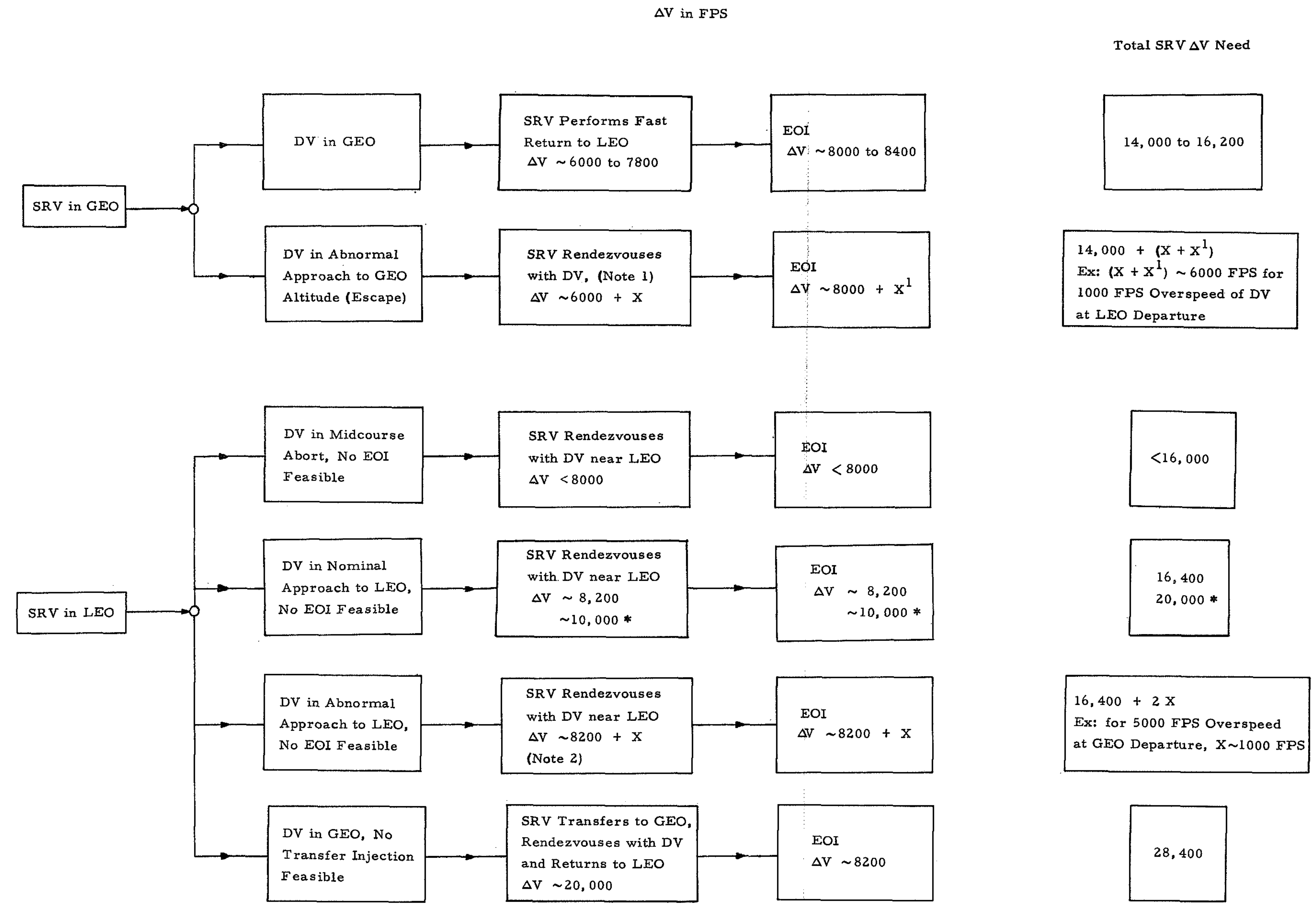
Notes:

(1) Shown as example only; less likely alternative because of limited launch window and increased difficulties of earth transfer.

(2) The case of LSB to DV to LSB not shown because of fewer launch opportunities and increased difficulties of earth transfer.

(3) The case of OLS to DV to LSB not shown because of increased difficulties of earth transfer.

Figure E-19. Summary of SRV ΔV Needs for Rescue of DV in Lunar Space



* If DV approaches LEO from LO

Note: (1) The maximum overspeed of which the DV starting from LEO would be capable is ~20,000 fps. It has not been determined what overspeed would exceed reasonable SRV capability.

(2) Overspeed could result in earth impact. It is unlikely that an SRV would be effective in that instance because of lack of time to intercept and rendezvous.

Figure E-20. Summary of SRV ΔV Needs for Rescue of DV in Earth Space

APPENDIX F

DECOMPRESSION SICKNESS

APPENDIX F

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APPENDIX F

DECOMPRESSION SICKNESS*

F.1 GENERAL

The analysis of the hardware and operational requirements of a space rescue vehicle (SRV) disclosed a number of operational paths which involved EVA for either or both the rescue crew and the crew of the distressed vehicle (DV). The rescue crew could require EVA during the inspection and damage control phases as well as the actual rescue phase, while the DV crew might require EVA in transferring to the rescue vehicle. A review of the timelines associated with these operational phases led to consideration of the decompression sickness problem since it affected the rapidity with which rescue operations could be performed. Additionally, this problem could affect the mobility of the rescue crew and the nature of the transfer equipment provided for ill or injured crew members.

The decompression sickness problem stems from the decision that hardware elements of the Integrated Program (IP) such as the Earth Orbit Shuttle and the Space Station/Base will operate with an oxygen/nitrogen atmosphere approximating standard atmospheric conditions; i.e., with total pressure of 14.7 psia and oxygen partial pressure of 3.1 psia. Current space suit design, however, provides an atmosphere of 3.5 - 4 psia of pure oxygen. Sudden transition from cabin to suit can therefore subject the crew to various degrees of dysbarism (decompression sickness). In a rescue situation such sudden transition may be desirable and means to permit it are desirable.

In this study consideration was given to several alternate means of avoiding decompression sickness, with emphasis on means which would allow rapid acclimation and thus reduce the time periods required to attain EVA capability.

*This appendix is based on the work of M. Donabedian, Ref. F-1.

F.2 SYMPTOMS AND SUSCEPTIBILITY

The term "decompression sickness" will be used in a general sense to cover the various physiological effects resulting from reduction in barometric pressure.

Of specific interest are the effects of gases, primarily nitrogen, evolving from body fluids and tissues, and resulting in such symptoms as bends and chokes, and in skin and neurological effects. Bends, the most common symptom, is characterized by deep pain in bones, joints, and muscles of the extremities, including hips and shoulders. Chokes, the next most common symptom, is characterized by a burning sensation in the chest, and by coughing and respiratory distress. Skin symptoms, characterized by tingling, itching, etc., and neurological problems (which occasionally result in headaches, fainting, blurred vision, etc.) are much less frequent. Other symptoms include abdominal pain resulting from trapped and expanding gas, and barodontalgia -- a painful condition of the jaws and teeth brought on by lowered atmospheric pressure.

The incidence of or susceptibility to bends is dependent upon a number of factors including (a) the ratio of the pressure change (significant if ratio of initial to final pressure exceeds two, (b) final pressure, (c) exposure time, (d) physical activity, (e) the ratio of body fat to lean body mass, (f) age, and (g) individual physiological variables.

The relative severity of bends has been classified into four grades (Ref. F-2) as follows: (a) Grade I -- intermittent or mild symptoms, tingling sensations and fleeting pains, (b) Grade II -- moderate to severe symptoms not requiring abort of mission, pain moderate but not constant, (c) Grade III -- severe symptoms requiring abort, pain intolerable, unable to work, (d) Grade IV -- severe sickness. Under normal activity, the probability of decompression sickness is very low at equivalent pressure altitudes below 23,000 ft (5.9 psia). With increased activity, incidence of decompression sickness, and specifically bends, has been observed at pressure altitudes as low as 17,000 ft (7.65 psia). There is generally a positive correlation of susceptibility to decompression sickness with age.

A number of studies have been made to assess the risk of bends resulting from decompression to 3.5 psia oxygen from pressures ranging from 5 to 14.7 psia mixed gas atmosphere. Several semi-empirical equations have been proposed for first order prediction of bends frequency after decompression from these atmospheres (Refs. F-3, F-4, and F-5).

Semi-empirical equations of Ref. F-5 suggest that after reaching total equilibrium in a 7 psia 50 percent nitrogen, 50 percent oxygen environment, a well conditioned astronaut, when decompressed to 3.5 psia oxygen at rest, will have less than a one percent chance of experiencing mild Grade I or II bends. If moderate exercise is imposed, the incidence rate would rise to about 7 percent. For the general population with only average physical status and conditioning, the bends incidence rate in an exercise environment would be between 10 to 15 percent. If the suit pressure were raised to 5 psia, the bends incidence rate would drop by a factor of 3. Complete equilibrium with a 5 psia, 30 percent nitrogen, 70 percent oxygen environment, with subsequent decompression to 3.5 psia, would probably not result in symptoms with even heavy exercise.

In comparison, direct decompression from air at sea level pressure to 3.5 psia oxygen presents a more serious hazard. At rest, about 25 percent of the subjects would probably experience the bends. Depending on the degree of exercise, from 50 to 100 percent of individuals exposed could experience moderate to severe bends. Experimental data show that most subjects with symptoms experience the symptoms between 20 and 60 minutes after exposure. Very few subjects show susceptibility to decompression sickness after enduring 2 to 3 hours of exposure without symptoms.

F.3 PREVENTION

F.3.1 De-nitrogenation

F.3.1.1 Physiology

The incidence of bends can be effectively reduced and incapacitation prevented by adequate de-nitrogenation before exposure to lower pressures. The ability of a tissue to reduce its nitrogen concentration depends primarily upon the circulation of the blood and the type and condition of the tissue. Breathing pure oxygen at sea level pressure is a most efficient means of removing nitrogen from the body. Total removal of nitrogen is possible by exposure to 100 percent oxygen atmospheres for periods above 16 hours, which will reduce the incidence of bends to zero. Shorter time periods of de-nitrogenation result in progressively greater incidence of bends. The rate of de-nitrogenation depends on the time, the difference in partial pressure of the nitrogen, tissue, age, and body condition. The incidence of bends as a function of oxygen pre-breathing is typically shown in Figure F-1, which is based on data from Refs. F-6 and F-7.

Based on a literature review, the following general observations can be made:

(a) De-nitrogenation follows an exponential rate. Approximately 50 percent de-nitrogenation is accomplished in a period of 30 minutes to one hour in a 100 percent oxygen atmosphere at sea level pressure.

(b) De-nitrogenation rates differ both between individuals and with the same individual from day to day. Subjects with a high rate of de-nitrogenation are generally more resistant to decompression sickness symptoms than are other subjects.

(c) In some cases, breathing 100 percent oxygen up to approximately 20,000 ft (6.8 psia) is nearly as effective in giving protection against bends and chokes as de-nitrogenation at ground level, but the effectivity can vary greatly.

(d) It has been found that approximately four hours of pre-breathing of 100 percent oxygen are necessary to completely protect more susceptible individuals who are expected to be active at a reduced pressure of 3.5 psia. One or two hours of oxygen inhalation offer relatively complete protection from bends when activity is limited.

F.3.1.2 Operational and Design Implications of De-nitrogenation

De-nitrogenation (oxygen pre-breathing) will have the greatest usefulness in missions initiated specifically for space rescue. If rescue team members anticipate the requirement for extensive EVA, planning for approximately four hours of oxygen pre-breathing is required. The simplest and most effective method of pre-breathing would be to utilize a demand type oxygen mask while seated in a shirtsleeve environment of the vehicle during the pre-rendezvous flight phase. This method implies that the normal two-gas vehicle atmosphere will continually be oxygen enriched during this phase, since these masks normally allow oxygen to be exhaled directly to the cabin atmosphere. For pad operations this would be undesirable from a safety standpoint. This problem could be alleviated, however, by allowing for a "controlled leak" in the vehicle and provide the necessary additional make-up nitrogen to maintain the desired sea-level pressure and atmospheric composition. Any interruption in the oxygen pre-breathing would nullify a large part of the de-nitrogenation already accomplished. The pre-breathing could also be accomplished in the airlock with no effect on the main compartment.

The rescue team members could also be pre-suited during the pre-flight and ascent phases while breathing 100 percent oxygen via a demand mask. A closed-loop recirculating system would have to be provided for suit ventilation and to prevent oxygen enrichment of the vehicle atmosphere. This can be accomplished either by providing a separate oxygen recirculating system (similar to Apollo, for example) as part of the vehicle, or by providing an additional portable life support system (PLSS) for each team member anticipating EVA. PLSS units designed primarily for EVA of four hours at average metabolic rates of 1,600 Btu/hr would provide approximately eight hours operation at resting metabolic rates in the order of 800 Btu/hr. However, units designed primarily for the pre-breathing function would be considerably simpler and lighter than the normal EVA units. In the case of the EOS, an alternative mode would be to provide a special rescue module within the cargo bay which would operate with the appropriate atmosphere to provide de-nitrogenation.

F. 3. 2 Solutions Other than De-nitrogenation

Alternate solutions (summarized in Figure F-2) to the de-nitrogenation process, applicable to the SRV crew, could involve increasing the suit pressure, reducing the vehicle operating pressure, substituting other inert gases, or limiting EVA time. Solutions available to the DV are discussed in Section F. 3. 3.

F. 3. 2. 1 Increased Suit Pressure

Current suit design precludes increasing suit pressure beyond 4 to 5 psia because of the reduced mobility. Increased suit leakage rates, increased metabolic rate with associated reduction in effective work duration, and increased cooling requirements are additional considerations. Further development of hard suits with constant volume joints would permit suit operation at a high enough pressure to minimize or eliminate incidence of bends. Although the use of normal sea level atmosphere in the suit would be ideal from the standpoint of decompression sickness, a mixed gas atmosphere ranging in pressure from approximately 7 to 10 psia would probably be more nearly optimum. Anticipated developments by NASA in improvement of soft suit joints and in improved multi-layered suit materials may allow suit pressures to be increased to 7 to 8 psia while retaining acceptable mobility. The use of 100 percent oxygen suit atmospheres would not present a serious oxygen toxicity problem as long as exposures were limited to less than about eight hours. The use of a two gas (O_2 - N_2) suit atmosphere would allow more extensive operations.

F. 3. 2. 2 Reduced Cabin Pressure

Vehicle operating pressure could be reduced to a level where low incidence of bends would preclude significant de-nitrogenation requirements.

Experimental data relating to decompression from approximately 7 psia 50/50 O_2/N_2 atmosphere to about 3.5 psia oxygen are contained in Appendix A of Ref. F-8. That study was designed to establish (among other things) the required time for de-nitrogenation at a simulated altitude of 18,000 ft (7.35 psia) in a 50 percent O_2 - 50 percent N_2 atmosphere for protection against decompression to 35,000 ft (3.47 psia at 100 percent O_2) and to determine bends susceptibility of the test subjects. A total of 12 naval enlisted personnel served as subjects in tests conducted in the Air Crew Equipment Laboratory of the Naval Air Engineering Center, Philadelphia, Pa. The specific test series of interest involved a rapid decompression (60 seconds) from sea level to 18,000 ft (7.35 psia), undergoing equilibration at 7.35 psia for either 12, 18, or 24 hours, followed by rapid decompression (60 seconds) to 35,000 ft (3.47 psia) and remaining there for three hours. Similar tests were also conducted with various degrees of de-nitrogenation (pre-breathing 100 percent O_2 at sea level pressure) and also with direct decompression from a normal two gas sea level atmosphere to 3.47 psia of 100 percent O_2 and remaining there for three hours. Results are shown in Table F-1. With 12 hours equilibration at 7.35 psia and without oxygen pre-breathing, incidence of decompression sickness was high (10 out of 12) but dropped sharply with equilibration of 18 and 24 hours.

With decompression from sea level pressure directly to 3.47 psia, the incidence of decompression sickness was very high (10 out of 12) even with two hours de-nitrogenation, but dropped sharply (1 out of 12) with three hours de-nitrogenation. Thus, the probability of decompression sickness was shown to be significantly less with the 7.35 psia intermediate atmosphere as compared with direct transition from the sea level atmosphere.

As a design alternative, a 7 psia two-gas atmosphere could be considered as the baseline system for all vehicles or as a back-up mode when the vehicle is used in rescue operations.

F.3.2.3 Replacement of Nitrogen with Helium or Other Inert Gases

Experience with decompression from high pressures associated with deep sea diving has shown that the use of helium in place of nitrogen reduces the incidence of decompression sickness. Although there are significant differences between the various data available (as reported in Ref. F-3) the primary advantage of helium is attributed to the body's faster rate of desaturation of the dissolved gas. The difference in solubilities between helium and nitrogen is magnified by the high pressures associated with diving and may not be as significant for space applications.

Relatively little data exist to assist in evaluating the effect of helium in the lower pressure environment associated with decompression to altitude. Data reported in Refs. F-3 and F-9 are inconclusive and, in fact, show that in certain instances the time of onset of bends symptoms may even by shorter for helium than for nitrogen. Unfortunately, the data available are only for short time exposures. No experimental data on decompression to altitude after 12 or more hours of equilibration in inert gases could be found. Thus, there does not appear to be clear evidence to suggest the use of helium or other inert gases as an effective alternative.

F.3.2.4 Limits on EVA

EVA time could be limited to about 10 minutes to minimize the probability of onset of bends symptoms. However, the risk of compounding the emergency situation with another hazard does not appear attractive, nor do such work periods appear practical in a rescue situation.

F.3.3 Operations within Distressed Vehicle (DV)

The options available to the DV crew prior to EVA in order to avoid decompression sickness are outlined in Figure F-3. One additional problem remains, related to the operational effectiveness of the rescue crew in the DV environment. If the rescue crew enters the DV via EVA, it faces a problem whether the spacesuit is the current design operating at 3.5 psia or an improved model at 7 psia. If the DV is at 14.7 psia, the rescue crew cannot remain within pressure suits while performing the rescue operation although this may be desirable for reasons of time economy as well as of isolation from contamination. Acclimation to the higher pressure of the DV requires only a short time, but acclimation to the lower suit pressure for the return trip requires the same procedures as outlined on Figure F-3.

It would appear desirable, therefore, to make provisions for bleeding the DV atmosphere to about 7 psia of 50/50 oxygen/nitrogen mixture after occurrence of an emergency requiring rescue and to couple this with the improvement in pressure suit technology to increase suit operating pressure to the same level. This would permit the rescue crew to remain sealed in their pressure garments after cycling into the DV through an airlock, which may be essential if the vehicle atmosphere is contaminated. It would also pre-condition the DV crew for EVA in either 7 psia pressure suits or in the current 3.5 psia soft suit, whether of EVA or IVA design.

If the higher operating pressure suit should not be developed, a space crew preconditioned at about 7 psia for a period of 18 to 24 hours (probably less than the time required for the rescue crew to reach them) would then not find it objectionable to have their vehicle's atmosphere reduced to 3.5 psia of pure oxygen in order to permit rescue operations by a fully suited and sealed rescue crew. Similar considerations should underlie the design of the EC/LS of any Bail-out and Wait (BOW) device. Such a device would initially be at the pressure of the DV in order to permit rapid entry of the DV crew. The system should then be capable of atmosphere change to the 50/50 oxygen/nitrogen mixture, at 7 psia, with subsequent reduction to the rescue crew suit pressure.

Bail-out and Return (BOR) devices should be similarly equipped, although, if the escape mission is completed according to plan, a pressure reduction may not be required.

Oxygen pre-breathing equipment should also be on board the DV and associated escape devices to provide a back-up position to cabin depressurization.

F.4 CONCLUSIONS AND RECOMMENDATIONS

1. Space rescue operations involving EVA, using current suit technology (i.e., 3.5 psia suits) and starting from a two-gas, 14.7 psia spacecraft atmosphere, will require approximately four hours of pre-breathing of 100 percent oxygen by both DV and rescue crews to prevent decompression sickness.

2. Oxygen pre-breathing can be most easily accomplished in a shirt-sleeve condition utilizing a demand-type O_2 mask. The avoidance of O_2 enrichment of the cabin atmosphere may require special closed-loop O_2 systems within the rescue vehicle or additional N_2 gas coupled with some deliberate leakage to maintain standard atmosphere composition.

3. The alternatives to pre-breathing 100 percent oxygen include (a) increasing suit pressure to 7 psia or greater and use of 50/50 O_2/N_2, (b) reducing cabin pressure to approximately 7 psia 50/50 O_2/N_2, (c) limiting EVA in current design suits to 10 minutes, and (d) replacing nitrogen with a different inert gas.

4. Development of suit technology to permit operation at 7 psia of 50/50 O_2/N_2 or greater, or providing O_2 pre-breathing equipment, appear to be the most practical solutions to the decompression sickness problem of the rescue crew.

5. Future manned space vehicles as well as associated escape devices should be designed to permit atmosphere reduction to the highest pressure level of planned EVA suits. Such vehicles should also be provided with oxygen pre-breathing equipment as a back-up. The use of airlocks or other spaces as recompression chambers in the treatment of bends should also be considered.

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USAF, Physiology of Flight, Air Force Pamphlet 160-10-4, Dept of Air Force Medical Sciences (January 1961).

Table F-1. Incidence and Time of Onset of Bends Under Various Test Conditions for 12 Subjects (Ref. F-8)

Test No.	Test Condition	Pre-Breathing 100% O_2 at S. L. (Hr)	Equilibration Time at 7.35 psia (50% O_2-50% N_2) (Hr)	No. of Subjects with Bends (Out of 12)	Range of Time of On-set of Sympt. (minutes)	No. of Subjects Which Req. Emerg. Pressurization
1	Standardization (S. L. to 3.47 psia*)	0	0	12	8 - 81	10
2	S. L. to 3.47 psia*	2	0	10	13 - 119	7
3	Same	2	0	10	40 - 152	5
4	Same	2	0	10	16 - 134	6
5	Same	3	0	1	106	1
6	S. L. to 7.35 psia to 3.47 psia*	2	12	1	21	1
7	Same	0	12	10	0 - 44	3
8	Same	0	18	1	18	0
9	Same	0	24	4	0 - 114	1

*100% Oxygen

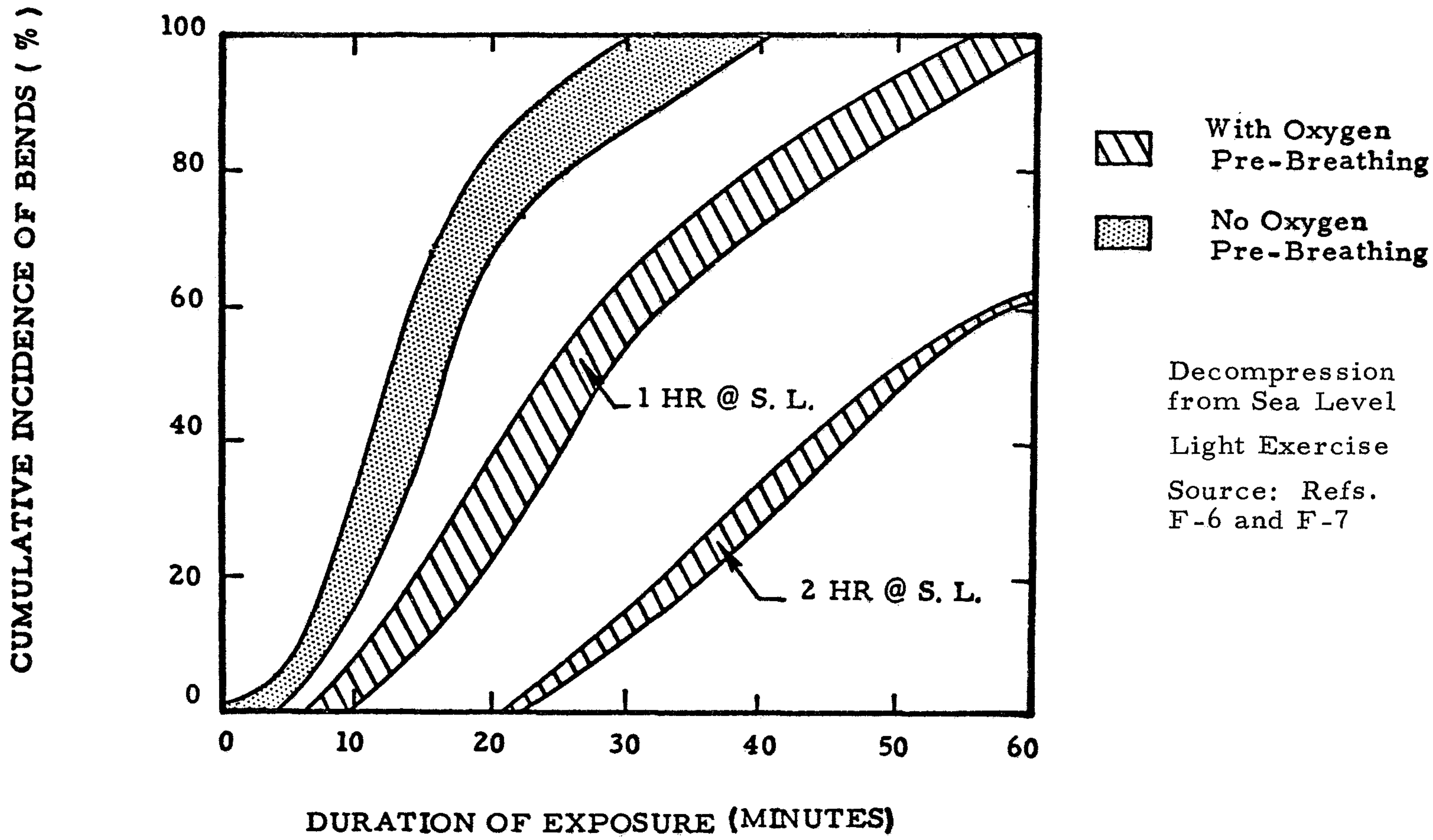
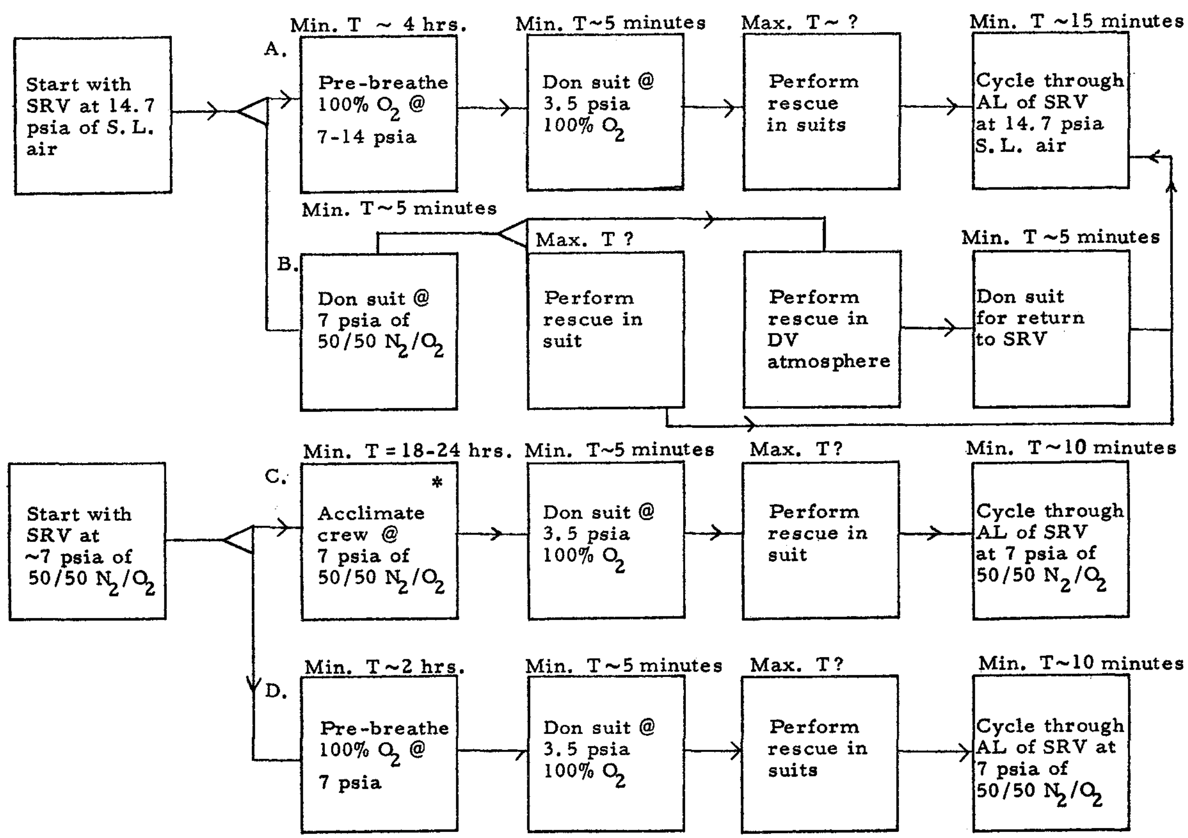


Figure F-1. Incidence of Bends at 3.0 psia



<u>Equipment Required</u>

A. - Current soft suit.
- or AL modified to provide 100% O_2.
- or crew in suits on 100% O_2.
- or special crew module on 100% O_2.

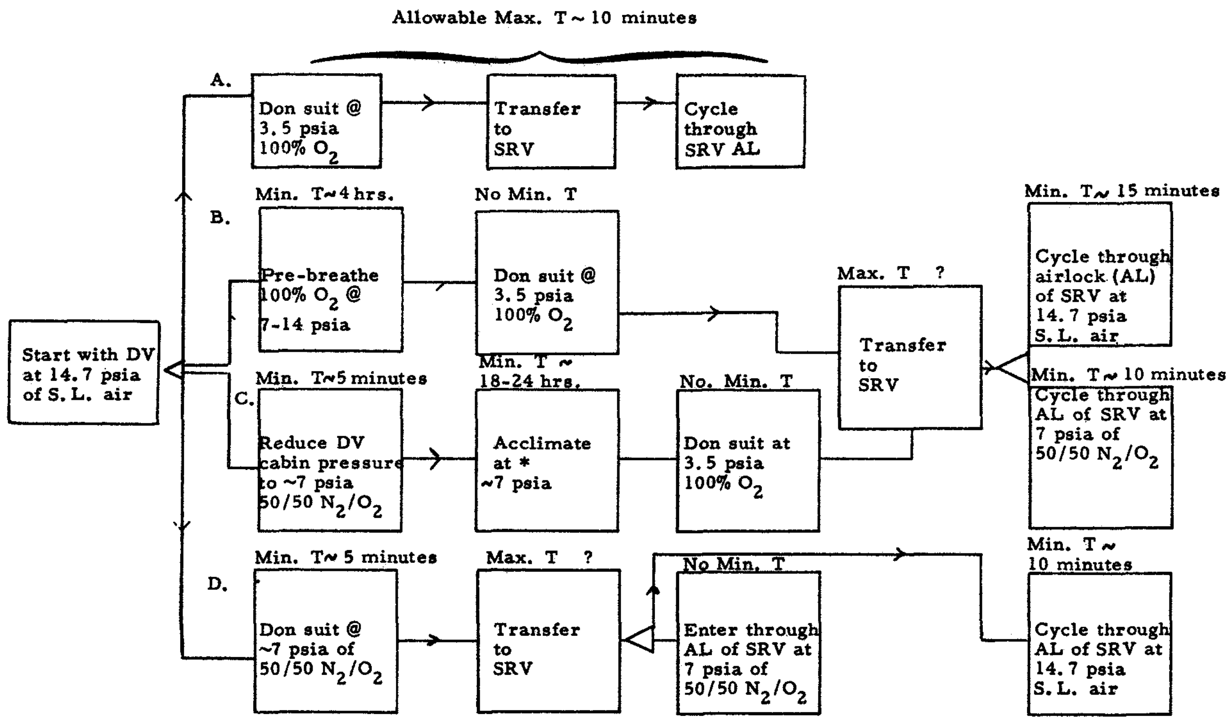
B. - New soft suit development with improved joints.
- or new hard suit development
- New PLSS development.

C. - ECLS modified to permit 7 psia of 50/50 N_2/O_2.
- Current soft suit.

D. - ECLS as above in C.
- 100% O_2 in SRV as in A.
- Current soft suit.

* Could be partially or completely performed external to SRV (prior to entering SRV).

Figure F-2. Alternate Procedures for Avoidance of Decompression Sickness in Space Rescue Crews During Rescue Vehicle Operations Requiring EVA



Equipment Required

A. - Current Design Soft suit/PLSS

B. - Oxygen mask/suit with plug-in O_2

C. - Current soft suits/PLSS
- ECLS of Space Station modified to permit change in pressure and composition.
- Current soft suit/PLSS

D. - New hard suit development
or
- New soft suit development with improved joints
- New PLSS development

* Without acclimatization, DV crew requires passive transfer in suit or shuttle.

NOTE: All procedures require airlock (AL) in SRV.

Figure F-3. Alternate Procedures for Avoidance of Decompression Sickness in Crews of Distressed Vehicles During Rescue Operations Requiring EVA

APPENDIX G

MEDICAL EQUIPMENT AND SUPPLIES

APPENDIX G

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APPENDIX G

MEDICAL EQUIPMENT AND SUPPLIES

G.1 GENERAL

Among the major goals of the Space Rescue Study was that of defining the equipment requirements of the Space Rescue Vehicle (SRV). Such a vehicle, responding to a space emergency, could reasonably expect to find either illness or injury on board the distressed vehicle (DV). In fact, among the number of possible emergency situations postulated which might require rescue was the category of "illness/injury." In addition, other possible emergency situations can produce illness or injury as an effect, such as for example, the situations of "metabolic deprivation," "non-habitable environment," etc. The equipment and supplies to be carried by the SRV should therefore not only include items for first aid but also for preventing deterioration of a serious medical problem in order to permit removal of the injured crew to a permanent haven. It was assumed that conclusive medical treatment would have to await return to such a haven by the SRV.

The listing of desired medical equipment, supplies and skills should ideally be based on an estimate of the types of medical problems which the rescue crew might encounter, and on their probability of occurrence, since providing for all medical eventualities could conceivably overburden the payload capability of the rescue vehicle. Since event probabilities for medical emergencies in space flight have not yet been determined, this phase of the study derived medical equipment needs on the basis that all of the medical problems had an equally high probability of occurring and that supplies or equipment for treatment or containment of all problems should be carried. Some information on event probabilities based on submarine experience was available and is summarized in the following sections, but only for the purpose of information and to form the basis for further study recommendations.

*This Appendix is based on the work of M. Donabedian, Ref. 1.

In addition to determining possible SRV medical equipment needs, this study subtask also considered desirable equipment and supplies to be routinely on board space vehicles to permit maximum self-help.

In order to provide the medical skills required by this phase of the rescue study assistance was solicited and was received on a no-cost basis from the RPC Corporation, El Segundo. This company performs analytical and experimental research in the life sciences and provided assistance of a graduate physiologist in the preparation of the input to this subtask.

G.2 IDENTIFICATION OF POTENTIAL INJURIES AND ILLNESSES

In order to identify requirements for medical equipment, either on board a potential DV or specific to an SRV, a systematic survey was made of potential illnesses or injuries which might occur. As part of this effort, the services of RPC Corporation were utilized. Initially, RPC provided a matrix of possible illnesses and injuries, together with estimates of resulting lost time and type of treatment and/or medication required. These data are presented in Tables G-1 and G-2. Explanations and/or examples of medical terminology used in these tables are provided in Tables G-3 and G-4.

Available information on space flight medical problems (Ref. G-2) shows that principal problems have concerned respiratory infections and minor bodily or gastrointestinal discomforts. However, with the increase in crew size, duration of flight, and mobility of the crew about, for example, a space station, the potential for more serious problems is considerably higher. Although the determination of event probability data is beyond the scope of this effort, a brief review of available data toward this end was made. The sources of data included the Apollo manned spaceflights and U.S. Navy experiences aboard submarines.

G.2.1 Apollo Data

A summary of medical experience in the Apollo 7 through 11 manned spaceflights is provided in Ref. G-2. The exposure to space environment of the Apollo 7 through 11 flights totals approximately 1035 hours, or the equivalent of 129 man-days for the three-man crew. This is obviously too little data from which to draw valid conclusions statistically; however, it does provide a basis of comparison with other data. The inflight medical problems in Apollo 7 through 11 crews are summarized in Table G-5.

The three cases of coryza (sinus infection) shown in Table G-5 occurred on the Apollo 7 mission. One episode each of nausea and vomiting, and aphthous ulcers, were reported on the flight of Apollo 8. The fiberglass irritation occurred on the Apollo 10 mission.

Five of the six crewmen on the Apollo 8 and 9 missions reported symptoms of motion sickness. The symptoms ranged from mild stomach awareness with head and body motion in the weightless environment, to nausea and vomiting in one crewman, and lasted from 2 hours to 5 days after which adaptation allowed movement without any symptoms re-occurring. One Apollo 10 crewman also had stomach awareness lasting 2 days, again indicating that adaptation to the weightless environment takes place.

It should be noted that the crew had been instructed prior to the Apollo 10 mission to carry out programmed head movements during the first two flight days to hasten the adaptive process. The crewman reporting stomach awareness noted an increase in the severity of this symptom after one minute of head movement. When attempted on the seventh flight day, these head movements produced stomach awareness after 5 minutes. Reference G-2 indicates that the opportunity to move about more freely in the Apollo cabin than in previous spacecraft contributed to the motion sickness problem. Sensory inputs from the semicircular canals to the central nervous system during head movements in space are apparently enhanced during the weightless state. This could become a significant problem in larger vehicles permitting and requiring increased mobility.

The 16 medical problems noted in Table G-5 represent a frequency of one medical problem every 8.1 man-days of flight.

G.2.2 Submarine Medical Experience

Long-term confinement of selected crews in a closed environment, such as in a submarine, provides a relatively good analogy to extended space flight. A summary of medical experiences aboard 360 patrols of Polaris submarines during the period 1963 - 1967 is contained in Reference G-4. Each of the 360 patrols involved a crew of approximately 140 men submerged for a period of two months so that this data covers approximately 50,000 man-patrols or 3 million man-days.

The data presented in Ref. G-4 has been summarized in Table G-6. The frequency of medical problems is broken down into 12 major categories. Except for dental problems, the bulk of the data came from cases actually involving sick days (i.e., removal of the patient from all duties for 24 hours or longer), cases involving surgical procedures, or those cases receiving special comments by the onboard medical officer. Table G-6 shows number of cases, number of sick days, and percentage of the total for each category. The total number of cases reported (1,760) results in a frequency of approximately one incident per 1,700 man-days as compared to one incident per 8 man-days in the brief Apollo experience. However, it should be noted that most or all of the 16 minor medical cases listed in the Apollo studies would not have been included in the submarine medical list based on the listing criteria of the latter, namely, removal of patient from all duties for 24 hours or longer. On this basis, the Apollo medical frequency data would be reduced to zero for the 129 man-day exposure.

A breakdown of the surgical procedures performed at sea is presented in Ref. G-4. It is important to note that of the 196 cases reported, approximately 133 or nearly 70 percent involved incision and/or drainage. Thus there would appear to be a requirement for an incision and drainage surgical equipment kit on board.

It is also of interest that over 35 percent of the medical problems were of a dental nature. The high frequency of dental problems encountered suggests that a minimum dental kit for the purpose of tooth extraction is required. Further study is required to identify the need for the treatment of caries and other problems.

The last column of Table G-6 shows the proportional number of cases for a 12-man space station for one year. This is based on a direct ratio of the man-days involved, i.e., 4,380 as compared to 3,000,000 covered by the submarine data.

G.2.3 Miscellaneous Data

Probability data concerning illness and/or injury are given in Ref. G-5. It is indicated that these data are based on information compiled by USAF; however, the exact nature of this information has not been identified.

The probability data presented in Ref. G-5 for a 12-man Space Station crew are as follows:

1. One major injury per 4 years which probably would call for return of crewmen
2. One minor injury per 1.5 years
3. About 0.0005 major illnesses per year which might require return of a crewman
4. About 25 minor illnesses per year
5. About 0.002 major contagions per year which may require return of all crewmen and temporary mission abort

These total approximately 25.92 medical cases per year or about 170 man-days/case. This compares with 8 man-days/case for the Apollo data and approximately 1,700 man-days for the submarine data.

These predictions of illness and disease serve to indicate that sufficient probability exists to justify an onboard treatment capability. It is not possible to predict the communication of disease once it appears, but for the general case it should be assumed that a highly viable pathogen, once introduced, will be propagated rapidly.

Because of the relatively high incidence of dental problems noted in the submarine data and the probability that a dental kit of some sort would be a definite requirement, contacts were made with dental officers both at USAF Aerospace Medical Division, Brooks AFB, Texas, and at NASA Manned Spacecraft Center, Houston. Based on Ref. G-6, dental provisions for the initial Skylab missions (28 day/3-man crew) involve primarily tooth extraction equipment. For longer durations, provisions for treatment of caries would probably be required.

The probability of having dental problems aboard Skylab is estimated by Ref. G-6 as 7 percent for a minor dental problem and 1 percent for a major problem (severe toothache). Projecting these figures to a 12-man space station would yield approximately 4 minor dental cases per year and a 50 percent chance of a major dental problem.

G.3 REQUIRED MEDICAL EQUIPMENT AND SUPPLIES

G.3.1 Primary Medical Items

Because of the relative short duration of previous manned spaceflights, onboard medical kits to date have been first aid kits with a selected number of analgesics, antibiotics, decongestants, etc. The contents of the medical kits for the Command Module (CM) of Apollo flight 7 through 11 are summarized in Table G-7.

Due to the increased mission duration and crew size of post-Apollo vehicles, and the opportunity for greater freedom of movement and activity, the requirements for medical kits are considerably increased. Based on inputs from

RPC Corporation (Ref. G-3), review of available data from previous manned spaceflights (Ref. G-2), submarine experiences (Ref. G-4), and communications with various medical personnel (Ref. G-6 and G-7), a preliminary list of medical items was compiled for a space rescue vehicle. However, most of the items defined were found to be also applicable to onboard space station kits. A list of medical items with estimated unit weight and number as required for both a space rescue vehicle and for a 12-man space station is shown in Table G-8. Details on the content of some of the individual kits are given in Table G-9. The total weight of the medical items for the space rescue vehicle is estimated as 35 pounds. The partial listing shown for the space station totals 80 pounds; however, as noted at the bottom of Table G-8, a number of items of potentially major significance in terms of weight and volume require further evaluation either to establish need, to define requirements, or to identify development priority. Most of these items appear to be more applicable to the space station than to the space rescue vehicle. Thus, the weight shown in Table G-8 for the space station probably represents only a fraction of the final total medical equipment weight.

If the probability of fractures is assumed to be high, the importance of onboard X-ray equipment, non-gravity dependent traction devices, and lightweight splinting and casting materials is obvious. The development of a means of providing non-gravity intravenous fluids administration should not pose a serious problem. The potentially large weight penalty associated with an adequate supply of intravenous solutions is a strong motivation for rehydratable solutions. The use of both pre-packaged and "cook book" concepts for the clinical laboratory could simplify onboard chemical analysis equipment and minimize onboard skill levels required. Utilization of vehicle EC/LS capabilities with minimum modification could provide an onboard hyperbaric therapy facility for burn and decompression sickness patients. The use of an existing air-lock with its pressure controls might be adequate based on determination of optimum pressure levels. Also use of the vehicle oxygen supply in conjunction with a Bennet respirator or equivalent would provide positive pressure breathing for inhalation therapy.

The individual items comprising the dental kit of Table G-9 were identified in Ref. G-6 and are oriented primarily towards tooth extraction. The kit, as defined, does not include items for treatment of caries, which, on the basis of submarine data, may be required for missions beyond four to six months. Development effort would be needed for such items as prepackaged temporary fillings and lightweight, low-power drilling equipment to permit the in-space treatment of caries.

Preliminary information obtained from Ref. G-7 subsequent to the completion of the requirements listing in Table G-8 indicated that a considerable increase may be made in the medical contents of the Skylab program as compared to the Apollo medical kit. Items under consideration include a surgical kit, a suture kit, a microbiology kit, a hematology kit, a urinalysis kit, and a relatively extensive list of drugs and medications. Any of these items, not already included in the requirements list in Table G-8, have been added to the list of items requiring further study at the bottom of the table.

G.3.2 Personnel Carrier and Auxiliary Aids

The transfer of injured personnel from the distressed vehicle to the rescue vehicle without further injury or damage can be a significant factor in assuring containment of the medical situation. Injuries requiring careful handling and immobilization include fractures and/or dislocations. Such injuries can result from moving in a weightless environment, body acceleration during maneuvering or docking operations, meteoroid penetration of the spacecraft cabin or the spacesuit during EVA, and mechanical injuries arising from explosive decompression, explosions, and walking on extraterrestrial surfaces.

The ideal characteristics of a device to transport an individual with such injury include:

1. Light weight, with minimum storage volume
2. Provision for body and limb restraints
3. Protection against bumping interior surfaces while being moved
4. Handles or grips, and tie-down provisions to the spacecraft interior

One concept combining these characteristics visualizes a stretcher-type inflatable air mattress with bumping shields, restraint belts and hand holds, and compressed air bottle. Restraint belts would be provided for both the torso and for each leg.

To provide full immobilization for fractures and/or dislocations, the use of pneumatic splints could supplement this personnel carrier. The storage volume of the carrier uninflated is estimated at 0.25 cubic foot with a total weight of under 10 pounds.

G.3.3 Other Equipment With Medical Utility

Medical conditions on board the distressed vehicle (DV) may require means for quarantining and/or decontaminating members of the DV crew and/or members of the rescue crew. Appendix H discusses two equipment items which could have secondary application in this context. The transfer capsule was conceived as a device to allow transfer of ill or injured personnel unable to don pressure garments for EVA transfer when docking was infeasible. This capsule, equipped with an independent environmental control system, could be docked against the SRV during the return-to-haven phase while serving as a one-man quarantine station. The portable airlock could hold two men for this purpose. This airlock could also be equipped to perform biological decontamination functions for personnel transferring in a docked situation or during a quarantine period.

These devices could also be used to isolate against radioactive contamination. In that role, docking against the SRV may not be feasible and tethering at a suitable separation distance may be required.

G.4 SUMMARY AND RECOMMENDATIONS

A review of available data shows a frequency of medical problems ranging from one case per 8 man-days of flight for minor problems in Apollo inflight medical experience to one case per 1,700 man-days for more serious problems in U.S. Navy Polaris submarine experience.

Based on examination of potential crew injury and illness data, preliminary medical equipment and supply requirements have been defined for a space rescue vehicle. A partial listing has also been provided for a space station. The rescue vehicle medical kits are estimated to weigh a total of 35 pounds for a rescue mission involving 12 crew members of a distressed vehicle.

Development is required for a number of space-oriented equipment items and supplies including non-gravity-dependent traction devices and means for intravenous fluids administration, lightweight X-ray equipment, rehydratable intravenous fluids, utilization of vehicle EC/LS capability for hyperbaric and inhalation therapy facilities, and lightweight dental equipment. Consideration should be given to equipment suitable for quarantine and decontamination of personnel.

Medical experience aboard submarines as compiled by the Submarine Medical Research Center provides a good source of data and shows that dental problems may be one of the more significant areas associated with extended missions.

It is recommended that an in-depth statistical study of Navy submarine data and other appropriate information be made to better identify risk factors for long-duration space flights. Of particular importance are the determination of event probabilities of medical emergencies in space and the selection of threshold values for such probabilities. This will permit a rational equipment selection for both the space rescue vehicle and a potentially distressed operating vehicle.

Based on better knowledge of medical emergency event probabilities, medical training requirements of rescue crews as well as primary mission crews should be analyzed and implemented.

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Table G-1. Potential Crew Illness and Required Treatment (Ref. G-3)

ILLNESS	SEVERITY					SUPPORT SERVICES REQUIRED				TREATMENT																							
	No Lost Time	Limited Duty (<1 week)	Bed Rest (>1 week)	Intensive Care	Return to Earth	Clinical Laboratory Tests	X-Ray	Surgery	Isolation	Analgesics	Antibiotics	Anticoagulants	Antiemetics	Antipyretics	Antispasmodics	Antitussives	Cathartics	Catheterization	Decongestants	Demulcents	Expectorants	Fungicides	Improved Hygiene	Incision & Drainage Set	Inhalation Therapy	Laxatives	Nasal Packing	Silver Nitrate Applicators	Special Diets	Steroids	Tracheotomy	Tranquilizers	Naso-gastric Suction
1. Athletes Foot	X																					X	X										
2. Dermatitis	X																					X	X							X		X	
3. Cellulitis	X					X				X	X			X										X									
4. Local infections	X					X				X	X			X										X									
5. Dental problems	X									X													X										
6. Epistaxis	X																											X					
7. Gastritis	X												X		X					X									X				
8. Bronchitis		X				X	X				X					X			X		X				X								
9. Common Cold		X				X								X		X			X		X				X								
10. Sinusitis		X				X					X								X														
11. Otitis media		X				X				X	X			X					X														
12. Influenza		X				X			X				X	X	X	X			X	X	X				X								
13. Gastroenteritis		X				X							X	X	X					X									X				
14. Diarrhea		X													X					X									X				
15. Dysentery		X							X						X														X				
16. Fever		X				X	X				X			X																			
17. Dental Abcess		X				X				X	X			X										X									
18. Epistaxis		X				X																					X	X		X			
19. Hemoptysis		X				X																											
20. Cystitis		X				X				X	X			X				X															
21. Epididymitis		X								X	X			X																			
22. Constipation		X															X									X			X				
23. Renal calculus		X				X	X			X	X		X		X			X															
24. Ileitis		X					X								X					X									X				
25. Tonsilitis		X				X				X	X			X																			
26. Bursitis or Tendonitis		X								X	X				X																		

Table G-1 (Continued)

ILLNESS	SEVERITY					SUPPORT SERVICES REQUIRED				TREATMENT																							
	No Lost Time	Limited Duty (< 1 week)	Bed Rest (> 1 week)	Intensive Care	Return to Earth	Clinical Laboratory Tests	X-Ray	Surgery	Isolation	Analgesics	Antibiotics	Anticoagulants	Antiemetics	Antipyretics	Antispasmodics	Antitassives	Cathartics	Catheterization	Decongestants	Demulcents	Expectorants	Fungicides	Improved Hygiene	Incision & Drainage Set	Inhalation Therapy	Laxatives	Nasal Packing	Silver Nitrate Applicators	Special Diets	Steroids	Tracheotomy	Tranquilizers	Naso-gastric Suction
27. Opthalmic infection		X									X																			X			
28. Local neuritis		X								X					X															X			
29. Supraventricular tachycardia		X				X																										X	
30. Appendicitis			X		X	X		X		X	X		X	X	X														X				X
31. Pneumonia			X			X	X				X			X		X			X		X				X						X'		
32. Renal calculus			X			X	X			X	X		X		X			X															
33. Cholelithiasis			X		X	X	X	X		X			X		X														X				X
34. Cholecystitis			X			X				X	X		X	X															X				X
35. Pancreatitis			X			X				X	X		X	X						X									X				X
36. Phlebitis			X		X	X	X			X	X	X		X																			
37. Otitis media c̄ vertigo			X							X	X			X																			
38. Pleural effusion			X			X	X																										
39. Dehydration			X			X							X																				
40. Hepatitis			X	X	X	X			X		X		X	X											X				X		X		X
41. Meningitis			X	X	X	X			X	X	X			X				X							X						X		
42. Encephalitis			X	X	X	X			X	X	X			X				X							X						X		
43. Pyelonephritis			X	X	X	X	X				X			X				X							X						X		
44. Glomerulonephritis			X	X	X	X	X				X			X				X							X						X		
45. Pericarditis			X	X	X	X					X	X		X											X								
46. Frequent premature ventricular contractions (PVC's)			X	X		X																											
47. Bundle Branch Block			X	X		X																											
48. Ventricular tachycardia				X	X	X																											
49. Heart Block				X	X	X																											
50. Respiratory sickness		X				X																											
51. Motion sickness	X												X																				

Table G-2. Potential Crew Injury and Required Treatment (Ref. G-3)

INJURY	SEVERITY						SUPPORT SERVICES REQUIRED				TREATMENT																							
	No Lost Time	Limited Duty (<1 week)	Limited Duty (>1 week)	Bed Rest (>1 week)	Intensive Care	Return to Earth	Clinical Laboratory Tests	X-Ray	Orthopedic Care	Surgery	Cleansing Agent	Antiseptic	Sterile Dressing	Topical Antibiotic	"Steri-strips"	Anesthetic, Local	Suture Kit	Elastic Bandage	Splint	Plaster Cast	Traction Device	Rubber Drains	Packings	Catheter	Suction	Gastric Lavage	Intravenous Fluids	Blood Transfusion	Tracheotomy	Hyperbaric Therapy	Antibiotics	Incision and Drainage Set	Analgesics	Non-Suit Transfer
1. Abrasion	X										X	X	X	X																				
2. Blister	X																																	
3. 1° Burn (sm-mod area)	X																																	
4. 2° Burn (small area)	X										X		X	X																				
5. Minor Laceration	X										X	X	X	X	X																			
6. Low Radiation Dose	X	X					X																											
7. Extensive Abrasion		X									X	X	X	X																	X		X	
8. 1° Burn (Lg area)		X									X																						X	
9. 2° Burn (moderate area)		X									X																				X		X	
10. Laceration (lg or deep)		X			X					X	X	X	X	X	X	X	X														X		X	
11. Joint Sprain		X						X	X									X	X														X	
12. Muscular Strain	X	X							X									X	X														X	
13. Moderate Dose Radiation			X	X			X																											
14. Costal Fracture		X						X	X							X		X															X	
15. Clavicular Fracture (uncomp)		X	X					X	X							X		X															X	
16. Opthalmic Burn or Abrasion		X												X		X																	X	
17. Colles Fracture			X					X	X							X		X	X	X													X	X
18. Smith's Fracture			X					X	X							X		X	X	X													X	X
19. Chauffer's Fracture			X					X	X							X		X	X	X													X	X
20. Simple Fracture of Hand		X	X					X	X							X		X	X	X													X	X
21. Simple Fracture of Ulna			X					X	X							X		X	X	X													X	X
22. Simple Fracture of Radius			X					X	X							X		X	X	X													X	X
23. Simple Fracture of Humerus			X	X				X	X	X						X		X	X	X													X	X
24. Pott's Fracture			X					X	X							X		X	X	X													X	X
25. Malleolar Fracture		X	X					X	X							X		X	X	X													X	X
26. Dupuytren's Fracture			X	X				X	X							X		X	X	X	X												X	X
27. Trimalleolar Fracture				X		X		X	X	X						X		X	X	X													X	X
28. Bimalleolar Fracture			X	X		X		X	X	X						X		X	X	X													X	X

Table G-2 (Continued)

INJURY	SEVERITY						SUPPORT SERVICES REQUIRED				TREATMENT																							
	No Lost Time	Limited Duty (<1 week)	Limited Duty (>1 week)	Bed Rest (>1 week)	Intensive Care	Return to Earth	Clinical Laboratory Tests	X-Ray	Orthopedic Care	Surgery	Cleansing Agent	Antiseptic	Sterile Dressing	Topical Antibiotic	"Steri-strips"	Anesthetic, Local	Suture Kit	Elastic Bandage	Splint	Plaster Cast	Traction Device	Rubber Drains	Packings	Catheter	Suction	Gastric Lavage	Intravenous Fluids	Blood Transfusion	Tracheotomy	Hyperbaric Therapy	Antibiotics	Incision and Drainage Set	Analgesics	Non-Suit Transfer
29. Barton's Fracture				X		X		X	X	X						X		X	X	X													X	X
30. Simple Fracture of Tibia			X					X	X							X		X	X	X													X	X
31. Simple Fracture of Fibula			X					X	X							X		X	X	X													X	X
32. Simple Fracture of Femur			X					X	X							X		X	X	X													X	X
33. Simple Fracture of Foot			X					X	X							X		X	X	X													X	X
34. Simple Skull Fracture				X	X			X	X																									X
35. Simple Spinal Fracture				X				X	X										X	X													X	X
36. 3° Burns (small area)		X	X								X					X															X		X	
37. Penetrating Abdominal Wound				X			X				X	X										X		X	X		X				X		X	
38. Penetrating Chest Wound					X		X				X	X										X			X		X		X		X		X	
39. Foreign Body in Trachea		X			X			X																	X				X					
40. Ruptured Viscus					X		X	X														X		X	X		X	X			X		X	
41. Clavicular Fracture (compl)				X	X		X	X	X	X						X			X								X	X					X	
42. Costal Fracture (complicated)				X	X		X	X	X	X						X			X								X	X	X				X	
43. Any compound Fracture				X	X		X	X	X	X	X	X				X						X		X			X	X			X		X	X
44. Spinal Fracture c̄ Paralysis						X		X	X	X														X									X	X
45. 2° Burns (extensive)					X		X			X	X													X			X			X	X		X	X
46. 3° Burns (extensive)					X		X			X	X													X			X		X	X	X		X	X
47. Heavy Radiation Exposure					X	X	X															X		X	X		X	X		X				X
48. Extensive Crush Injury					X		X	X	X	X	X	X										X	X				X	X	X	X	X		X	X
49. Head Injury c̄ Coma					X	X					X											X		X	X		X		X					
50. Poison																										X	X		X					
51. Decompression Sickness		X																												X				

Table G-3. Explanation of Medical Terminology Used for Injury and Illness from Tables G-1 and G-2

Line No. (Tab.I or II)	Illness (From Table I)	Injury (From Table II)
1.	--	--
2.	Skin eruption, "breaking-out"	
3.	--	--
4.	--	--
5.	--	Minor cut
6.	Nosebleed	--
7.	--	--
8.	--	--
9.	--	--
10.	Sinus infection	Large or deep cut
11.	Ear infection	--
12.	"Flu"	--
13.	--	--
14.	--	Rib fracture
15.	--	Collarbone fracture
16.	--	Burn or abrasion of eye
17.	--	Types of fractures at wrist
18.	Nosebleed	Types of fractures at wrist
19.	"Coughing of blood"	Types of fractures at wrist
20.	Bladder infection	--
21.	"Infection of testicle"	Fractures of bones of the forearm
22.	--	Fractures of bones of the forearm
23.	Kidney stone	Fracture of upper arm
24.	Irritation of lower small bowel	Type of ankle fracture
25.	--	Type of ankle fracture
26.	--	Type of ankle fracture
27.	Eye infections	Type of ankle fracture
28.	--	Type of ankle fracture
29.	"Fast heart" - impulse arising	Type of ankle fracture
30.	--	Fracture of bones of the lower leg
31.	--	Fracture of bones of the lower leg
32.	Kidney stone	Fracture of upper leg
33.	Gallbladder infection	--
34.	Gallstone	--
35.	Infection of pancreas	--
36.	Local infection of vein	--
37.	Ear infection with dizziness	--
38.	Fluid collecting in chest	--
39.	--	Object in windpipe
40.	Liver infection	Ruptured internal organ
41.	"Infection of brain"	Collarbone fracture
42.	"Infection of brain"	Rib fracture
43.	"Kidney stone"	Fracture involving torn skin over break
44.	"Kidney infection"	--
45.	Infection of heart's protective sac	--
46.	Early beats or heart-out of rhythm	--
47.	Electrical conduction block in heart	--
48.	"Fast heart" - arises in ventricles	--
49.	--	--
50.	--	--
51.	--	--

Table G-4. Explanation of Medical Terminology for Treatments Used on Tables G-1 and G-2

Treatments for Illness from Table I		Treatments for Injury from Table II	
Treatment	Explanation or Example	Treatment	Explanation or Example
Analgesics	Aspirin, pain killers, etc.	Cleansing Agent	-
Antibiotics	-	Antiseptic	-
Anticoagulants	Temporarily prevents clotting	Sterile Dressing	-
Antiemetics	Medications associated with central nervous system	Topical Antibiotic	Local antibiotic in paste form
Antispasmodics	Control of muscle spasms, etc.	Steri-Strips	Adhesive used in lieu of stitches
Cathartics	Cleansing or flushing	Suture Kit	Used for laceration or incision closure
Catheterization	Withdrawal of fluid from a cavity or organ	Elastic Bandage	-
Decongestants	-	Splint	-
Demulcents	Treat inflammed membranes	Plaster Cast	-
Expectorants	Facilitate discharge of mucus	Traction Device	-
Fungicides	Inhibit growth of spores/fungi	Rubber Drains	Soft rubber tubes used to drain infected areas
Improved Hygiene	-	Packings	-
Incision and Drainage	Infected wounds	Catheter	Used to drain fluid from a cavity
Inhalation Therapy	Positive pressure breathing	Suction	-
Laxatives	-	Gastric Lavage	Stomach pump
Nasal Packing		Intravenous Fluids	-
Silver Nitrate	Closure of small veins in nose	Blood Transfusion	-
Special Diets	-	Hyperbaric Therapy	Increased pressure environment
Steroids	Compounds for inflammation	Antibiotics	-
Tracheotomy	Incision of "windpipe"	Incision & Drainage	Infected wounds
Tranquilizers	-	Analgesics	Aspirin, pain killers, etc.
Naso-Gastric Suction	Evacuation of stomach via nasal passage		

Table G-5. Inflight Medical Problems in Apollo 7 through Apollo 11 (Ref. G-2)

Symptom/Illness	Cause	Number of Cases
Coryza (sinus infection)	--	3
Stomatitis	Ulcers	1
Nausea and Vomiting	Motion Sickness (1) Undetermined (1)	2
Stomach Awareness	Motion Sickness	5
Facial Rash	Contact Dermatitis	1
Respiratory Irritation	Fiberglass	1
Eye Irritation	Fiberglass	1
Skin Irritation	Fiberglass	2
	Total	16

Table G-6. Frequency of Medical Problems Experienced Aboard Polaris Submarines During the Period 1963 - 1967 (Three million man-days of operation)(Ref. G-4)

Medical Classification or Area	No. of Cases	No. of Sick Days	Percentage of Total		Proportional No. of Cases in One Year for a 12-Man Space Station *
			Cases	Sick Days	
Surgical Procedures Performed at Sea	196	532	11.2	14.5	0.287
Neurology	19	162	1.2	4.4	0.028
Orthopedics	109	558	6.2	15.2	0.160
Urology	56	275	3.2	7.5	0.082
Ear, Nose, and Throat	107	297	6.1	8.1	0.156
Opthalmology (Eye)	22	75	1.3	2.2	0.032
Upper Respiratory	30	67	1.7	1.8	0.044
Pneumonia, Bronchitis, etc.	78	354	4.4	9.6	0.114
General Internal Medicine	293	1061	16.5	28.8	0.430
Dermatology	34	156	1.9	4.2	0.050
Dental	624	66	35.4	1.8	0.915
Psychiatric	192	69	10.9	1.9	0.282
Totals	1760	3672	100.0	100.0	2.58

* Based on a direct ratio of the man-days involved in the space station (4,380) as compared to submarine data.

Table G-8. Medical Kit Requirements for a Space Station and a Rescue Vehicle (sources: Refs. G-3, G-6, and G-7)

Item	Description and/or Remarks	Unit Weight (lb)	No. Required		Total Weight (lb)	
			Space Sta.	SRV*	Space Sta.	SRV*
Medication Kit	See detail listing (Table G-9)	2.5	6	2	15	5
Intravenous (IV) Fluids Kit	See detail listing (Table G-9)	15.0	2	1	30	15
Sterile Dressings	Surgipads, gauze, bandaids	0.50	6	2	3.0	1.0
Suture Kit (wound closure)	See detail listing (Table G-9)	1.0	3	2	3.0	2.0
Dressings, Packings, Bandages	---	1.5	4	2	6.0	3.0
Inflatable Splints	---	0.25	4	2	1.0	0.5
Incision and Drainage Kit	Scalpel, hemostat, forceps, dressings, etc.	0.50	3	2	1.5	1.0
Tracheotomy Kit	---	0.25	2	1	0.5	0.25
Rubber Drains	Drainage of infected areas	0.25	2	2	0.5	0.5
Naso-Gastric Suction	Stomach drain via nose	0.25	2	1	0.5	0.25
Plaster Cast Kit	Stockingette, webril, plaster roll	2.0	3	2	6.0	4.0
Dental Kit	Primarily for extraction (see Table G-9)	8.0	1	-	8.0	--
Surgical Kit	Forceps, retractors, scissors, scalpel, etc.	2.5	2	1	5.0	2.5
			Total		**80.0	35.0

ITEMS REQUIRING FURTHER STUDY

- Light-Weight X-Ray Equipment
- Non-Gravity Dependent Traction Devices
- Non-Gravity Dependent IV Fluids Administration
- Pre-Packaged Clinical Laboratory
- Hyperbaric Therapy
- Inhalation Therapy
- Rehydratable IV Fluids
- Pre-Packaged Temporary Fillings
- Light-Weight Drilling Equipment
- Microbiology Kit
- Hematology Kit
- Urinalysis Kit

* Space Rescue Vehicle

** This represents only a partial listing for the space station.

Table G-9. Detail Listing of Medications, Drugs, Intravenous Fluids, and Miscellaneous Kits

Classification	Description	Unit	No. Required Per Kit
Medication and Drugs			
Antibiotics			
Topical	neosporin ointment	1 oz. tube	2
Opthalmic	neosporin ointment	1/8 oz. tube	1
Systemic	pollycillin (ampicillin)	250 mg tablet	48
Anesthetics			
Opthalmic	opthaine drops	15 cc bottle	1
Local	xylocaine 1% injectors	5 cc	4
Analgesics	demeral	100 mg injectors	3
	darvon	65 mg tablets	12
	aspirin	300 mg tablets	72
Antiemetics (for motion sickness)	marezine	50 mg injectors	4
	marezine	50 mg tablets	12
Antispasmodics	lomotil	tablets	24
	donnatal	tablets	12
Antitussives (cough remedics)	actifed	tablets	60
Decongestants			
Systemic	actifed	same as above	--
Nasal Spray	afrin	3 cc bottle	3
Expectorants	antifed - C	10 cc	16
Fungicides	tinactin cream 1%	15 gm	2
Steroids			
Topical	celestone cream (0.2%)	15 gm	1
Systemic	to be selected	--	--
Tranquilizers	vistaril (25 mg)	capsules	18
	seconal (100 mg)	capsules	24
Antiseptics	befadine solution	1/2 oz.	3
Intravenous Fluids	ringers lactate	1000 cc	2
	5% dextrose in water	1000 cc	2
	dextran	500 cc	1
	administration set	--	1
Miscellaneous Kits			
Suture Kit (wound closure)	adhesive steri-strips		6
	needle holder, forcep, scissors, gloves, drape, nylon plus silk suture		1 each
	gauze 4 x 4		12
Dental Kit	forceps		8
	penlight/mirror		2
	elevators (for extraction assistance)		2
	hand instruments		8
	dental syringe		2
	disposable needles		12
	local anesthesia		--
	magnetic tray/pouch		1

APPENDIX H

SPACE RESCUE VEHICLE REQUIREMENTS

APPENDIX H

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APPENDIX H

SPACE RESCUE VEHICLE REQUIREMENTS

H.1 GENERAL*

H.1.1 Objectives

The primary aim of this phase of the Space Rescue Operations Study was to provide the data base for the conceptual design of a space vehicle capable of performing required rescue operations, and, additionally, to evaluate the capability of the planned Integrated Program (IP) vehicles to perform these operations. In order to attain this primary objective, a number of subsidiary goals were established for this task. These included the determination of all major functions which a Space Rescue Vehicle (SRV) and crew would have to perform during a rescue operation, and which could generate special equipment requirements and special operational procedures. It also included a review of operations which the SRV would have to perform to protect itself in the event the emergency within the distressed vehicle (DV) resulted in an external environment hazardous to the SRV. Here again, the goal was disclosure of special equipment and operational requirements for a potential rescue vehicle imposed by such a hazardous environment.

The output sought from this study task would be quantitative only with respect to equipment weight and volume requirements which would be imposed upon an SRV or an IP vehicle to be used for rescue missions. Rescue operations timelines are of necessity "rough order of magnitude" during this early phase of rescue analysis. Even more qualitative would be output data related to hazards which the rescue vehicle itself might encounter because these hazards cannot be quantitatively defined at this time.

H.1.2 Ground Rules and Assumptions

Ground rules initially provided by NASA were amplified during review meetings with the NASA Study Monitor. Among the more important ground

*This Appendix is based on the work of E. J. Rattin, N. Campbell, and others as indicated.

rules was the restriction of the study effort to only those emergency situations which could reasonably be expected to require rescue. A number of other emergency situations can be postulated which might result from equipment failures but which could be resolved with onboard emergency supplies at least until the next scheduled arrival of a logistics vehicle. Similarly, the emergency could result in personnel injuries calling for the return of personnel to earth. However, if the treatment capability on board the distressed vehicle is adequate until arrival of a regular scheduled logistics flight, a rescue situation would not exist.

This phase of the study was also constrained to consider only those vehicle and rescue crew operations, shown in Figure H-1, to be conducted after rendezvous between SRV and DV and prior to the departure of the SRV from the vicinity of the DV. The latter could take place either after successful rescue or after a decision that rescue could not be accomplished. The disposition of the DV after rescue was to be considered as part of the problem under consideration. For this task only, rescue situations to be considered were restricted to the Earth Orbit Shuttle (EOS), and the Space Station or Space Base, in earth orbit. After completion of the analysis, however, it was noted that the operations and equipment derived as special to a rescue operation would be equally useful if applied to rescue in lunar orbit or in geosynchronous orbit.

Among the many emergency situations disclosed as possible by the hazards analysis (Appendix B), the ground rules require specific attention to the problem of a tumbling DV, docking with a non-cooperative spacecraft, and rescue from a DV with a damaged or incompatible docking port. Other situations considered included:

- DV-generated debris
- Uncontrolled nuclear radiation
- Loss of communication
- EVA from DV not feasible
- DV damage interferes with rescue
- External medical aid required

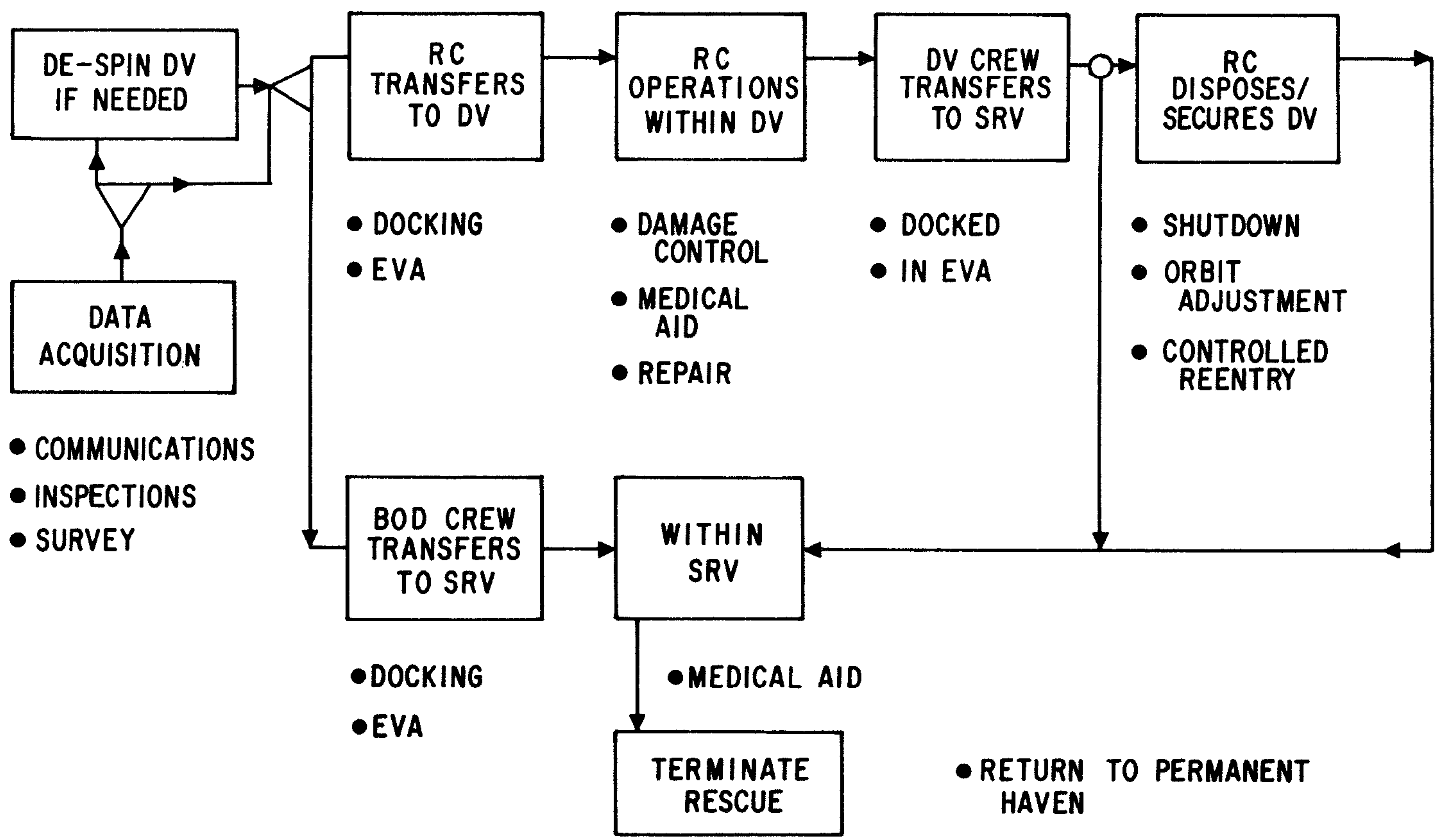


Figure H-1. Space Rescue Vehicle Requirements; Rescue Operations--Top Flow

The probabilities of occurrence of these situations versus those of the many other emergency situations was beyond the scope of the study. Therefore, equal probability was assumed for all situations.

The results of this study phase were to be generally applicable. It was specified that rescue vehicle requirements and the rescue crew equipment and operational requirements not be unique to any planned IP vehicle.

Since most emergency situations might permit alternate operational plans and different types of equipment, it was determined that all reasonable rescue alternatives would be defined. Subsequent optimization based on cost or other effectiveness parameters would follow.

H.1.3 Rescue Requirements

The hazards analysis reported in Appendix B resulted in the definition of various emergency situations requiring rescue, and produced a listing of the capabilities which a remedial system such as a rescue vehicle should possess. Reference H-1 also provided important guidance.

The remedial system should be able to supply the following essential functions:

- A habitable haven
- Medical aid
- Life support
- Communication
- Power
- Transportation to a final haven of safety

The remedial system will also be required to provide some or all of the following capabilities:

- Collision avoidance
- Radiation protection (nuclear radiation from DV)
- Docking to a disabled spacecraft
- Arrest of a tumbling spacecraft
- Retrieval of personnel from EVA or from DV

H.1.4 Approach

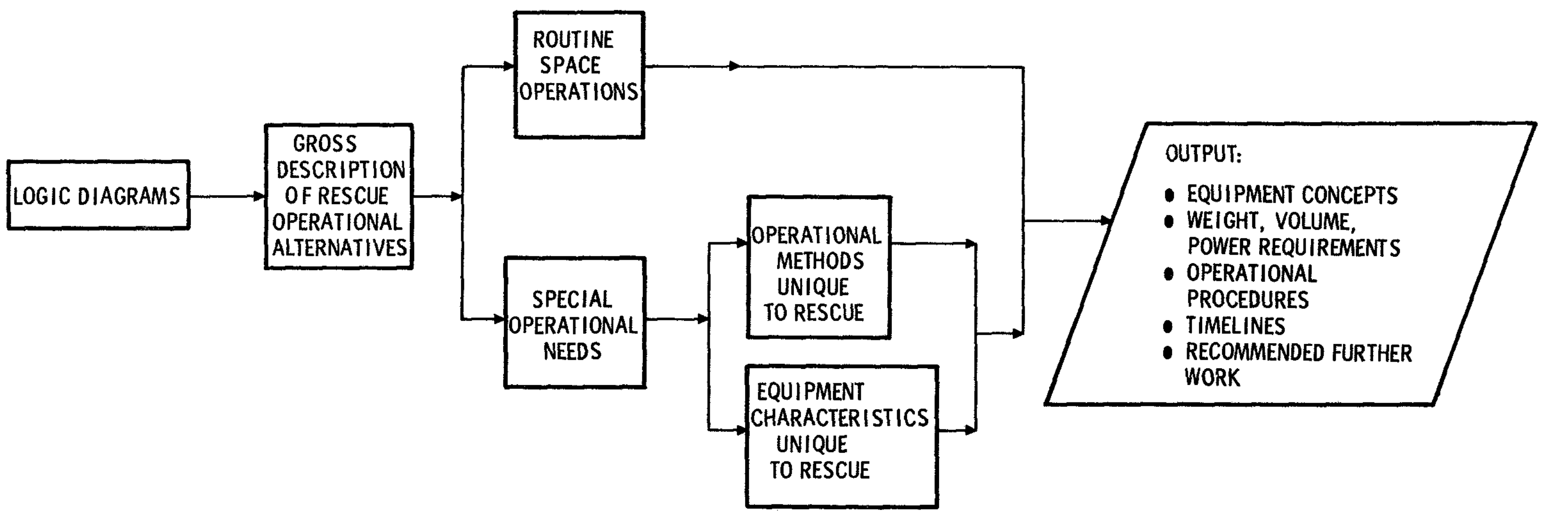
Because of the complexity of a rescue operation in terms of the many available alternate operational paths, the approach chosen and depicted in Figure H-2 called for the preparation initially of simple binary logic diagrams. Starting with a top flow diagram, this method permitted the charting of alternate operational flows to that level of detail required to identify major operational segments. This set of logic diagrams also permitted segregating flow segments representing routine space operations to be performed by, for example, logistics vehicles, from those operations specific to the rescue mission. These special rescue operations were then further detailed with the aid of additional levels of flow charts and logic diagrams to define methodology and equipment needs unique to the rescue mission. Conceptual design studies were then undertaken to develop equipment details to sufficient detail to permit rough order of magnitude weight and volume estimates, to identify technology requirements and additional study needs, and to estimate timelines for the operations involving these equipment concepts.

H.2 LOGIC DIAGRAMS

H.2.1 Explanatory Notes

The logic diagram approach was chosen to assist in the preparation of the rescue operational flow because its binary logic aids in the identification of all reasonable alternate operational modes. In the chronology of performing this rescue study it precedes the evaluation of planned transportation elements of the Integrated Program such as the EOS and the Space Tug for rescue use. The nomenclature chosen for this phase of the study does not reflect actual or planned vehicles and its results are generally applicable.

For example, the bail-out device (BOD) is used in the logic diagrams in its basic functional sense, i.e., a shelter into which the DV crew has fled to await rescue and which is still in the vicinity of the DV, possibly still attached. In the subsequent study phase the BOD was further defined as a bail-out and



- LOGIC DIAGRAMS DEVELOPED FOR ALL RESCUE OPERATION PHASES

Figure H-2. Approach to Space Rescue Vehicle Requirements wait device or a bail-out and return device. Either could be derived by modifying standard IP hardware or could be an entirely new development.

Similarly, as used in this subtask the SRV represents the vehicle which has brought the rescue crew close to the DV. If it is able to dock against the DV and/or carry the special rescue equipment, then no other vehicle is required. If it cannot dock, a transfer module (TM) would have to be carried for that purpose. This TM is equipped with sufficient propulsion to dock to the DV while carrying the rescue crew and its special equipment, and to return with both the rescue crew and DV crew to the SRV. The TM is also useful in performing external surveys or aiding in damage control.

During the study phase concerned with the final remedial system selection (Appendix J), it was concluded that a special transfer module equipped for rescue would always be required, and subsequently the term SRV was exclusively used for such a vehicle. The term "transfer module" was then dropped and its basic concept, that of providing the short-distance transfer between transporter and DV, was retained in the form of the SRV.

H.2.2 Logic Diagrams

Figures H-3 through H-13 and Tables H-1 through H-36 form a unified set that illustrates and interprets the logic flow. The major operational segments to which the logic flow diagram approach is applied are shown on the top flow diagram of the rescue operations, Figure H-3. Each of these segments is given a letter designation on the top flow logic diagram to which the following detail diagrams are keyed. Likewise, second-order codes are assigned in the detail diagrams, and these sub-segments are further treated in the accompanying tables, which are keyed to the detail diagrams.

The intent in preparing these diagrams was not to cover all of the individual operational steps making up the total rescue effort but to concentrate upon those operations unique to rescue and involving possible special equipment. As a consequence, and also to simplify the process, a number of questions are not asked in the logic diagram format but are listed under the heading of "Required Prior Knowledge" on the tables following each diagram. The actions shown on the diagrams therefore reflect only the critical questions directly related to unique rescue operations. They are preceded and supplemented by other questions as shown on the tables, which also indicate the means used by the rescue crew to provide needed answers. Some of the detail diagrams use a dashed line to enclose an area of the diagram. This line indicates that the tables following the diagram cover only the actions within the enclosure.

Under the "Required Action" heading of the tables are listed those actions shown or implied by the logic diagram, which may require special equipment not normally available on a transporter vehicle. The stated operations times associated with these actions are not based on special analysis but represent experience as reflected in Gemini and Apollo data, as well as analysis performed under the USAF Manned Orbiting Laboratory program and judiciously translated to the rescue problem. The "Equipment Needs" are the special equipment needed to accomplish the required actions.

The top flow diagram shows an overview of the individual operational phases to be described in more detail in subsequent diagrams and tables. As stated earlier, only those operations between the establishment of rendezvous conditions between SRV and DV and the departure of the SRV from this rendezvous position are included in this analysis. Unless the exact nature of the emergency is known to the SRV crew, this rendezvous condition is established at a stand-off distance of some miles to permit a situation survey as indicated in Action Box A. If this survey discloses all of the information about the DV which the SRV requires to perform rescue, the SRV moves to whatever position relative to the DV has been indicated as safe. This may involve direct docking or merely a much shorter stand-off distance from which EVA transfer is feasible. The initial survey may have indicated that the DV crew has reached the BOD. If this vehicle is not attached to the DV, the SRV will make suitable contact with the BOD, as indicated by Action Box D, and proceed with further action as shown by Action Boxes L and J, or M. If the initial survey under A was incomplete in the sense of not informing the SRV crew of DV status, DV crew condition, and/or hazards possibly facing the SRV or its crew, a close survey may be performed. As indicated by Action Box B, such a survey may require a motion stabilizing operation, if DV motion is so severe as to prevent, for example, a survey crew from performing an external inspection from EVA.

If one follows the logical flow of questions and resulting action boxes, one finds several instances where the rescue mission is suspended because of information indicating that rescue is infeasible or no longer necessary. Because of the many alternative situations which might warrant such action, as well as the time constraints on this study phase, such situations have not been further treated. The logic flow has in those cases been terminated by Action Box M, indicating that the rescue control center would determine subsequent course of action of the SRV.

For the purpose of this study the rescue mission can be terminated by finding that the emergency on the DV can be relieved by replacement of supplies or by minor repairs, thus permitting the DV either to abort to safe haven or to continue with its original mission. The rescue mission will, of course, also terminate after successful completion of rescue as indicated by Action Box G. The multiple occasions for medical aid are also indicated by the use of Action Box J in several of the flow paths.

Disposing of or securing the DV after rescue or when rescue is infeasible is an important requirement which has not received the attention it warrants in this study because of time constraints. It should, however, be the subject of further effort, particularly with respect to a DV in low earth orbit. In such circumstances, orbit degradation as a result of natural causes not self-correctible by an inoperative DV, or caused by the emergency itself, could pose a hazard to earth populations.

The meaning of the other action boxes shown on the top flow logic diagram will become evident upon inspection of the detailed diagrams and tables to follow. Further details concerning the operations to be performed under each action box (i. e., segments A through M) are presented in Section H-3.

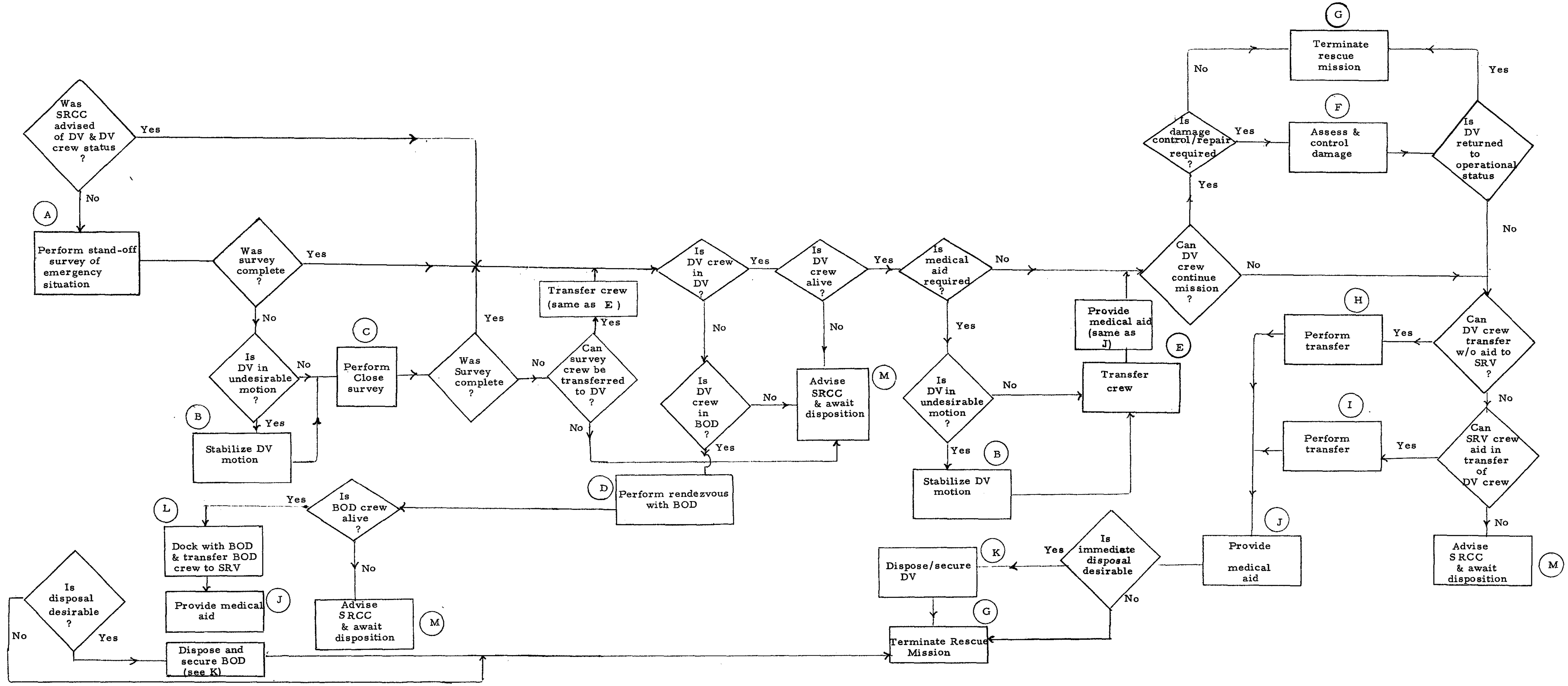


Figure H-3. Top Flow Logic Diagram of Space Rescue Operation

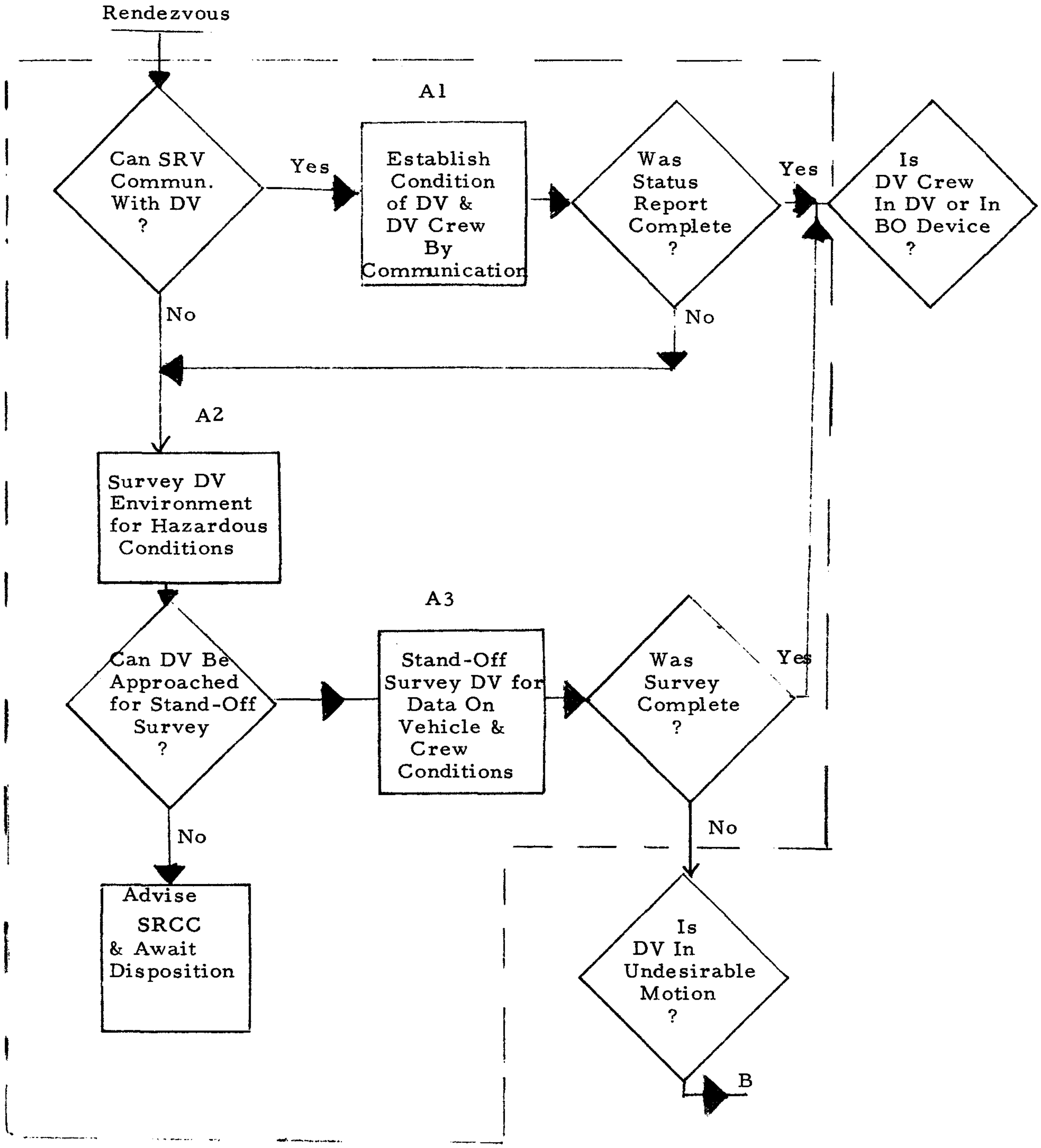


Figure H-4. Segment A: Perform Stand-off Survey of Emergency Situation

Table H-1. Segment A. 1: Establish Condition of DV and DV Crew by Communication from Stand-off Range

Required Prior Knowledge	Means
What is maximum range for emergency communications?	Handbook*
What are communications systems possibly available on DV or BOD?	Handbook
Is DV provided with BOD?	Handbook

Required Action	Equipment Needs	Operations Time
Attempt to communicate with DV and/or BOD	RF communications and blinkers in SRV and DV/BOD	30 minutes
Obtain telemetered diagnostics data	Automatic sensor reading telemetry transmitter on DV, receiver on SRV	

*This term, as used here and in subsequent tables, means that the rescue crew is provided with descriptive data covering details of equipment and operational capability of the specific DV being contacted. Such data files, in the interest of payload weight and volume considerations, will need to be restricted to items impacting upon the rescue operation.

Table H-2. Segment A. 2: Survey DV Environment for Hazardous Conditions

Required Prior Knowledge	Means
Orbital position at time of hazard occurrence	Ground data*
Hazardous equipment on board DV	Handbook
Nature of hazard	Ground data
DV orbital parameters	Handbook, ground data

Required Action	Equipment Needs	Operations Time
Search for debris, presence and vector data	LWIR/laser search system	30-90 minutes
Search for presence of harmful radiation	Radiation sensors	

*This term, as used here and in other tables, implies data obtained through a communication link with the SRCC, either prior to launch of the rescue mission or during flight.

Table H-3. Segment A. 3: Stand-off Survey DV/BOD for Data on Vehicle and Crew Status

Required Prior Knowledge	Means
Safe approach range and approach corridor	Previous survey as in A. 2 Or Handbook Or Communication with DV/BOD
DV configuration and manning level	Handbook
Location and type of passive survey aids on DV/BOD	Handbook and/or communication with DV/BOD

Required Action	Equipment Needs	Operations Time
Approach DV/BOD	Existing propulsion on SRV	30 Minutes
Observe condition of DV/BOD	Viewports, telescopes and illumination source in SRV	90 Minutes
Measure motion of DV/BOD	Laser system on SRV, passive targets on DV/BOD Visual means	5 Minutes
Obtain diagnostic data		
Debris Radiation (nuclear) Thermal radiation	IR/laser mapping Radiation sensors IR thermal mapping	During above operations

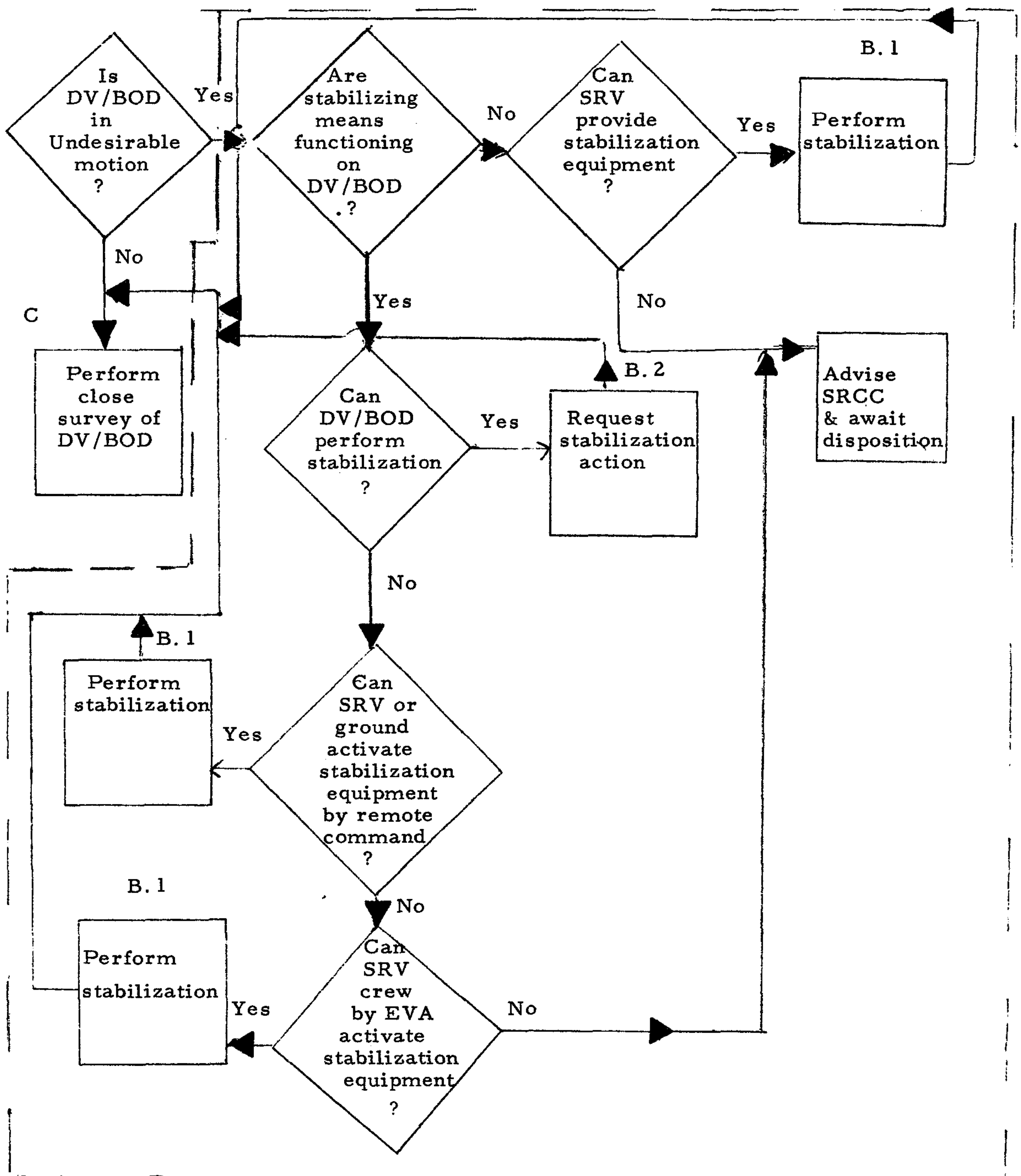


Figure H-5. Segment B: Stabilize DV Motion for Close Survey

Table H-4. Segment B. 1: Perform Stabilization of DV/BOD

Required Prior Knowledge	Means
Description of undesirable motion	Laser, visual observation during stand-off survey
Axis (Axes) of rotation Rates	
Condition of on-board systems	Communication, telemetry
Availability of suitable stabilizing equipment	
Onboard DV/BOD Onboard SRV	Handbook, communications
Availability of external attachment points on DV/BOD	Handbook, observation
Does existing motion permit attachment of stabilization equipment by SRV?	Handbook

Required Action	Equipment Needs	Operations Time
1. If onboard stabilization system is potentially functioning on DV:		
a. Request that DV crew activate system	Existing communications system	2 minutes
b. If DV crew cannot activate system, attempt remote command activation by SRV or ground	Command and control link between DV and both or either SRV and ground	2-10 minutes
c. If remote activation is not feasible, attempt activation by SRV crew in EVA	EVA suits for SRV crew Portable plug-in command and control electronics, with portable power supply	*5 minutes to dress, 7 min. for AL cycle, 5 min. for transit one way

*Each man

Table H-4. Segment B. 1: Perform Stabilization of DV/BOD (Continued)

Required Action	Equipment Needs	Operations Time
	AMU's, manipulators to assist in anchoring EVA crew to rotating DV, tether lines	Activation time not determinable at this time
d. If DV onboard stabilization system is not functioning, attempt to provide portable system from SRV	EVA suits for SRV crew	*5 minutes to dress 7 min. for AL cycle
	Mini-shuttle with manipulators	Unloading of equipment from SRV ~30 min.
	De-spin system	5 minutes for transit one way
	Attachment system	Anchoring of equipment on DV ~ 30 min.
	Tether lines, AMU's with manipulators to assist in anchoring EVA crew to rotating DV	Despin operation ~30 min.

*Each man

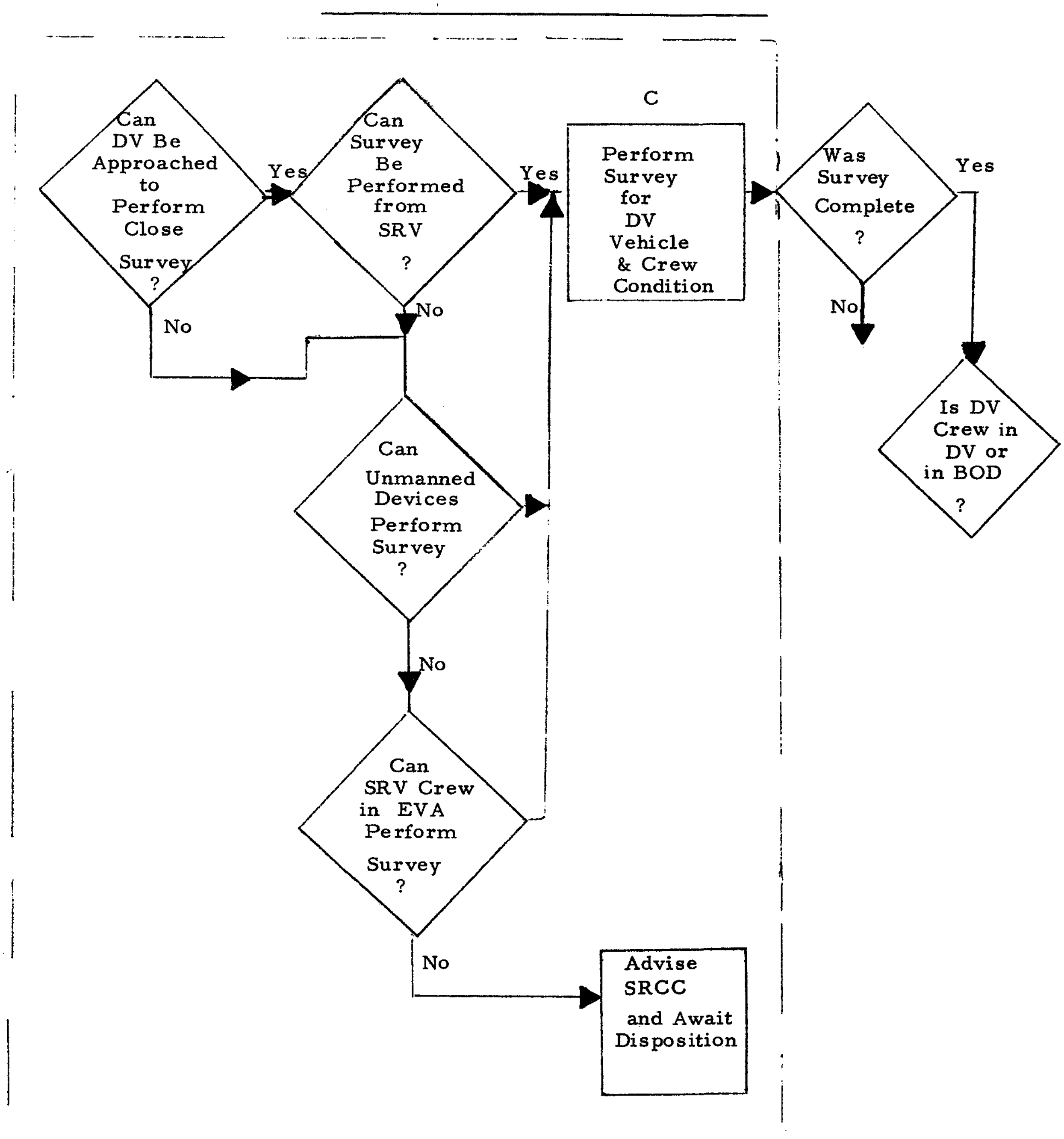


Figure H-6. Segment C: Perform Close Survey of DV/BOD

Table H-5. Segment C: Perform Close Survey of DV/BOD

Prior Knowledge Required	Means
Safe approach distance to DV/BOD	Communication, stand-off survey
Crew quarters location	Handbook, communications
Location of DV exterior plug-ins for hardline communications	Handbook, communications
Location of DV exterior repeaters of damage sensors	Handbook, communications
Location of atmosphere sampling points on DV exterior	Handbook, communications
Location of DV hatches and airlocks	Handbook, communications

Required Action	Equipment Needs	Operations Time
1. Search for debris presence and determine vector data	IR/laser search system	5 minutes
2. Search for presence of harmful radiation	Radiation sensors	5 minutes
3. If survey can be performed from SRV:		
a. Approach DV/BOD to permissible range	Existing SRV propulsion and guidance system	5-10 minutes
b. Fly-around DV/BOD for visual and sensor observations	Existing SRV propulsion and guidance systems, viewports, telescopes and illumination on SRV, IR thermal mapping, radiation sensors	90-180 minutes (b and c)
c. Attempt communications	Blinker* system	

*Assumes that previous attempts at RF communications have failed.

Table H-5. Segment C: Perform Close Survey of DV/BOD (Continued)

Required Action	Equipment Needs	Operations Time
4. If unmanned devices perform survey:		
a. Make ready and launch TV carrier and manipulator	Self-propelled manipulator and TV carrier with power source and communications system	30 minutes
b. Perform fly-around DV/BOD for visual and sensor observations	TV carrier's propulsion system, remote guidance from SRV, illumination source on carrier, TV camera on carrier, IR thermal mapping system (?) on carrier, radiation sensors on carrier*	10-90 minutes
c. Land TV carrier on DV/BOD for contact-type survey to:	Propulsion system and landing guidance system	5 minutes
- read exterior damage sensor repeaters - plug-in hardline communicator system	TV camera, illumination source, manipulator arms and communication set, hardline telemetry receiver	5 minutes
- perform atmosphere sampling	Power drill, sampling probes, instrumentation, sample collectors	30 minutes
5. If SRV crew in EVA performs survey:	EVA suits, AMU's or self-propelled manned manipulators	5 min. transit one way
a. Perform visual inspection	Portable illumination source plus power pack	10 minutes
b. Read damage sensors	Portable plug-in repeaters plus power pack	5 minutes

*Feasibility uncertain

Table H-5. Segment C: Perform Close Survey of DV/BOD (Continued)

Required Action	Equipment Needs	Operations Time
c. Establish communications		
- by phone	Portable plug-in telephone hand sets	10 minutes
- by visual means	Blinkers, writing slates	
- by audible means	Contact speakers and microphones	
d. Determine feasibility of entering DV/BOD		
Sample atmosphere	Portable instrumentation	15 minutes
Determine radiation environment	Portable instrumentation Body shield	

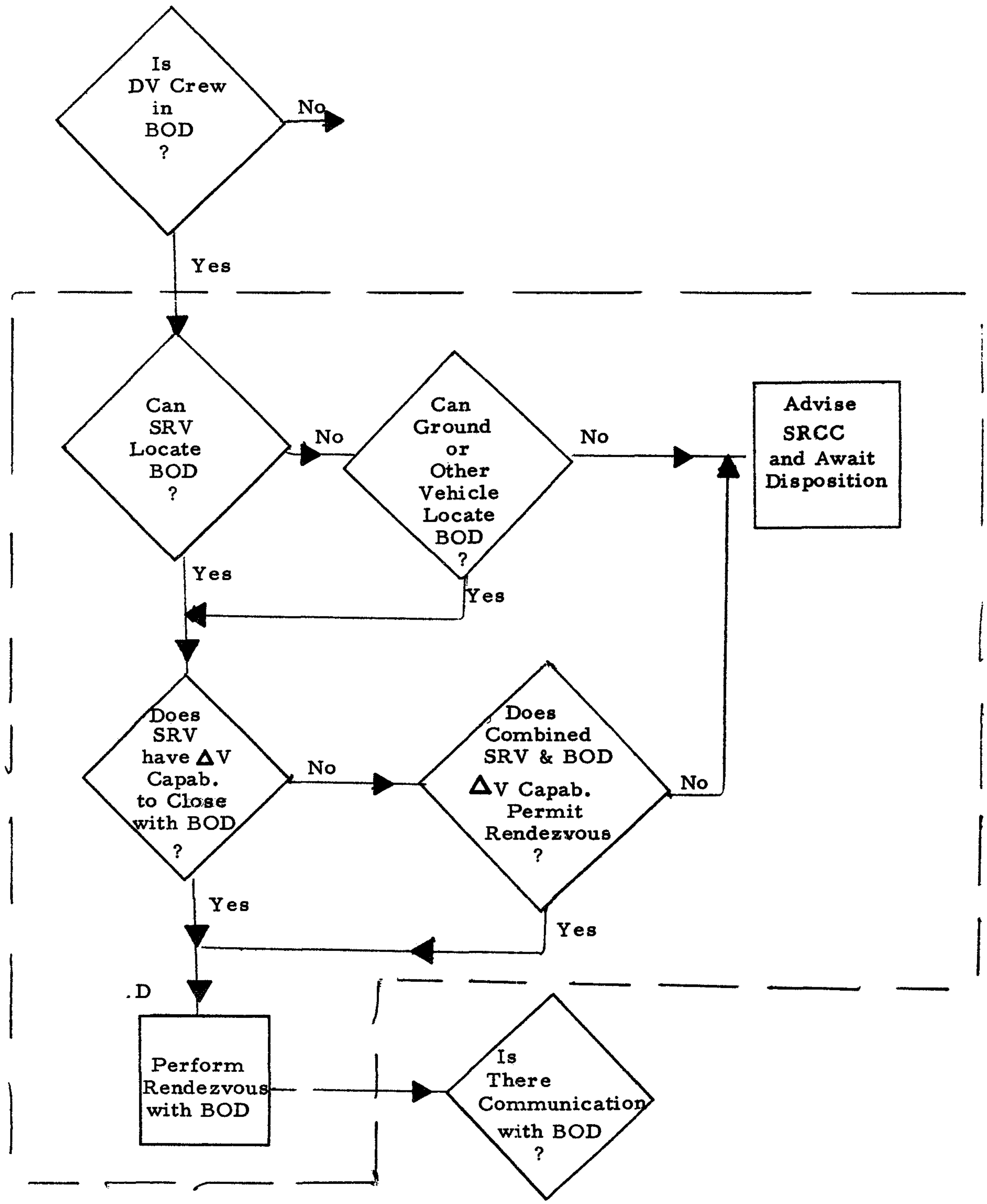


Figure H-7. Segment D: Perform Rendezvous with Bail-Out Device (BOD)

Table H-6. Segment D: Perform Rendezvous with Bail-Out Device

Required Prior Knowledge	Means
Configuration of BOD*	Handbook
Number of BOD available to DV	Handbook, communications, observation
ΔV and ECLS capability of BOD	Handbook, communications
Location aids on BOD (beacons)	Handbook
Communication systems on BOD	Handbook
Ground tracking net capability	Handbook

Required Action	Equipment Needs	Operations Time
1. SRV locates BOD		
a. If near DV	Visual, laser, RDF	5 minutes
b. If distant, conduct volume search, determine range, vector, rate data	LWIR/laser Or: RDF and doppler ranging system	5 minutes
2. Ground net or other vehicle locates BOD	Communications with SRCC	5-45 minutes
3. If SRV has sufficient ΔV capability, compute and execute rendezvous maneuver	Guidance computer on SRV or SRCC provides navigation data Laser rendezvous and docking guidance, existing SRV propulsion	5 min. for computer 1-3 orbits
4. If combined BOD and SRV ΔV capabilities are required, compute and execute rendezvous maneuver	As under 3 above, plus communication link with BOD, and BOD propulsion	1-3 orbits

*Could be non-propulsive bail-out and wait system, or propulsive bail-out and return system electing to remain near DV. Could also be IP vehicle like tug at DV at time of emergency.

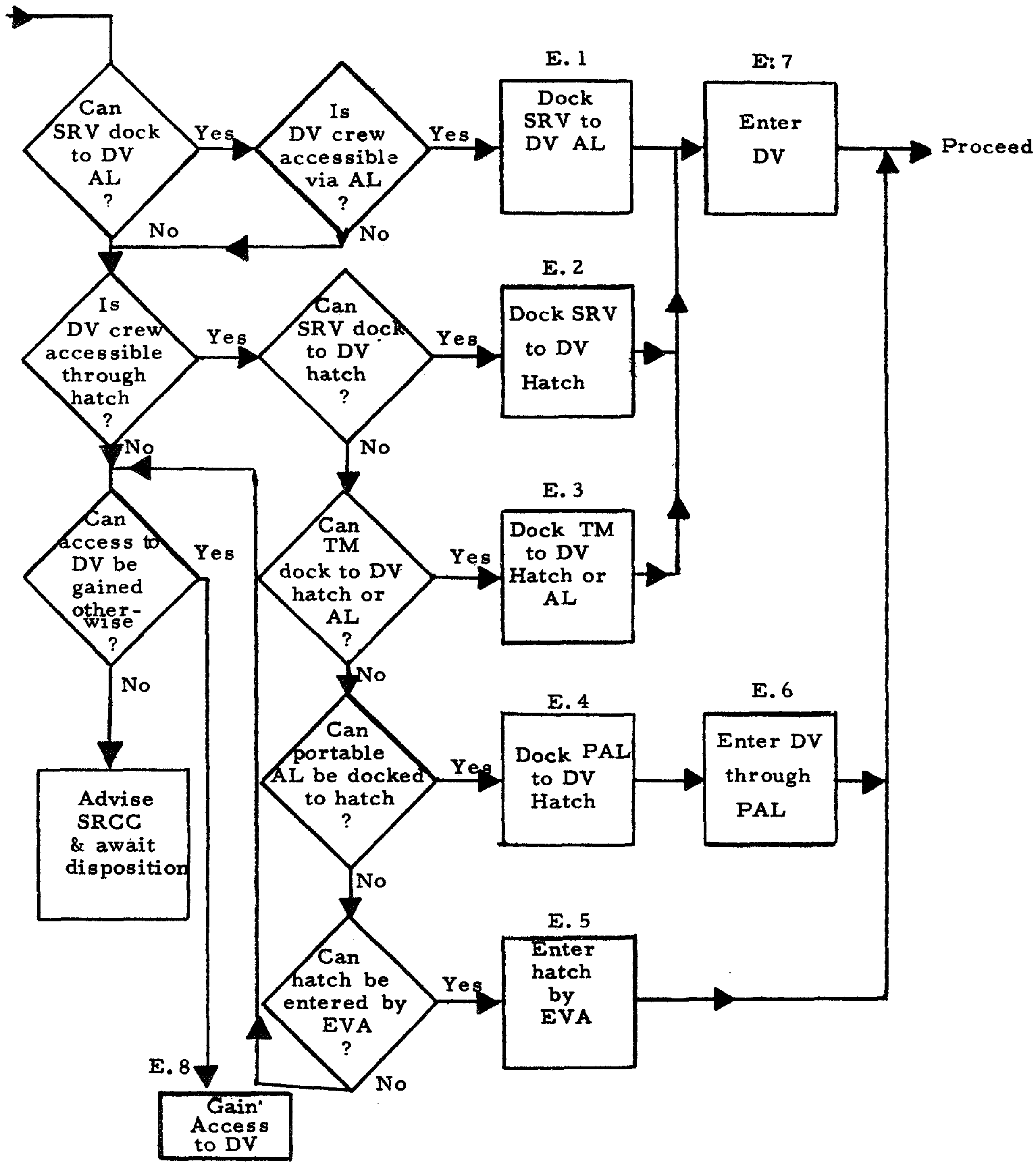


Figure H-8. Segment E: Transfer Rescue Party into DV

Table H-7. Segment E. 1: Dock SRV to DV Airlock (AL)

Required Prior Knowledge	Means
Is object already docked to AL? (space vehicle, experiment module)	Observation, communication
Is object self-propelled?	Observation, communication, handbook
Can DV separate object?	Communication
Can SRV separate object?	Handbook, communication, observation
Is AL operable?	Communication, observation
Does AL have docking mechanism?	Observation, handbook

Required Action	Equipment Needs	Operations Time
Remove object by external command	RF or hard command link	5 minutes
Remove object by entry and internal command	Crew in EVA mode	15-30 minutes
Remove object by docking SRV and subsequent disposal	Docking fixtures on object	30 minutes
Remove object by external or internal disconnect and added auxiliary propulsion	RF or hard command link and crew in EVA mode; attachable auxiliary propulsion system	60 minutes
Dock SRV to AL	Mating docking fixtures, docking guidance and docking propulsion Electric potential equaliz. kit	20 minutes

Table H-8. Segment E. 2: Dock SRV to DV Hatch

Same as for E. 1 except read hatch for airlock

Table H-9. Segment E. 3: Dock Transfer Module (TM) to DV Hatch or AL

Required Prior Knowledge	Means
Same as for E. 1 except read TM* for SRV and Hatch/AL for AL	Same as for E. 1

Required Action	Equipment Needs	Operations Time
Same as for E. 1 except read TM for SRV	Same as for E. 1 except add: One transfer module	Same as for E. 1

*The Transfer Module carries rescue crew and all equipment required for the rescue operation. It has sufficient propulsion for the transit from the mother ship to the DV and its return. If this approach is used, the TM becomes in effect the SRV and the mother ship's role is that of a transporter to and from rendezvous point.

Table H-10. Segment E. 4: Dock Portable Airlock (PAL) to DV Hatch

Required Prior Knowledge	Means
Is portable airlock necessary to transfer DV crew to SRV?	Communication
- SRV, TM, cannot dock?	Observation, handbook
- DV crew cannot transfer in EVA?	Communication, handbook
- to enter DV and to exit?	Communication, handbook
- AL onboard DV not functioning?	Communication, observation
Is hatch available?	Observation
Is hatch functioning?	Observation, communication
Does hatch have docking mechanism?	Observation, communication

Required Action	Equipment Needs	Operations Time
Make hatch available by removing object as in E. 1	As in E. 1	As in E. 1
If needed, attach docking mechanism on hatch	Crew in EVA plus docking mechanism	Unload 20 minutes Transit 5 minutes Attachment 20 min.
	or: Docking mechanism attached by manipulators	Unload 20 minutes Transit 5 minutes Attachment 20 min.
	or: Portable airlock with docking interface not requiring special DV docking mechanism	Unload 20 minutes Transit 5 minutes Docking 5 minutes
Transport PAL to DV	with TM	Unload 20 minutes Transit 5 minutes
	or: With reaction motors on PAL	Unload 20 minutes Transit 5 minutes

Table H-10. Segment E.4: Dock Portable Airlock (PAL) to DV Hatch (Continued)

Required Action	Equipment Needs	Operations Time
	or: With remotely actuated or manned self-propelled manipulators	Unload 20 minutes Transit 5 minutes
Dock PAL to DV	Docking guidance and docking propulsion	5 minutes
	Electric potential equaliz. kit	

Table H-11. Segment E.5: Enter Hatch by EVA

Required Prior Knowledge	Means
Can DV compartment behind hatch be evacuated?	Communications, inspection
Is hatch available?	Observation, communication
If not, can hatch be made available?	Observation, communication, handbook
Is hatch functioning?	Inspection, communication
If not, can it be opened by other means?	Inspection, communication

Required Action	Equipment Needs	Operations Time
1. If needed, remove object from hatch	As in E.4	As in E.4
2. Evacuate compartment behind hatch (if needed)		
- SRV crew in EVA opens bleed-down valve on exterior	- valve in proper exterior location on DV	5 minutes
or: drills hole in hatch	- power drill or explosively actuated punch	10 minutes
- DV crew opens bleed-down valve through command circuit	- no special equipment	5 minutes
or: manually opens valve	- original design provision	5 minutes
3. Open hatch		
- DV crew opens through command circuits	- original design provision	1 minute
or: DV crew opens manually	- original design provision	1 minute

Table H-11. Segment E.5: Enter Hatch by EVA (Continued)

Required Action	Equipment Needs	Operations Time
- SRV crew in EVA opens through external command	- hard command link plus power source or: RF command link plus power source	1 minute
- SRV crew opens hatch manually	- original design provision	1 minute
or: SRV crew forces hatch	- with special tool or: with explosive (FLSC)	30 minutes
4. If hatch was forced, protect against hazardous edges - install soft edge guard	Crew in EVA suits, foamed rubber edge guard	10 minutes
5. Transfer SRV crew to hatch area (for above operations or for entry)	Crew in EVA suits, AMU's, tether lines or: crew in EVA suits within TM	5 minutes*
6. Enter through hatch	Illumination source	1 minute*

*Each man

Table H-12. Segment E. 6: Enter DV Through Portable Airlock (PAL)

Required Prior Knowledge	Means
What is atmosphere behind DV hatch?	Communications, inspection

Required Action	Equipment Needs	Operations Time
Transfer SRV crew to PAL	- SRV crew in EVA suits - AMU's	5 minutes*
Open outer PAL hatch	No special equipment	1 minute
Enter PAL	No special equipment	1 minute*
Close outer PAL hatch	No special equipment	1 minute
Equalize PAL atmosphere to that of DV	- original design provisions - atmosphere source	5 minutes
Open inner PAL hatch	No special equipment	1 minute
Open DV hatch	See E. 5	1 minute
Same as for E. 5 except that bleed down of DV compartment is not required		
Enter DV	No special equipment	1 minute*

*Each man

Table H-13. Segment E. 7: Enter DV from SRV Docked to DV Airlock or to DV Hatch or from TM Docked to DV Airlock or DV Hatch

Required Prior Knowledge	Means
What is atmosphere behind hatch?	Communications, inspection

Required Action	Equipment Needs	Operations Time
1. Open inner SRV or TM AL hatch	No special equipment	1 minute
2. Enter SRV or TM AL	In EVA suits, if needed	1 minute*
3. Close inner SRV or TM AL hatch	No special equipment	1 minute
4. Equalize AL atmosphere to that of DV airlock or DV compartment behind hatch	Original design provision	5 minutes
5. Open outer SRV or TM AL hatch	No special equipment	
a. If docked to DV AL open outer DV AL hatch:		
- If hatch is opened normally	No special equipment	1 minute
- If hatch is forced	Special tools, FLSC	30 minutes
If hatch was forced install edge guard	Foamed rubber edge guard	10 minutes

*Each man

Table H-13. Segment E. 7: Enter DV from SRV Docked to DV Airlock or to DV Hatch or from TM Docked to DV Airlock or DV Hatch (Continued)

Required Action	Equipment Needs	Operations Time
Enter DV AL	Illumination source	1 minute*
Open DV AL inner hatch (as for outer hatch)	(As for outer hatch)	1 minute
Enter DV	No special equipment	1 minute*
b. If docked to DV hatch (As for E. 6)	(As for E. 6)	As for E. 6

*Each man

Table H-14. Segment E. 8: Gain Access to DV Other than Through Hatch or Airlock

Required Prior Knowledge	Means
Location of unoccupied compartment	Handbook, communication
Bulkhead (shell) construction	Handbook
Location of intra-bulkhead service lines	Handbook
Location of hazardous stowage or equipment in compartment	Handbook

Required Action	Equipment Needs	Operations Time
1. Bring bulkhead cutting equipment to access location on DV	SRV crew in EVA, or unmanned teleoperated manipulator	Unload 20 minutes Transit 5 minutes
2. If cutting into unpressurized, sealed compartment		
a. Perform cutting action*	FLSC cutting kit	30 minutes
b. Remove cut-out	As under (1) above	2 minutes
c. Attach edge guard and seal damaged service lines	Sealing kits and rubber edge guards	10-30 minutes
3. If cutting into pressurized, sealed compartment		
a. Bleed pressure	Bleed valves on DV accessible from exterior	5 minutes
	or: Power drill or explosive punch	20 minutes

*Requires original design provision (see Section H. 3. 3. 2)

Table H-14. Segment E. 8: Gain Access to DV Other than Through Hatch or Airlock (Continued)

Required Action	Equipment Needs	Operations Time
b. (As in 2a, b, c, above)	(As in 2a, b, c, above)	As above
4. If cutting into pressurized unsealed compartment (with or without personnel)		
a. Attach portable pressurized shelter	Portable airlock at pressure level matching that of compartment in DV	Unload 20 minutes Transit 5 minutes Attachment 20-60 minutes
b. (As in 2a, b, c, above)	(As in 2a, b, c, above)	As above

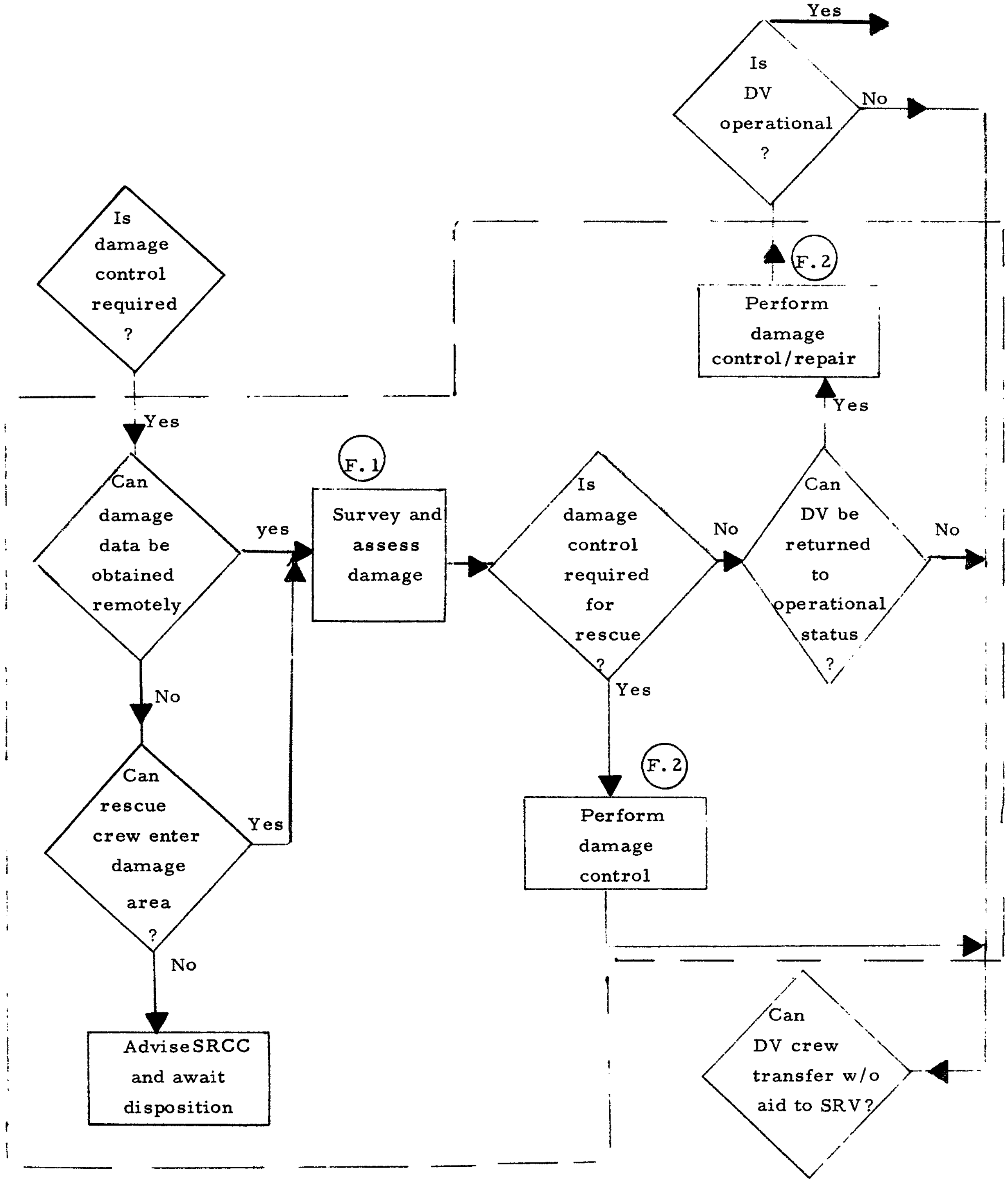


Figure H-9. Segment F: Assess and Control Damage

Table H-15. Segment F. 1: Survey and Assess Damage

Required Prior Knowledge	Means
DV configurations and systems details	Handbook
Location of exterior and interior damage sensor readouts	Handbook
Location of interior communication system	Handbook
Damage control procedures specific to DV	Handbook
Damage data already available	Communications from DV crew, from SRCC

Required Action	Equipment Needs	Operations Time
1. Assess damage:	Built into DV:	
a. Readout of fixed sensors in DV, if accessible	Fire sensors, contamination sensors, pressure sensors, radiation sensors, leak indicators, illumination	5 minutes
	or: With SRV crew:	
	Illumination, plug-in test equipment, power pack	10 minutes
	EVA or IVA suits for damage control team	
b. If fixed sensor readouts not available:		
1. Compartment by compartment survey	Hatch opening tools, bulkhead cutting system, portable test and sampling kits, illumination source, tether lines, EVA or IVA suits for damage control team, radiation suits, leak detectors	Not determinable at this time

Table H-16. Segment F. 2: Perform Damage Control

Required Prior Knowledge	Means
Is or was there fire?	Data from survey
Was there an explosion?	Data from survey
Is there decompression?	Data from survey
Is there a contaminated atmosphere?	Data from survey
Is there radiation?	Data from survey
Is DV crew protected?	Data from survey

Required Action	Equipment Needs	Operations Time
1. Fight fires		
a. By decompression	Hatch opening tools, bulkhead cutting tools or FLSC	5 minutes
b. By chemical means	Extinguisher	5-30 minutes
2. Decontaminate		
a. For smoke and toxic vapors: by decompression	As above, or: Purge provision	5-30 minutes
b. For radiation	Scrubdown equipment cutting tools, equipment removal tools	Not determinable at this time
c. For bacterial presence	Disinfectant	20 minutes
3. Repressurization	Hole sealing kit, hatch sealing kit, air or oxygen bottles or other atmosphere supply system	Not determinable at this time
4. Repair of essential subsystems	Replacement parts as required	Not determinable at this time

Table H-17. Segment G: Terminate Rescue Mission*

Prior Knowledge Required	Means
Rescue has been accomplished	Observation
DV has been secured or disposed of (See Segment K)	Observation
Rescue cannot be accomplished	Observation, communications with SRCC

Required Action	Equipment Needs	Operations Time
Separation from DV: Undocking Jettisoning Return	No special equipment	5 minutes

*Note: There is no flow diagram for Segment G. See top flow logic diagram (Figure H-3).

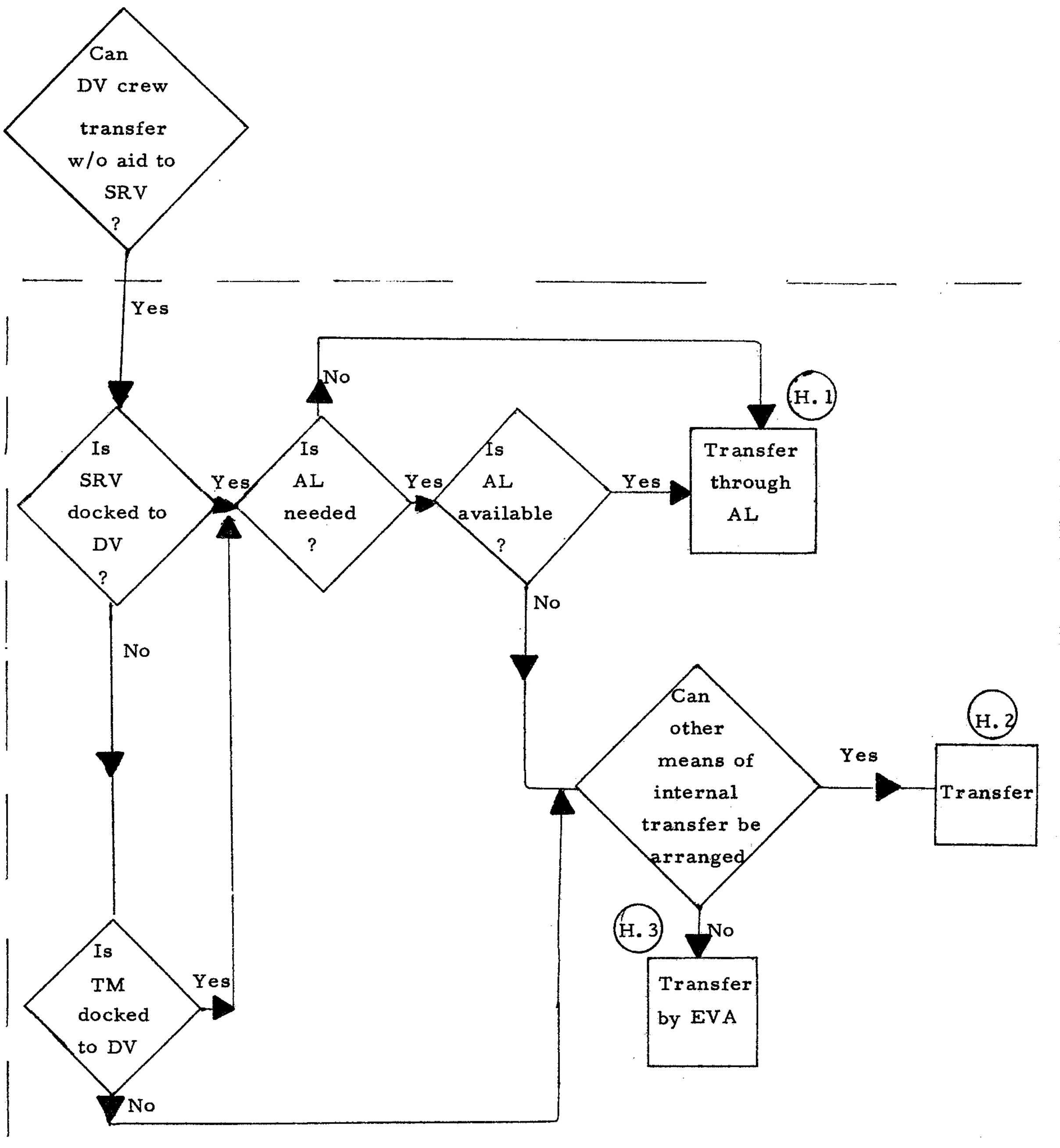


Figure H-10. Segment H: DV Crew Transfers to SRV by Itself

Table H-18. Segment H. 1: Transfer Through Airlock

Required Prior Knowledge (Segments H. 1 through H. 3)	Means
Is docking of SRV or TM to DV feasible?	Survey, communications
Are atmospheres of SRV/TM and DV compatible? Can they be made compatible?	Handbook, communications, survey
Is DV crew capable of transferring without aid in EVA or IVA?	Communications, survey
Does DV crew have required transfer equipment?	Communications, survey
Is DV crew decontamination necessary?	Communications

Required Action	Equipment Needs	Operations Time
1. Transfer through AL	Functioning docking AL in SRV/TM or DV or: Portable AL	1 minute
2. Perform decontamination in AL	Decontamination system change of clothing Disposal means for clothing	10 minutes

Table H-19. Segment H. 2: Transfer Through Other Internal Means

Required Action	Equipment Needs	Operations Time
1. SRV/TM and DV are docked compartment to compartment:		
a. If atmospheres are compatible, transfer through hatch	No special equipment	1 minute*
b. If atmospheres are not compatible, DV crew:		
1. Enters exiting compartment of DV in EVA or IVA suits	EVA or IVA Suits	1-5 minutes*
2. Seals compartment from DV		1 minute
3. Bleeds compartment to SRV/TM pressure	Bleed valves	5 minutes. May require acclimating time for DV crew
or: Changes composition to SRV/TM composition	Variable atmosphere source	10 minutes. May require acclimating time for DV crew
or: Pressurizes to SRV/TM pressure and enters SRV/TM	Pressurization means	(10 minutes. May require acclimating time for DV crew)
Or:		
c. If atmospheres are not compatible:		

*Each man

Table H-19. Segment H.2: Transfer Through Other Internal Means (Continued)

Required Action	Equipment Needs	Operations Time
1. SRV/TM crew in EVA suits bleeds crew cabin or entry compartment to DV pressure	Bleed valves, EVA or IVA suits	5 minutes. May require acclimating time for SRV crew
or: Changes composition to DV composition	Variable atmosphere source	10 minutes. May require acclimating time for SRV crew
or: Pressurizes to DV pressure and admits DV crew	Pressurization means	5 minutes
Or:		
d. If atmospheres are not compatible:		
1. SRV/TM crew in EVA/IVA suits bleeds crew cabin or entry compartment to vacuum	EVA or IVA suits, bleed valves	5 minutes. May require acclimating time for SRV crew
2. DV crew in EVA/IVA suits enters DV exiting compartment and bleeds it to vacuum	Bleed valves	5 minutes. May require acclimating time for DV crew
3. DV crew enters SRV/TM compartment or crew cabin and pressurizes it to SRV/TM pressure and atmosphere, or to DV pressure and atmosphere, or to EVA/IVA suit conditions	Variable atmosphere source, pressurization means	10 minutes

Table H-20. Segment H. 3: Transfer by EVA

Required Action	Equipment Needs	Operations Time
1. DV crew in EVA suits exits DV	EVA suits, operating EVA AL or means to depressurize exiting compartment or entire DV	AL cycle - 7 min. each Exiting compartment - 10 minutes May require acclimating time
2. DV crew transfers to SRV/TM	AMU's or means of propulsion	5 minutes each
3. DV crew enters SRV/TM AL (Decontamination as in H. 1)	No special equipment As in H. 1	10 minute/cycle
Or:		
DV crew enters SRV/TM evacuated compartment and repressurizes it to either SRV/TM or to EVA suit condition	Variable atmosphere source Pressurization means	10 minutes

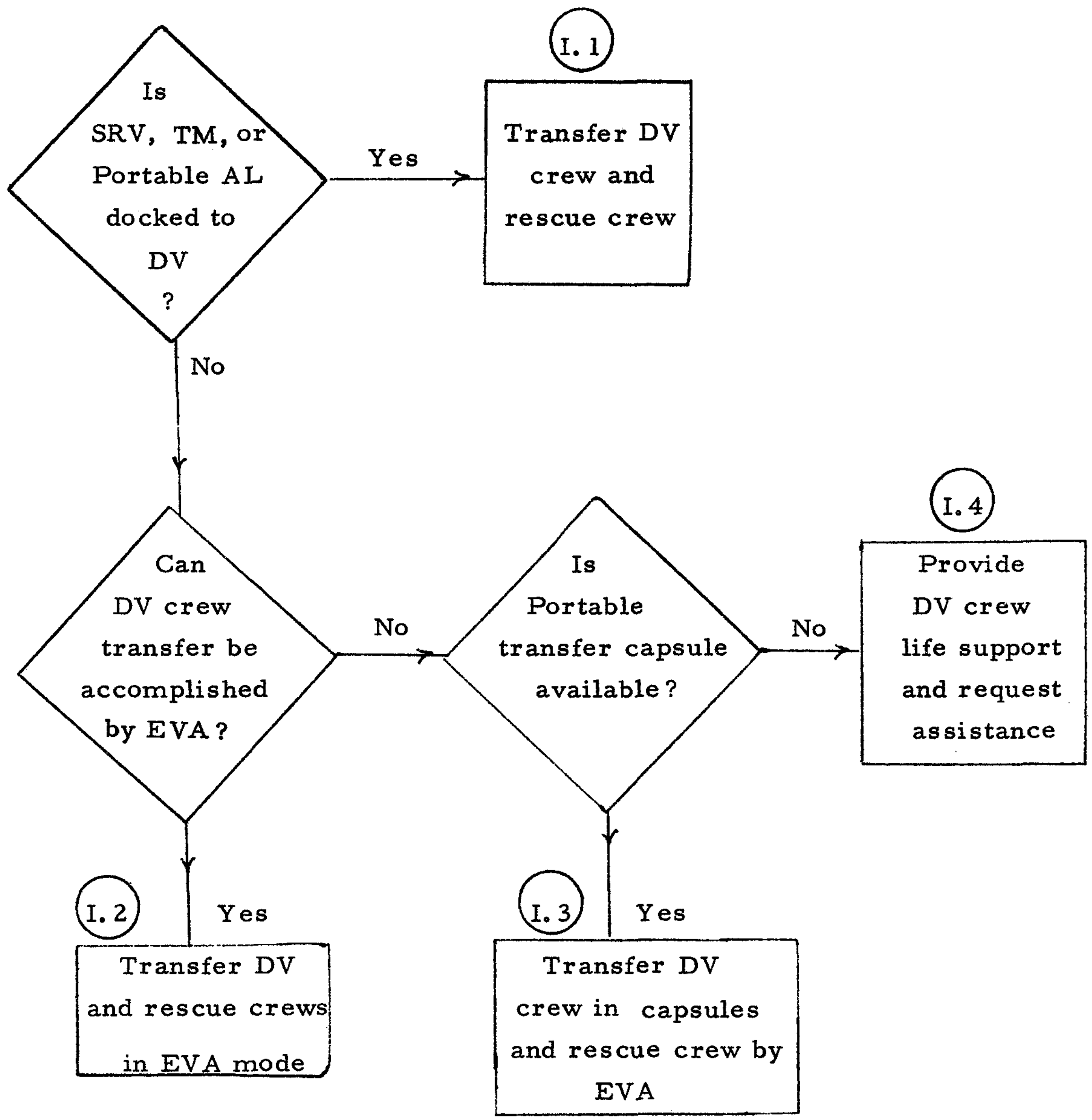


Figure H-11. Segment I: Transfer DV Crew to SRV with Aid

Table H-21. Segment I. 1: Exit DV and Transfer to SRV or TM without EVA

Prior Knowledge Required	Means
Condition of DV crews:	
Capable of self-help?	Observation
Capable of getting into IVA suits?	Observation
What is shortest safe internal route to SRV or TM?	Handbook, observation
What are characteristics of the docking connection between DV and SRV or TM?	Handbook, observation
No airlock (AL)	
Fixed AL in either DV or SRV/TM	
Portable AL	
Is decontamination required?	Communication, observation

Required Action	Equipment Needs	Operations Time
1. If needed, get DV crew into IVA suits	IVA suits. Possible aid by SRV crew	5 minutes* May require acclimating time
2. If needed, place on carrying device	Personnel carrier	2 minutes*
3. Enter SRV or TM		
a. Cycle through AL of SRV or TM	No special equipment	7 minutes/cycle
b. Cycle through portable AL	Portable AL	7 minutes/cycle
c. Perform decontamination in AL	As in H. 1	

*Each man

Table H-22. Segment I. 2: Exit DV and Transfer to SRV or TM by EVA

Prior Knowledge Required	Means
Condition of DV crew:	
Capable of self-help?	Observation
Capable of getting into EVA suits?	Observation
What are available means of propulsion in EVA mode?	Handbook, observation, inspection

Required Action	Equipment Needs	Operations Time
1. DV crew into EVA suits	EVA suits, PLSS	10 minutes* May require acclimating time
- autonomously		
- with aid	SRV crew aid	
2. Place on carrying device (if needed)	Personnel carrier	2 minutes*
3. Alternate egress modes		
a. Depressurize compartment	Prior design provisions	5 minutes
	or: Cut or drill hole in hatch, power tool	20 minutes
b. Through AL (As in H. 1)	No special equipment	7 minutes/cycle
4. Alternate transfer modes		
a. Propelled with external aid	Astronaut Maneuvering Units (AMU)	5 minutes*
	or: Hitch ride on teleoperated or manned manipulator	5 minutes*
	or: Pulled by SRV crew	10 minutes*

*Each man

Table H-22. Segment I. 2: Exit DV and Transfer to SRV or TM by EVA (Continued)

Required Action	Equipment Needs	Operations Time
b. Autonomous (manual)	Tether line between SRV and DV	10 minutes*
5. Enter SRV or TM		
a. Cycle through standard AL (As in H. 1)	No special equipment	7 minutes/cycle
b. Cycle through special compartment	SRV compartment capable of pressure cycling with suitable atmosphere	15 minutes/cycle

*Each man

Table H-23. Segment I. 3: Transfer DV Crew in Capsules

Prior Knowledge Required	Means
What is condition of crew?	Observation
Where is location of hatch leading to capsule?	Observation
Which hatch on the SRV or TM can accommodate capsule?	Handbook

Required Action	Equipment Needs	Operations Time
1. If not yet in place, move capsule from SRV to DV hatch and dock	SRV crew with manipulators Capsule or: Autonomous capsule propulsion, and SRV crew manual guidance	Unload 20 minutes Transit 5 minutes Docking 5 minutes Erection 5 minutes
2. Move DV crew to capsule hatch	Possibly IVA suits	Dressing 5 minutes* Transit 1-5 minutes
Aided, if needed	Personnel carrier SRV crew	Dressing 5 minutes* Carrier 2 minutes* Transit 1-5 minutes*
3. Place DV crew in capsule	Autonomously	2 minutes*
	or: Aided by SRV crew	5 minutes*
4. Close hatch and transfer capsule to SRV hatch or AL, or PAL (decontaminate as in H. 1)	SRV crew with manipulators	10 minutes*
	or: Autonomous capsule propulsion and SRV crew manual guidance	5 minutes*
	PAL	
5. Move DV crew into SRV	Aided by SRV crew, if needed	3-5 minutes*

*Each man

Table H-24. Segment I. 4: Provide DV Crew Life Support and Await Further Assistance

Prior Knowledge Required	Means
Size of DV crew	Handbook, observation
ECLS requirements of DV crew	Communications, observation
Availability of assistance	Communications with SRCC
Time period until assistance	Communications with SRCC

Required Action	Equipment Needs	Operations Time
1. Transfer to DV of required life support supplies	Oxygen source, CO_2 removal source, water, food, etc.	Unload 10 minutes Transit 5 minutes Entry 2-7 minutes
2. Provide stand-by aid	SRV crew	Not determinable at this time
3. Request assistance	Communication link with ground	5 minutes

Table H-25. Segment J: Provide Medical Aid*

Required Prior Knowledge	Means
What is condition of crew?	
Diagnosis	Inspection, communication, handbook
Prognosis	Handbook, communication
What are limits to aid capability of:	Handbook
SRV?	
EVA crew?	
What time is available for medical aid?	From condition of DV crew, from limits on SRV crew EVA, and limits on transfer and rescue operation times

Required Action	Equipment Needs	Operations Time
Check DV crew for symptoms	Medic or medically trained SRV crew member, portable diagnostic equipment	Not determinable at this time
Check onboard diagnostic instrumentation	Medic or medically trained SRV crew member	Not determinable at this time
Check ground for prognosis and advice on medical needs	Communications link	Not determinable at this time
Treat illness and/or injury	Medical kit, oxygen mask, etc.	Not determinable at this time

*Note: There is no flow diagram for Segment J.

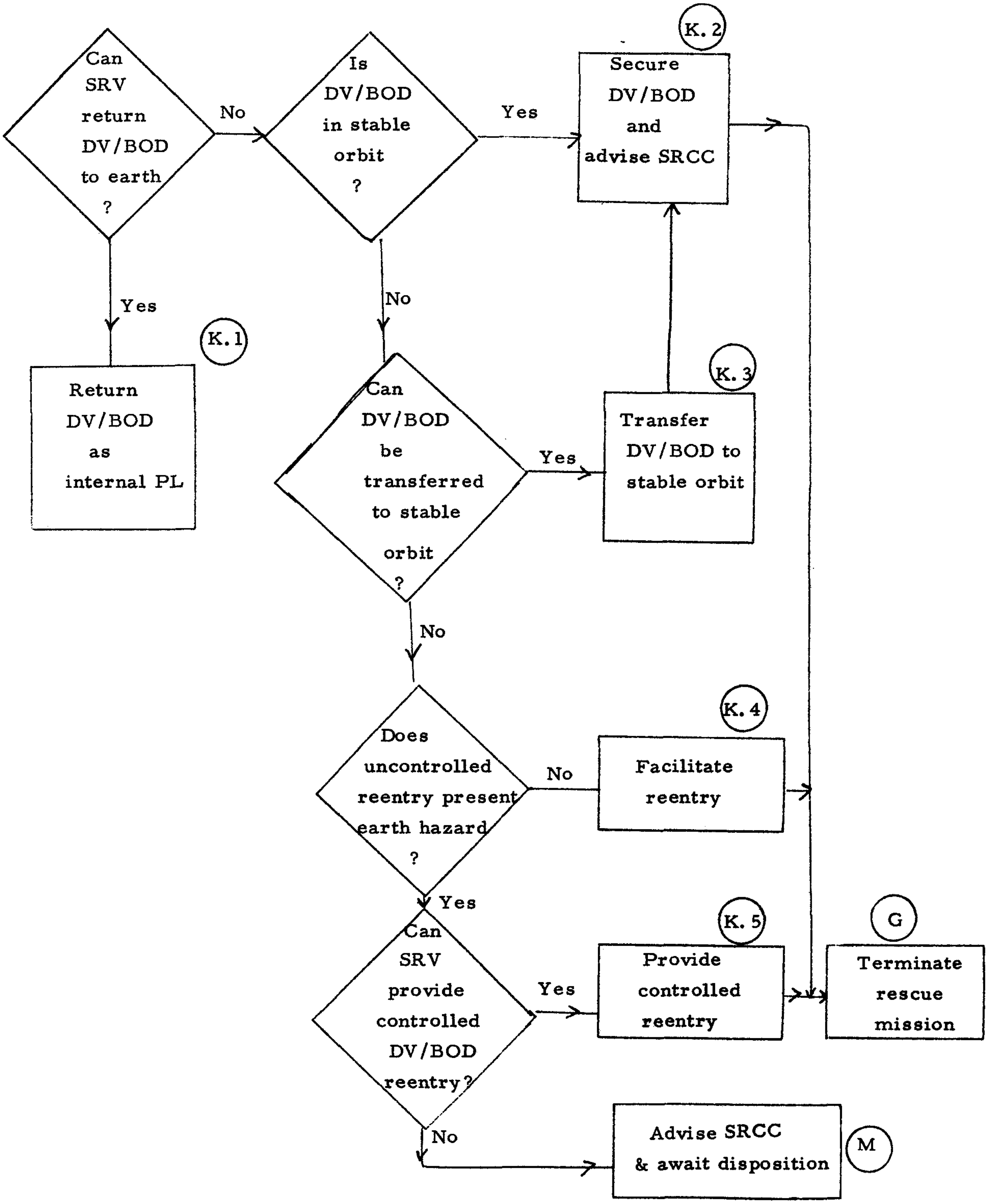


Figure H-12. Segment K: Dispose of or Secure DV and/or BOD

Table H-26. Segment K. 1: Return DV/BOD as Internal Payload

Required Prior Knowledge (Segments K. 1 through K. 5)	Means
SRV payload return capability	Handbook
Hazardous components of DV/BOD	Handbook, survey
DV/BOD orbital parameters	Communication with SRCC
ΔV requirements for orbit change	Communication with SRCC

Required Action	Equipment Needs	Operations Time
1. Grapple DV/BOD	Tether lines and attachment device, retractable arms and attachment device	20-60 minutes
2. Secure DV/BOD		
a. Remove hazard source	Decontamination equipment	Not determinable at this time
b. Shutdown systems	Damage control equipment	Not determinable at this time

Table H-27. Segment K. 2: Secure DV/BOD and Advise SRCC

Required Action	Equipment Needs	Operations Time
1. Shutdown systems	No special equipment	Not determinable at this time
2. Remove hazard sources	Damage control equipment	Not determinable at this time
3. Install location aids	RF and/or laser beacons	10 minutes
4. Report status and actions to SRCC	Communication system	5 minutes

Table H-28. Segment K. 3: Transfer DV/BOD to Stable Orbit

Required Action	Equipment Needs	Operations Time
1. If not already docked:		
a. Dock to DV/BOD	Docking fixtures	10 minutes
b. Transfer auxiliary propulsion system	Auxiliary propulsion system, manipulators manned or remotely operated, crew in EVA, attachment devices, remote command and control system	60-120 minutes
2. Provide required ΔV	If docked, use SRV propulsion system; otherwise, use auxiliary propulsion system	5 minutes

Table H-29. Segment K. 4: Facilitate Reentry

Required Action	Equipment Needs	Operations Time
1. If desirable, reduce size of reentering mass (exclude nuclear devices)	Explosives, FLSC cutting systems, manned or tele-operated manipulators, remote actuation devices	Not determinable at this time
2. If desirable, reduce on-orbit time by providing retro impulse (As in K. 3)	(As in K. 3)	5 minutes

Table H-30. Segment K. 5: Provide Controlled Reentry

Required Action	Equipment Needs	Operations Time
1. If entire DV/BOD is to be reentered:	(As in K. 3)	75-135 minutes
a. (As in K. 3)		
2. If only hazardous components require controlled reentry:		
a. Separate components from DV/BOD	Cutting methods and equipment, manned or teleoperated manipulators	Not determinable at this time
b. Provide protective devices for reentering components	Radiation shielding, reentry heat shield	Not determinable at this time
c. Provide retro propulsion for reentering components, and produce needed ΔV	Auxiliary propulsion system, attachment devices	60-120 minutes
3. Facilitate non-hazardous reentry	(As in K. 4)	Not determinable at this time
(As in K. 4)		

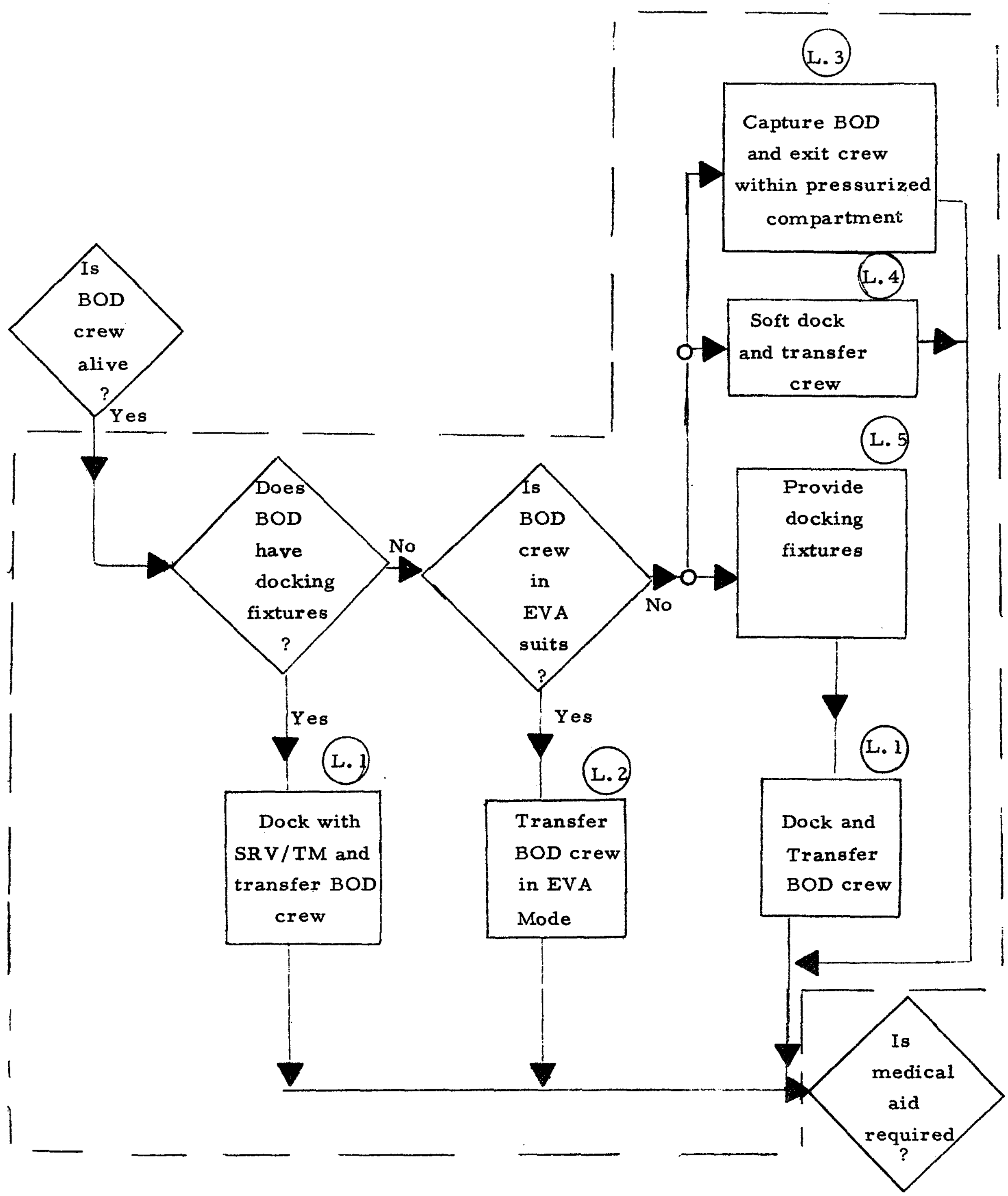


Figure H-13. Segment L: Dock with BOD and Transfer Crew to SRV

Table H-31. Segment L. 1: Dock with BOD and Transfer Crew to SRV

Prior Knowledge Required (Segments L. 1 through L. 5)	Means
Configuration and capability of BOD	Handbook
Condition of BOD crew	Communication, survey
BOD crew equipment and life support system status	Communication, survey

Required Action	Equipment Needs	Operations Time
1. If BOD and SRV/TM atmospheres match: dock, open hatch, and transfer	No special equipment	Docking 10 minutes Hatches 2 minutes Transfer 1 minute*
2. If BOD and SRV/TM atmospheres do not match:		
a. Transfer through existing AL on SRV/TM	No special equipment	7 minute/cycle
b. Change SRV/TM atmosphere to that of BOD and transfer	Variable atmosphere source, repressurization means, acclimating means	10 minutes May require acclimating time for SRV crew
c. If SRV and BOD crew are in EVA/IVA suits: bleed SRV/TM and BOD to vacuum, transfer, repressurize SRV/TM	EVA/IVA suits for SRV/TM crew, bleed valves, repressurization means	20 minutes

*Each man

Table H-32. Segment L. 2: Transfer BOD Crew in EVA Mode

Required Action	Equipment Needs	Operations Time
1. Assist BOD crew in moving to SRV/TM	Tether lines, crew with AMU's, EVA suits	5 minutes*
2. Transfer through AL if available	No special equipment	7 minutes/cycle
3. Enter through SRV/TM compartment, if no AL:		
a. Bleed down compartment, enter through hatch, repressurize	Bleeddown valve, repressurization system, EVA/IVA suits for SRV crew	20 minutes May require acclimating time for SRV crew

Table H-33. Segment L. 3: Capture BOD and Exit Crew within Pressurized Compartment

Required Action	Equipment Needs	Operations Time
1. If BOD is of appropriate size:		
a. Approach		5 minutes
b. Attach haul-in device	Tether lines, attachment device or: Retractable arms, attachment device, power winch	20-60 minutes
c. Pull BOD into SRV/TM compartment	Compartment of sufficient size to contain BOD, with entrance hatch of sufficient size, Tug to haul to SRV	10 minutes
d. Repressurize compartment and exit crew	Repressurization system	20 minutes

*Each man

Table H-34. Segment L. 4: Soft Dock and Transfer via Tunnel

Required Action	Equipment Needs	Operations Time
1. Approach BOD		5 minutes
2. Attach haul-in device	Tether lines, attachment device or: Retractable arms, attachment device	20 minutes
3. Pull BOD into close position to entry hatch of SRV/TM	Power winch	5 minutes
4. Attach transfer tunnel, pressurize it, seal it against SRV/TM and BOD hatches	Collapsible/expandable transfer tunnel, pressurization means, sealing means	30 minutes
5. Open hatches and transfer crew		Hatches 2 minutes Transfer 1 minute*

Table H-35. Segment L. 5: Provide Docking Fixture

Required Action	Equipment Needs	Operations Time
1. Transfer docking fixture to BOD exit hatch	Docking fixture, attachment means, crew in EVA with AMU's or: Crew in self-propelled manipulator or: Teleoperated manipulators	Unload 20 minutes Transit 5 minutes Attachment 20 min.

*Each man

Table H-36. Segment M: Advise SRCC and Await Disposition*

Prior Knowledge Required	Means
Inability to resolve emergency condition and to perform rescue	Observation, handbook
Availability of assistance from SRCC	Handbook, communication

Required Action	Equipment Needs	Operations Time
1. Data gathering in response to SRCC request	Surveys as in A and C, life support supplies for both SRV and DV	30-90 minutes
2. Data transmission to SRCC	RF communication: Voice TV Telemetry	5-10 minutes
3. Alternate responses as per SRCC instructions:		
a. Stand-by and wait for further instruction, further assistance	Life support for both SRV and DV	Up to 48 hours
b. New rescue methodology	(Not determinable)	
c. Dispose/secure DV and return (See K)		Not determinable at this time

*Note: There is no flow diagram for Segment M.

H. 2. 3 SRV Equipment Requirements

The preceding tables describing required action and equipment needs of the various rescue operational steps depicted in the logic diagrams of Section H. 2. 2 served as the source of the following tabulations. The "Equipment Needs" columns of these tables were searched for special rescue equipment items to be carried by the SRV and are listed in the following tables under the categories of avionics equipment, other hardware items, and special instrumentation equipment items. In the following tables, the column headed "Phase" refers to the operational phase in which the equipment item was shown to be required and corresponds in nomenclature to the segment designations used in the top flow logic diagram and the detailed diagrams of the preceding section (Figures H-3 through H-13).

These equipment lists were used as the basis for the conceptual design studies reported in Section H. 3 of this Appendix.

H. 2. 3. 1 Avionics Equipment

Phase*	Item	Capability
C, A. 2, A. 3, D	Laser/IR system	Detect DV debris due to explosion. Determine its velocity vector
A. 1, C	Emergency voice radio	Short range, omnidirectional communication between SRV and DV
A. 3	Laser	Measure spin rate and wobble motion of DV or BOD

*Referenced to segment codes on Top Flow Logic Diagram (Figure H-3).

Phase	Item	Capability
A. 1	Emergency telemetry receiver	Reception of damage sensor data
A. 3, C	Telescopic periscope or telescope	To permit SRV crew to visually inspect DV
C, E, F	Plug-in telephone set (external plug-in)	To provide hard-link for communication with DV crew
B. 1, E. 1, E. 5, K. 3	Command transmitter and power pack	To actuate DV mechanisms from the exterior, such as hatch opening, undocking of experiment modules, RCS, special despin systems
D, E. 4	Docking guidance	Provide for terminal guidance with DV spinning at up to 4 rpm. Docking along axis of spin
D	Radio direction finder	To assist in locating BOD
K	RF and Laser beacons	To be placed on DV/BOD for securing/disposal action

H. 2. 3. 2 Other Hardware

Phase	Item	Capability
B. 1	Despin device	Despin DV
B. 1, C, E. 4, E. 8, I. 2, I. 3, K. 3, K. 4, K. 5, L. 5	Manipulator unit (teleoperated)	Attach despin unit to DV
B. 1, C, D, E. 5, E. 2, F, A. 2, H. 3, I. 2, K. 3, L. 1	EVA suits	To enable SRV crew to inspect DV exterior
B. 1, C, E. 5, E. 7, F	Illumination plus power pack (portable)	To aid in inspection of DV exterior and interior

Phase	Item	Capability
A. 3, C	Illumination source on SRV (fixed)	
C	Remote controlled TV carrier (self-propelled)	To allow inspection of DV when EVA operation is too hazardous
C	Soft docking device	To allow docking to DV with residual motion present
L. 4	Transfer tunnel (flexible)	To be used when hard docking and rigid connections are not feasible
E. 3, E. 4	Transfer Module	To allow crew transfer between SRV and DV when SRV cannot dock directly
E. 4, E. 8, H, I. 1	Portable airlock	To permit transfer of DV crew (not capable of EVA) between vehicles of differing atmospheres Or: To permit entry from EVA into DV not equipped with functioning airlock Or: To serve as contamination barrier between DV and SRV
E. 1, E. 4, L. 5	Portable docking fixtures	To be attached to entry port of DV not equipped with docking provisions
C, E. 5, H. 3, I. 2	Power drill plus power pack or explosive punch	To drill pressure-bleed hole into DV hatches or bulkheads
E. 6, E. 7	Hatch forcing tool	To open jammed hatches
E. 5, E. 6, H. 3, I. 2	Astronaut Maneuvering Units	To be used for mobility in EVA

Phase	Item	Capability
F. 2, I. 4, M	Portable O_2 or air containers	To replenish DV atmosphere
	Bulkhead cutting tool	To enter compartments with jammed hatches
F. 2	Hole sealing kit	To permit repressurizing of damaged compartments
I. 1, I. 2, I. 3	Personnel carrier	To act like a stretcher in moving injured DV crew to SRV
I. 3	Transfer capsule (possibly expandable)	To permit transfer of DV personnel without EVA and in absence of docking SRV or TM
A, C	Blinker set	For communication between SRV and DV crew
C, E. 5, E. 7, F. 2, H. 3, I. 2, K. 4, K. 5	FLSC cutting kits	For hole cutting - Bulkheads - Hatches
I. 4, M	Portable Life Support Systems	For transfer into DV to increase its shelter capability until rescue is accomplished
F, K. 1, K. 2	Damage control kit	To permit counteracting of effects of hazard to DV equipment and structure
J	Medical kits	For use by DV crew in first aid. For use by SRV crew in first aid, for diagnostic purposes
C, K. 5	Radiation suits or shielding	For EVA or IVA near radiation sources
F. 2	Fire extinguisher systems	For fire fighting when decompression is infeasible

Phase	Item	Capability
F. 2, K. 1	Decontamination kits	To combat toxic materials or bacterial contamination
E. 1, E. 4	Electric potential equalizing kits	To reduce or eliminate potential differences between DV and SRV
K	Grappling system	To capture free-floating crew in EVA, bail-out devices, tools, etc.
B. 1, E. 5, F, I. 2, K. 1, L. 2, L. 3	Tether lines	To permit EVA crew transfer, to anchor BOD
K. 5	Reentry heat shields	To prevent break-up of hazardous equipment on controlled reentry

H. 2. 3. 3 Instrumentation

Phase	Item	Capability
A. 3, C	Thermal radiation sensors	Thermal mapping of exterior and interior of DV
A. 2, A. 3, C, F	Nuclear radiation sensors	To permit mapping of the external and internal radiation environment of DV, to permit diagnosis of nuclear equipment failures
C, F	Atmospheric sampler kit	To test atmosphere behind bulkhead or hatch for pressure, composition, toxicity, radiation
C, F. 1	Leak detector	To discover source of atmosphere leaks from compartments, to test for fuel or propellant leaks into compartments and discover sources
C, F	Plug-in visual readout devices with power packs (external plugs)	To form hard-link connection with damage sensors within DV for damage assessment

H. 2. 4 DV/BOD Equipment Requirements

In addition to the SRV equipment requirements, the logic diagrams previously described also provided some insight into equipment pré-installed in a candidate DV which would aid a rescue effort, or which is required to allow the special SRV equipment to properly perform their functions. Such equipment items are listed in the following tables in the same manner in which the SRV items were listed in Section H. 2. 3.

H. 2. 4. 1 Avionics Equipment

Phase	Item	Capability
A, C	Emergency voice radio	Short range, omnidirectional communication sets in every compartment
A, C, D, E	Laser reflectors on exterior	To permit rendezvous and docking, to permit measurement of spin and wobble rates and axes
A, C	Emergency telemetry	Automatic transmission of damage sensor data
D, K	RF beacons and laser beacons	To ease acquisition and tracking, particularly of BOD separated from DV
B, E, K	Command receivers	To permit remote control by SRV of mechanisms such as hatch opening, RCS, special despin devices, etc.
C, E, F	Wire communication system with plug-ins at exterior of every hatch (internal as well as external)	To provide hard-link for communication with SRV crew in EVA or IVA

H.2.4.2 Other Hardware

Phase	Item	Capability
B	Despin device	To back up RCS in overcoming undesirable motion; externally installed and capable of remote actuation by either DV crew or rescue crew
H, I, L	EVA suits	To permit DV crew to transfer to SRV if docking is not feasible
K	Auxiliary propulsion	To permit transfer into stable orbit in event of primary propulsion failure
E, H, I	Docking AL Or: Compartment adjacent to docking hatch capable of atmosphere cycling	To permit transfer of DV crew without EVA, between vehicles of different atmospheres, to serve as contamination barrier between SRV and DV
E, H, I	EVA airlock	To permit entry from EVA into DV not equipped with docking airlock
E	Double hatches, explosively actuated hatches, bulkheads with provisions for FLSC cutting	To assure entry into DV and DV compartment in event of jammed hatches or absence of accessible hatches
F, K	Damage Control Kits Decontamination kits	To enable DV crew to clear access for rescue crew
J	Medical Kits Personnel restraints Diagnostic equipment	To enable DV crew to administer first aid while waiting for rescue
K	Radiation shielding for personnel	To survive nuclear hazard until rescue

Phase	Item	Capability
K	Design provisions for quick-jettisoning of hazardous components	To enable separate disposal of hazardous components such as reactors if DV reentry seems unavoidable
K	Hazardous component design so as to promote non-destructive reentry (heat shields, aerodynamic stability)	To allow intact reentry of items such as reactors into pre-selected landing zones
B, K, L	Attachment fixtures	To allow attachment of despin devices to exterior of DV, to allow retrieval of BOD into SRV compartment, to allow attachment of portable docking device, portable AL, auxiliary propulsion, soft docking tunnel, etc.

H. 2. 4. 3 Instrumentation

Phase	Item	Capability
C, F	Damage sensors	Detect fire, contamination, loss of pressure, change in atmospheric composition, etc.
C, F	Exterior readout devices near hatches	To repeat damage sensor readings to SRV crew in EVA or to TV carrier
	Sample ports	

H. 2. 5 Rescue Operations Listing

In order to provide a summary of the special operations identified by the logic diagrams as required for rescue, the following table was prepared. The nomenclature is as used in the previous equipment tables.

Phase	Operation	Purpose
A, C	Attempt to communicate by RF and other means	To learn status of DV and DV crew
M	Communicate with SRCC	For data transmittal and instructions
A, C	Circle the DV in several directions from stand-off and close distances - with SRV - with TV carrier	To survey DV and DV environment for hazards to SRV and for status of DV and DV crew
A, C	Measure motion of DV	To determine feasibility of docking or need to stabilize and/or despin DV
B, E, L, F, H, I	Remote control and command by SRV crew	To remotely activate despin unit, hatch opening mechanisms, manipulators, TV carriers, etc.
B, E	Activation by EVA crew	To activate despin unit, hatches, etc.
B, E, I, H, K, F, L	Transport, attachment and removal of equipment by: crew in EVA, tele-operated manipulator unit, transfer module, SRV	For use with: despin units, portable airlocks, portable docking, fixtures, transfer capsules, etc., auxiliary propulsion units
C	Perform contact survey by: TV carrier and remote controlled manipulator, crew in manned manipulator, crew in EVA	To read exterior sensor repeaters, to plug-in hard-line communication system (telemetry and voice), to collect and test DV atmosphere samples, to determine feasibility of entering DV
D	Search space volume with SRV sensors	To locate BOD
E, L, C, I, H	SRV to rendezvous and dock	To dock with DV or BOD

Phase	Operation	Purpose
E, F, H, I, K	Evacuate DV compartment by: opening bleed valve, drilling hole	To permit entry from EVA if no AL available, to fight fire, to decontaminate
E, F, H, I, L, K	Open external and internal hatches by: manual means, command links, explosives	To enter compartments, to fight fire, to decontaminate
E, F, K	Open entrance into DV or DV compartment through bulkhead by FLSC	To permit entry if hatches non-functioning or non-existent
E, F, H, I, L	Transfer crew in: SRV EVA, transfer module, transfer capsule	To permit entry into vehicle of dissimilar atmosphere, to enter from EVA
E, F, H, I, L	Transfer crew through airlock: in DV, in SRV, in transfer module, portable airlock	To guard against contamination of vehicle atmosphere
E, F, K, L	Transfer cargo between vehicles by: movement within docked vehicles, by crew in EVA, by manipulators (manned or remote controlled) in EVA	To transport tools and/or supplies to DV/BOD to perform: forced entry, resupply damage control and repair, medical aid
C, F	Compartment by compartment examination of DV	To survey for damage, read sensor instrumentation
F	Seal holes in bulkheads, hatches	To repressurize compartments
F	Replace and repair as needed	To attempt to make DV operational
F, H, I, G	Undock SRV from DV or BOD	To terminate rescue mission

Phase	Operation	Purpose
E, H, I, F, L	Depressurize and repressurize compartments	To permit docked transfer without AL, to permit entry from EVA, to fight fire, to decontaminate
C, B, D, E, F, H	Dress in EVA suits, undress from EVA suits	To permit EVA operations, to permit cabin operations
B, C, E, F, I, K, L	Place crew in EVA suit into AMU	To enable crew to perform transfer to DV or BOD
	Place crew in IVA suits into manipulator unit	To permit crew to perform operations on exterior of DV or BOD
Same	Place injured or ill crew on personnel carrier	To facilitate movement by rescue crew of DV crew through hatches, airlocks, into transfer capsules, etc.
J	Provide diagnostic services, medical aid, therapy	To stop deterioration in DV/BOD crew physical condition, to enable transfer to SRV, to enable survival until permanent haven is reached
K, L	Grapple objects in space exterior to SRV by: use of retractable arms, nets, tether lines with EVA crew	To rescue free-floating crew, to retrieve equipment items, to retrieve BOD
K	Reduce size of DV/BOD by: explosive, FLSC, other cutting means	To facilitate safe reentry
K	Provide ΔV by: docked SRV, auxiliary propulsion system	To dispose of/secure DV/BOD by: retro impulse, orbit adjustment impulse
K	To remove sections of DV by: cutting means, manipulators	To reduce hazard in reentry, to dispose of hazardous equipment

H. 3 SPECIAL RESCUE EQUIPMENT

The rescue operations analysis described in the logic diagrams and supporting tables of Section H. 2 led to a listing of a variety of special equipment considered either desirable or necessary for manned rescue operations. Some of these equipment items are obtainable essentially "off-the-shelf," others represent current state of the art but require development or space qualification, and some require advanced technology effort with some uncertainty as to the feasibility of the desired concept.

Because of their importance to the success of the rescue mission, as well as technological uncertainties, four major areas were selected for further study. These study areas concerned the problems of:

a. Lack of information concerning the nature of the DV emergency

b. Hazards which the SRV itself might encounter due to the DV emergency

c. Transfer difficulties encountered by either the rescue crew attempting to enter the DV or the DV crew in leaving the DV

d. Delays introduced into the rescue operation due to the need to control damage within the DV prior to rescue or to provide medical aid prior to removal of the DV crew

Effort was also devoted to equipment items not covered by the above so that estimates of weight and stowage volume of interest to subsequent tasks of this rescue study could be made.

H. 3. 1 Communications and Data Surveys

Lack of information on the condition of the DV and of its crew can prove a serious handicap to the rescue mission. Some examples of questions important to the planning of the mission, possibly left unanswered by a break in communications with the DV, are:

a. What hazards would the rescue crew face in attempting to enter the DV?

b. Which compartment of the space station/base contains the survivors of the emergency?

c. What equipment must the rescue crew bring into operational status prior to rendezvous or put on board the SRV prior to launch?

Several alternate approaches are available in assuring the availability of such data. Sufficient redundancy in onboard communication equipment within any potential DV can be provided to avoid total blackout of communications. Although quantitative data are not available, it is reasonable to assume that, in the vast majority of emergencies, such redundancy will suffice. It is however, also reasonable to assume that in a small number of emergencies all communications systems will be inoperative, since there will be practical limits to the degree of redundancy that can be provided. In such an event, SRV equipment must provide as much as possible of the needed data. This is done by external survey techniques utilizing sensors installed on the SRV or carried to the DV (by remote control or by rescue crews in EVA), and by readout equipment also carried to the DV and operated in conjunction with sensors prepositioned within the DV.

This study considered both communication system redundancy and external survey equipment requirements to some detail to determine feasibility. Weight and volume requirements were also determined to support subsequent study effort.

H.3.1.1. Redundant Communication Equipment*

Since redundant communication equipment will be utilized within the potentially distressed vehicle, a brief review was made to assess its influence on the selection of equivalent SRV equipment.

*This Subsection is based on work by R. T. Luke, Ref. H-2.

The baseline assumptions for this review were:

a. A complete power failure in the distressed vehicle (DV).

b. Personnel in the DV may be incapable of communicating because of lack of access to the equipment or because of illness/injury.

c. The space rescue vehicle (SRV) is within a 50 n mi radius of the DV and knows the location of the DV.

These baseline assumptions lead to the following equipment requirements:

a. The redundant emergency equipment should be battery powered.

b. Both voice and telemetry service are desirable, with emphasis to be placed on voice communications.

c. Omni antenna coverage must be provided.

The characteristics of communication equipment compatible with these requirements are outlined in Tables H-37, H-38, and H-39.

Table H-37 shows the more important frequency tradeoff parameters which led to the selection of 2.2 GHz as the preferred frequency for the emergency equipment. This frequency will permit low-loss communication with either the SRV, or with a ground station when the DV is within line-of-sight of the latter. Link calculations are shown in Table H-38, indicating that a transmitter power of 250 mW will be sufficient. Table H-39 indicates the recommended emergency communications equipment for the DV, together with weight, power, and stowage volume requirements. The SRV equipment would be similar, except for antenna and battery.

Other recommendations resulting from this study include the design of the emergency transmitter with transponder capability and the provision of battery-powered handsets in each compartment so that the emergency equipment would be accessible for voice communication via an RF link wherever the crew might be located at the time of the emergency.

Table H-37. Communication Frequency Considerations

Frequency Range	Atmospheric Conditions	Omni Antenna Parameters	Present Ground Facilities*	
			NASA	SCF
3 MHz - 30 MHz (HF)	Ionospheric refraction, very high galactic noise	λ = 100 m to 10 m long wire or fractional λ		
30 MHz - 300 MHz (VHF)	Ionospheric refraction, high galactic noise	λ = 10 m to 1 m multiple fractional λ or slot	260 MHz 296 MHz	225 - 260 MHz
300 MHz - 3 GHz (UHF)	Atmospheric Windows available	λ = 1 m to 10 cm multiple slot or spirals	2.1 GHz 2.3 GHz	375 MHz 400 MHz 1.8 GHz 2.2 GHz
3 GHz - 30 GHz (SHF)	Atmospheric Windows available	λ = 10 cm to 1 cm multiple spirals or stubs		

*Emergency space rescue frequencies which are compatible with existing ground services offer the advantage of space-to-ground communications up to synchronous altitudes.

Table H-38. Emergency Link from DV to SRV and Ground Station

	DV-SRV	DV-GROUND
DV Transmitter (250 mW)	24 dBm	24 dBm
Losses to Antenna - (Transmitter to Antenna)	- 2 dB	- 1.5 dB
Omni Antenna Gain	- 3 dB	- 3 dB
Space Loss (2.2 GHz)	- 139 dB (50 n mi)	- 191.5 dB (22,000 n mi)
Received Signal Power	- 120 dBm	- 172 dBm
Receiver Antenna Gain*	- 3 dB	
Receiver Sensitivity	- 127 dBm	
Required Signal Power**	- 124 dBm	- 178 dBm
Received Signal Power	- 120 dBm	- 172 dBm
Required Signal Power	- 124 dBm	- 178 dBm
Power Margin	4 dB	6 dB

*The SRV could easily employ a directional antenna yielding +14 dB gain characteristics thus reducing the receiver sensitivity requirements.

**Required Signal Power for a 1 kbps, high quality data link.

Table H-39. Emergency Communication Equipment

Transmitter (voice/telemetry)	
Required Transmit Power:	250 mW
Size:	32 $in.^3$
Weight:	2 lb
Prime Power:	1.5 W
Receiver (voice)	
Required Sensitivity:	0.1 μV
Size:	20 $in.^3$
Weight:	1.25 lb
Prime Power:	0.75 W
Battery: Nickel-Cadmium	
Max Power:	2.0 W
Volts:	28 - 24 V
Useful Life:	100 hr
Assumed Duty Cycle:	20%
Size:	50 $in.^3$
Weight:	10 lb
Total Package	
Weight:	12 lb
Size (4 × 5 × 5 in.):	100 $in.^3$

Consideration might be given to special protective shielding for this emergency set so as to assure survival in the event of fire, explosion, rapid decompression, etc.

Additional communication redundancy in the form of hard-wire links could be provided by installing phone contacts on the exterior of the DV near hatches as well as within the DV. A rescue crew equipped with handsets could then attempt to establish communications by plugging into hardlines as they enter the DV and as they progress in their search for the crew.

Another communication method, not to be neglected merely because of its lack of sophistication, is a conventional blinker used for many years on water-borne vessels and in early aircraft applications. View ports will be available on all IP vehicles and visual communications can therefore be established under most foreseeable conditions.

H.3.1.2 Survey Equipment and Methods

Both distant and close surveys of the DV by the SRV might be required as a prelude to the actual rescue. The distance (or stand-off) survey would determine whether a closer approach by the SRV would be hazardous. The primary reason for caution would be the possibility that debris generated by the DV as a result of the emergency still remains in the vicinity. In the absence of knowledge concerning the nature of the emergency, such a determination of debris presence should be made routinely. However, communication with the DV might bring a warning concerning the presence of debris; in that event the distance survey would locate the debris and determine whether closer approach is feasible.

The distance survey could also check for dangerous radiation on or near the DV. Here again, communication with the DV, if feasible, would alert the SRV to this danger, but a survey might still be required to map the radiation field and to plot safe approach corridors, if any. In the absence of communication, knowledge that the DV carried sources of nuclear radiation (i.e., power sources) should cause a mapping survey to be routinely carried out.

Close surveys would be required to determine the extent of DV damage caused by the emergency, to discover the best method of entry to the DV, to determine tumbling characteristics, etc. All of these determinations might have to be made even if communication were available. In the absence of communication, the objectives of a close survey would expand to include determination of any residual life on board the DV, the presence of hazards affecting the safety of a boarding rescue crew, etc.

H. 3. 1. 2. 1 Distance Survey Equipment

H. 3. 1. 2. 1. 1 Debris Detector*

A brief discussion of the motion of debris in the vicinity of the DV has been provided in Appendix I-1, together with preliminary data on the probability of its presence in the vicinity of the DV. Nothing, however, can be stated about the nature of the debris and its characteristics, since this is strictly a function of the design and construction of the DV and the nature and force of the explosion or collision which created the debris. The final design of the detection system must therefore be preceded by considerable analysis, and perhaps experimentation, to provide an adequate target model. It is clear, however, that DV-generated debris will be a passive target, can vary in size from inches to several feet, and will be travelling along a variety of vectors both outward from the DV as well as returning to the DV.

Sophisticated electro-optical instrumentation has been proposed in recent years for detection and identification of non-cooperative space objects such as the debris of interest here. Most of the documentation discussing details of such techniques is classified and specific details will not be presented in

*This subsection is based on the work of J. Camus, Ref. H-3.

this brief survey. It is possible to outline some selection criteria which will eventually help determine a useful solution to the problem of debris detection and tracking. It is not, however, possible at this time to delineate a firm solution. Technology, it is believed, will be available in from 5 to 10 years, both in the laser and detector areas, to accomplish debris detection and tracking without the need for a major technical breakthrough.

Five possible approaches to detect debris were considered. They are summarized in Table H-40.

Considering the state of the art, multiple-use potential, and probable weight and storage volume limitations, it was concluded that a LWIR (Long Wave Infrared) system for acquisition and a scanning laser radar for tracking and ranging are appropriate for this application. Some advancement in the state of the art of laser radars would be required to produce a useful range for the skin tracking case represented by the debris detection problem.
It must be reemphasized that much additional study is necessary to properly optimize a debris detection system and that, in particular, a good target model must be provided. The purpose of this brief discussion was to indicate whether such a concept could even be considered feasible and worthy of further investigation, whether the physical characteristics of the system made its installation in a SRV practical, and whether such a system would be useful for other rescue mission needs.

The passive LWIR detection approach suggested operates by sensing target thermal emissions in the 8 - 13 micron region. The information obtained by the sensor can be presented on a real-time TV display. Under certain conditions of cold background, the IR vidicon can also be useful. However, equipment used in long wave infrared applications requires cryogenic cooling which is a detriment in long duration missions.

Table H-40. Summary of Approaches for Debris Detection

		I High Resolution Optics	II Laser Radar	III Gated Laser Imaging	IV LWIR	V TV Tracker
Range Measurements Capability		None	Yes	Yes	None	None
Operating Range		750 Mi	Typ: 5 Mi for Skin, 200 Mi for Retro-reflector	Typ: < 1 Mi	150 Mi	5 Mi
Range Rate Measurement Capability		None	Yes 0.1 Mi/sec	Yes 0.1 Mi/sec	None	None
Typical Diam. of Collector Optics		30 in.	Narrow field 3 in. Wide angle 75 in.	6 in.	10 in.	4 in.
Field of View		2°	1° to 15°	1°	5°	5°
Imaging Multiple Target Capability		Yes	Possible	Yes	Yes	No
Background Discrimination	Sky	Yes	Yes	Yes	Yes (Qualified)	Yes
	Earth	No	Yes	Yes	Yes	Yes (Qualified)
Wavelength Region		Visible	Several	0.9μ	8-13μ	Visible
Active or Passive		Passive	Active	Active	Passive	Passive
Acquisition Capability		Yes	Yes	None	Yes	Yes
Tracking Capability		None	Yes	Yes	None	Yes

The scanning laser which could be used with the LWIR system to provide tracking and ranging capability uses an image dissector detector and can be used for skin tracking over short distances. With present and anticipated developments in the state of the art of YAG (Yttrium Aluminum Garnet) lasers, it is anticipated that the maximum range of the skin tracking sensor could be extended to about 25 miles during the next 10 years without an excessive increase in system weight. If skin tracking ranges of about 100 miles are determined to be desirable as a result of target model studies, the CO_2 laser could be considered. Feasibility of CO_2 lasers for range and range rate determinations has been reported in the literature. CO_2 laser ranging is still in its early development phase, making it difficult to evaluate the suitability of this system for this application. It is likely, however, that this system will be quite heavy.

Table H-41 provides estimates of the physical characteristics of the suggested debris detection system.

Table H-41. Physical Characteristics of LWIR/Laser Debris Detection System

Characteristic	Range = 25 n mi		Range = 100 n mi	
	LWIR	Laser Radar	LWIR	Laser Radar
Field of View, deg	15	1	15	1
Minimum Target Size, ft^2	2	2	2	2
Weight, lb	30	400	200	-
Volume, ft^3	3	10	10	-
Power, watts	25	250	150	-

As discussed in Section H. 3. 2. 1. 1, the laser portion of this system may also be of use in connection with DV spin rate characterization. The LWIR acquisition system as well as the laser should also be considered for the rendezvous and docking guidance system. This multiple-use capability is an obvious advantage in spite of the weight and complexity penalty of the system.

H. 3. 1. 2. 1. 2 Radiation

As in the case of debris, hazardous nuclear radiation which may result from an emergency aboard the DV can only be defined quantitatively when DV vehicle design and configuration are fixed, and when the nuclear radiation sources have been carefully defined. In addition, probable failure modes must be developed. It can be safely projected, however, that reactors and/or isotope power sources will play a role in the IP and that a rescue vehicle may therefore encounter uncontrolled radiation. In consequence, means for surveying a DV for such radiation are desired, with the specific objective of determining safe approach corridors from as remote a location as possible in order to reduce the hazard to the SRV crew.

Nuclear radiation sources and the type of uncontrolled radiation which may result from emergency situations are listed on Table H-42.

The distance at which a radiation hazard can be evaluated will depend on the strength of the radiating source and on the background level of natural radiation, plus the orientation of the geomagnetic field between the source and the detector, in the case of charged particles. If a reactor is involved, neutrons may be emitted in sufficient numbers to constitute a hazard. Additionally, they might be used as a diagnostic tool for determining the state of the reactor. Neutron counters can be made with some directionality. The earth's magnetic field will not deflect the path of the neutron. Conventional neutron detectors, modified for use in vacuum, could be used.

Table H-42. Detection of Uncontrolled Radiation

Source	Location	Type of Radiation
Malfunction of Reactor Power System	Space Station Space Base Nerva Engine	Neutron Beta Gamma, X-Ray
Malfunction of Isotope Power System	Space Station Space Base Experiments	Neutron Alpha Beta Gamma, X-Ray

Capability Required
• Determine safe approach corridor to DV • Determine nature of malfunction and effect on DV, SRV, and Crews

Over distances of several kilometers, the deflection of the path of an alpha-particle due to the geomagnetic field is sufficiently small that it can be neglected in the assessment of alpha-particle hazard (due, for example, to a ruptured isotope power generator). Alpha-particles will not constitute a hazard to anything except directly exposed sensitive surfaces (bare solar cells, bare transistors, film, etc.) because of their high rate of ionization in materials and therefore very short path length.

If measurements of alpha-particles are desired for diagnostic purposes, special detectors would have to be manufactured. The principal measurement means is a thin-window ion chamber or Geiger detector. The external vacuum presents difficulties in making a thin-window gas-filled counter. Another type of detector is the thin-window solid state sensor. Its principal drawback is its sensitivity to light. Collimators and care in use can circumvent this problem. Such devices are already in use in space, measuring the natural alpha-particle population.

If electrons are being emitted by a source on the spacecraft, even though they are emitted isotropically, they will not be isotropically distributed. The ambient geomagnetic field will convert their trajectories into approximately helical form, with the axis of the helix aligned along the magnetic field. A 1 MeV electron in a 0.1 gauss field will have a path with a radius of curvature of about 200 meters if the path is perpendicular to the field. The radius of curvature approaches zero as the momentum perpendicular to the field approaches zero. Hence, a very low energy particle would not get very far from the source if it were emitted perpendicular to the local magnetic field. Conversely, if a particle of any energy is emitted parallel to the field, it is unaffected by the field (i.e., until the field curvature becomes significant).

Therefore, when making measurements of electrons from some distance away, the orientation of the geomagnetic field between the source and detector is of prime importance. Measurements must be made parallel to the field lines passing through the source and only a qualitative estimate of source strength can be obtained without a detailed survey of the adjacent field lines. If one cannot assume that the electrons are being emitted isotropically, pitch-angle distributions on all the adjacent and direct field lines would also be needed for a quantitative estimate. For these reasons, plus the fact that electrons would not constitute a direct hazard to personnel unless they are very energetic (i.e., from a fission source), it is probably better to ignore electron measurements in the distant survey phase. However, standard spacecraft electron detectors are available, if desired.

X-ray and gamma-ray measurements are also possible. Since these electromagnetic radiations are not affected by the magnetic field and are not attenuated by the vacuum, they should constitute the most useful type of measurement for distant survey (except for neutrons in the case of a reactor). Quantitative analysis may be made by making measurements with a detector such as a collimated scintillation counter and extrapolating by assuming an isotropic emission at the source with an inverse square diminution at the detector. If the distressed spacecraft is rotating, a survey may be successful in pinpointing the location of the emitting source.

In all of the far encounter measurements, the detected levels due to a source at the DV will probably be small. Thus, natural background radiation may mask the desired measurements. Measurement techniques which take the natural radiation level into consideration would have to be used.

Because of the many uncertainties concerning this problem and the essentially low-weight nature of the instrumentation required for radiation surveys, effort to estimate weight and volume requirements for these items was not undertaken.

H. 3. 1. 2. 2 Close Survey Equipment

A close survey of the DV might be required to determine the best entry point for the rescue crew, the status of the crew, the location of the crew, damage to the DV, hazards to the rescue crew attempting entry, the nature of any motion of the DV in order to plan attachment of despin equipment, etc. A close survey could be performed by the SRV itself in a circumnavigation of the DV, by remotely controlled, self-propelled TV and sensor carriers, or by the rescue crew in EVA. Data could be collected by visual means, by sensors such as heat sensors or laser systems, by plug-in read-out devices, if the DV were equipped with contacts tied by hardwire to internal sensors still functioning, and by radiation measuring instrumentation.

The laser system already discussed (Section H. 3. 1. 2. 1. 1) could be used in conjunction with corner reflectors, pre-positioned on a potential DV in a proper pattern, to permit precise characterization of the motion of a spinning and tumbling space vehicle. This problem is discussed in Section H. 3. 2. 1. 1.

Externally provided illumination would be desirable for a close survey. The spacecraft making the survey should have this capability. In addition, the EVA crew would be equipped with portable lighting systems for the same purpose. These portable systems would, of course, also be available for rescue crew operations aboard the DV. The EVA crew could also carry portable radiation detection and field strength measurement instrumentation. Radiation measurements from the SRV could utilize the same instrumentation already provided for the distant survey. For radiation measurements by the EVA crew, it would be desirable to provide small body shields such as lead-loaded aprons until the hazard level can be certified to be non-dangerous.

A portable atmospheric sampling kit would be useful for close survey by a rescue crew, both on the exterior of the DV as well as within the DV during exploratory entry or a damage control operation. This kit would enable the rescue crew to test interior atmospheres for contaminants, for composition, and for pressure either through sampling ports already pre-positioned on potential DV's or by drilling sampling holes and inserting suitable sensor probes. Such a kit would probably consist of a colorimetric analysis system for contaminant determination, pressure gages, and an atmospheric analyzer to determine the partial pressure of oxygen within the sampled DV compartment.

Equipment characteristics for the close survey function are summarized below:

	Weight, lb	Volume
Portable plug-in damage sensor reader	5	50 $in.^3$
Illumination installed in SRV	20	1 ft^3
Remote controlled TV carrier	300	6 ft^3
Portable radiation detector	5	0.25 ft^3
Portable atmospheric sampling kit	35	1 ft^3
Portable illumination	5	0.25 ft^3

H.3.2 Transfer Aids

Special equipment is required during phases of the rescue operation concerned with moving the rescue crew to the DV, and returning both the rescue crew and the DV crew to the SRV. These requirements relate to possible incompatibility between the docking arrangements of SRV and DV, as well as to possible damage to the DV as a result of the emergency situation.

Considerable effort was devoted during the course of the rescue study to the exploration of the operational and equipment requirements of crew transfer and is described in the following sections.

H. 3. 2. 1 Reduction of Undesirable Motion

The causes of undesirable motion in a DV, and the characteristics of such motion, are described in Appendix I-1 to this report. Given the possible existence of such motion, means to reduce it to acceptable levels are essential to a successful rescue mission. Uniform motion around a single axis of rotation may permit docking if the rotation rate is low enough to permit the SRV to match angular rates and if the DV docking port is located along the axis of rotation. Entry by EVA would also prefer no motion or at least uniform motion around a single axis but can permit some tumbling of the DV if rates are low. With sufficiently low rates, and with the EVA crew equipped with appropriate transporter devices, entry may even be feasible if the DV airlock or entry hatch is not located on the axis of rotation. If such conditions are found not to prevail upon inspection of the DV by the SRV, they can be achieved under certain favorable circumstances. Despinning the DV or changing a compound motion (tumbling) to nearly pure rotation around a single axis would appear possible. The equipment requirements for this purpose are not excessive if DV spin rates are in order of 4 rpm or less around any axis and if either pre-positioned despin devices on the DV or, at the minimum, attachment points for such devices are available.

H. 3. 2. 1. 1 Measurement of Motion*

Decisions concerning feasibility of docking to a tumbling spacecraft, or entering such a DV from EVA, will have to be made on the basis of predetermined limits on such uncontrolled motion. These limits will relate to the capabilities of the docking systems of both vehicles to take instantaneous

*This subsection is based on the work of J. P. Janus, Ref. H-4.

torques, of propulsion systems to match motion, etc. Visual observation will in many instances, particularly in the case of motion around a single axis of rotation, be sufficient to disclose whether such limits are being exceeded. Compound motion such as tumbling may present a more difficult observational problem for which instrument aid may be essential. The location for despin devices to be placed by the SRV crew on the DV will in some instances have to be based on fairly accurate knowledge of the instantaneous center of rotation of the DV at the time of attachment and on the rate of rotation. Here, again, instrument aid will either be desirable or necessary.

A very brief review was conducted to determine whether feasible instrumentation schemes exist to aid the measurement of tumbling motion, and whether systems already planned for rendezvous and docking guidance and for debris detection would have utility for this measurement function. As a consequence only laser systems were considered.

Three basic techniques were examined and all three appeared to be feasible means of determining the motion of a distressed vehicle. These included a passive scheme as well as two schemes requiring the passive augmentation of the distressed vehicle with some form of retro-reflectors. Although these solutions appear to be feasible, error analysis was not performed nor an examination of geometric singularities which may cause problems with the practical implementation of the various sensor configurations. These problems could impose sensor requirements far beyond the state of the art.

It was assumed that the spacecraft could be designed to include passive augmentation which would assist in the determination of its motion. This includes both painted markings and/or retro-reflectors. It was also assumed that the distressed craft was in force-free motion. Furthermore, the sensors were assumed to be capable of being positioned in any configuration and not restricted to a particular area of the DV. It was also assumed that the sensors were capable of measuring derived angular rate when retro-reflector augmentation of the target was provided.

Of the three sensor/target configurations, the first offers the basis for the other two. The primary differences between the three sensor/target configurations is that two of these take advantage of the use of retro-reflectors on the target vehicle and, consequently, are capable of obtaining angular rate data by tracking a particular point on the distressed vehicle.

The first configuration, shown on Figure H-14, consists of three sensors, each of which take three measurements to points on the target vehicle. These 9 measurements, taken simultaneously, consist of position (range and two angles) and range rate. The lines of sight of the measurements from each sensor are assumed not co-planar.

The second sensor configuration uses augmentation of the target or distressed vehicle to make it possible to obtain angle rate. This configuration uses three sensors to measure range, range rate, angle, and angle rate of various points on the distressed spacecraft. The measurement geometry for this configuration is shown in Figure H-15. Although each sensor is shown to be sighting a separate retro-reflector, all three sensors may also be sighting the same reflector.

The third sensor configuration is similar to the previous configuration in that it requires passive augmentation of the target to provide angle rate data. The measurement geometry for this configuration is shown in Figure H-16.

Configuration I has the basic advantage of not requiring passive augmentation of the target vehicle because it uses skin tracking. However, the poor reflectivity of the target may require fairly large sensor power to provide adequate illumination. In order to obtain sufficient accuracy, it may be

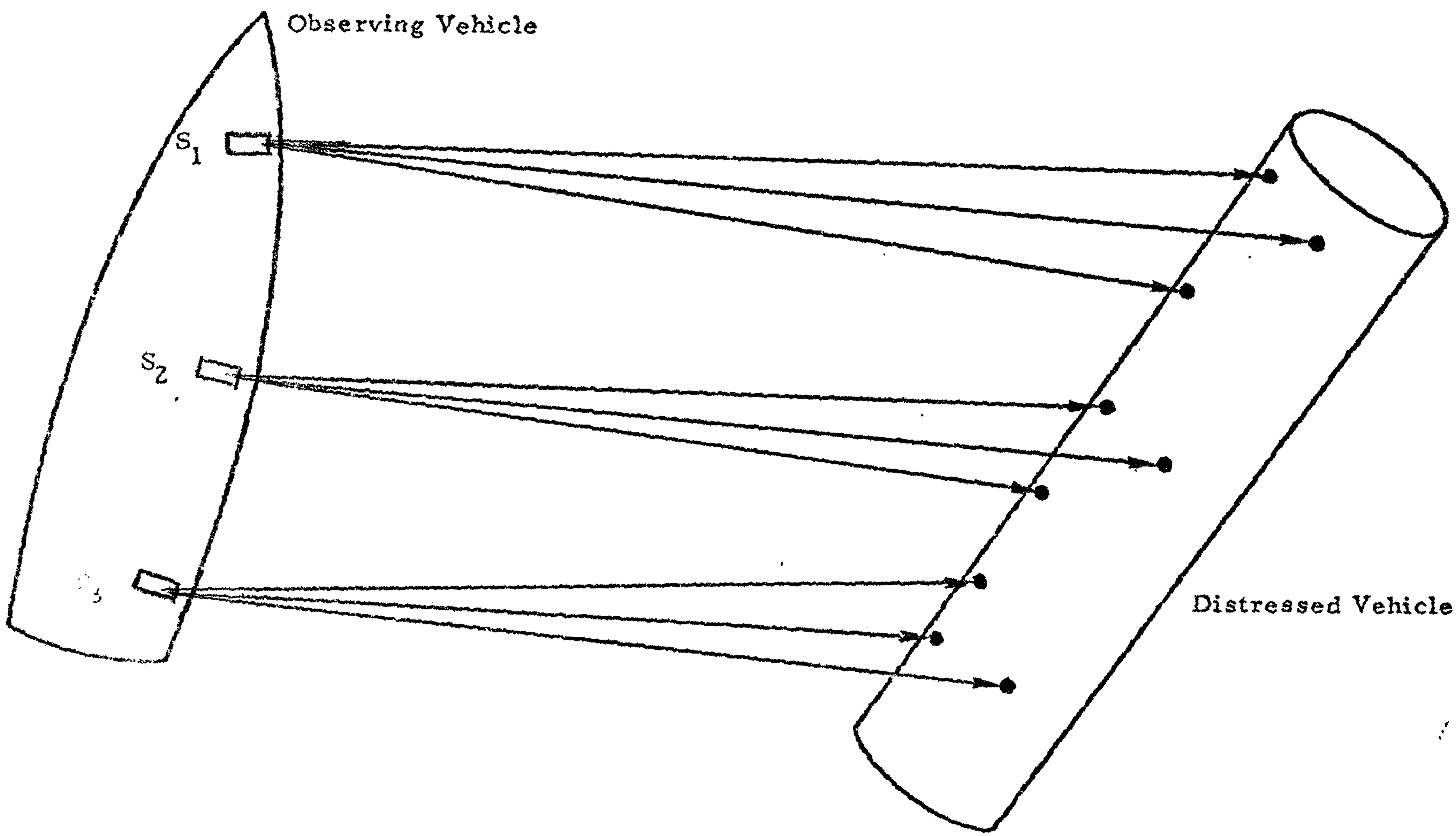


Figure H-14. Measurement Geometry for Configuration I

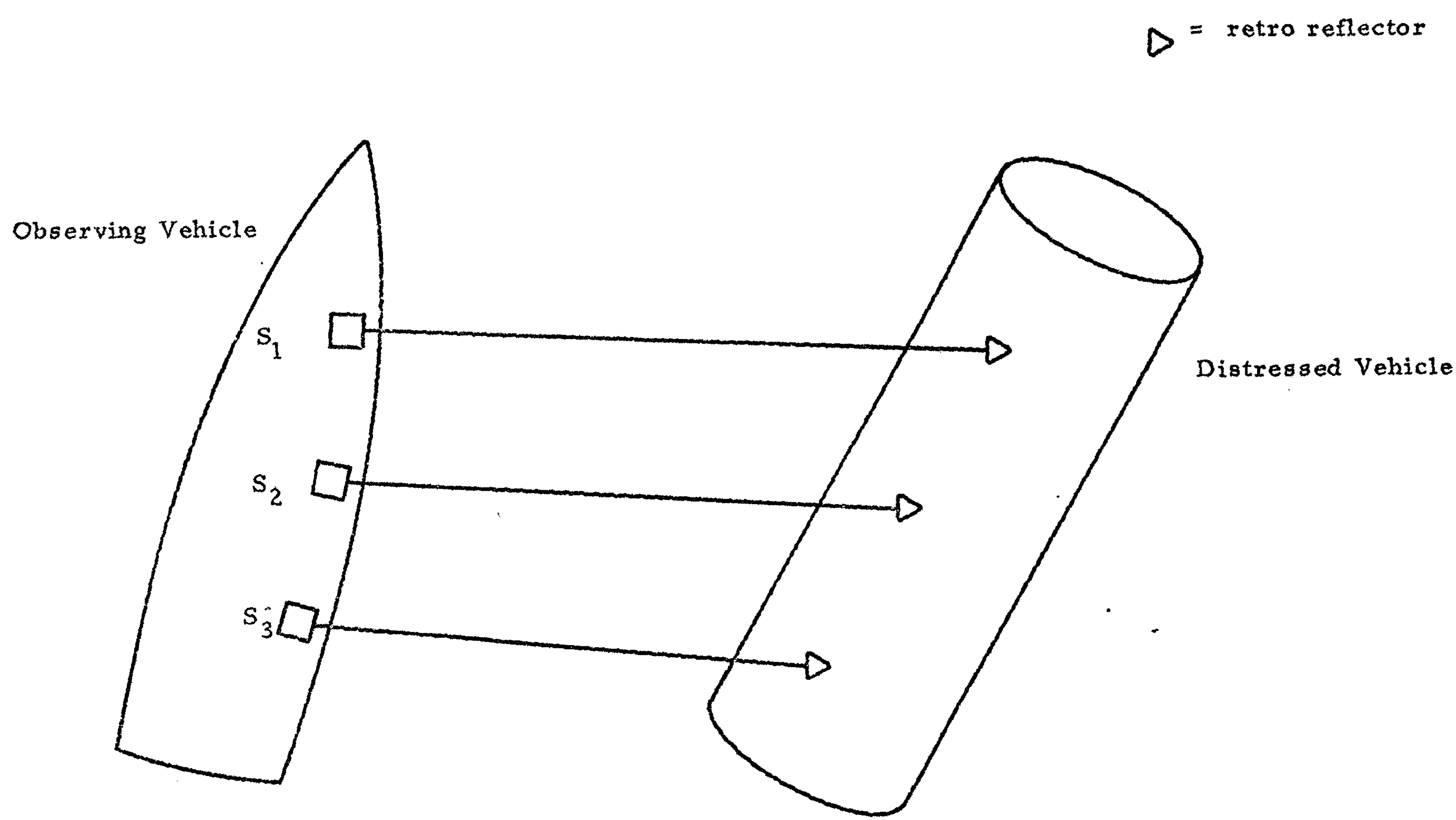


Figure H-15. Measurement Geometry for Configuration II

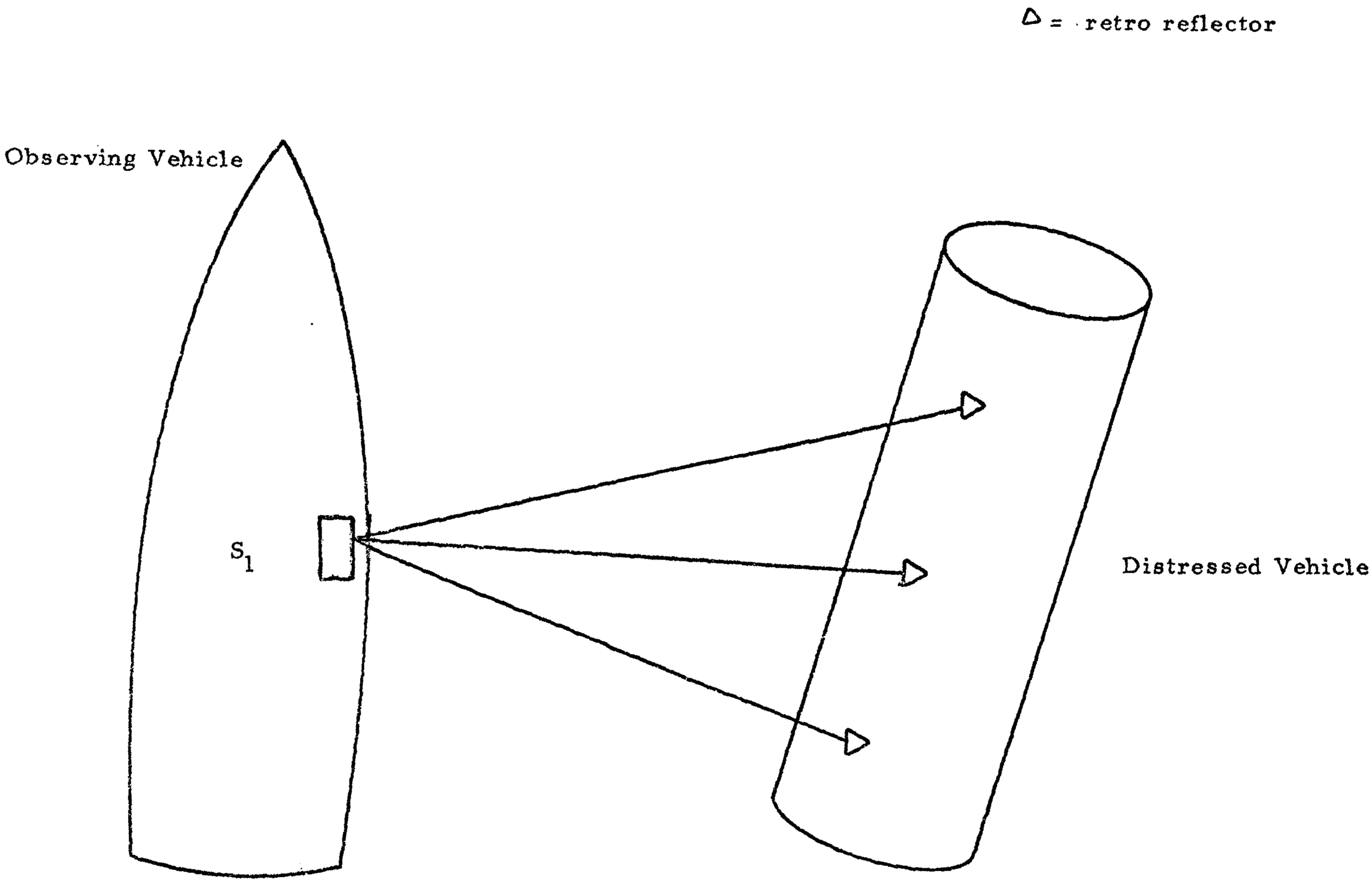


Figure H-16. Measurement Geometry for Configuration III necessary to average the measurements over areas of the skin, tending to increase computational requirements. Also, this technique requires instantaneous range rate measurements, which would require the use of heterodyne or doppler techniques. In Configuration I the sensors are required to track three points on the vehicle simultaneously in the so-called acquisition mode. A fast scan in this mode might not give three measurements in a short enough time interval. The feasibility of a sensor giving essentially simultaneous measurements requires further study.

Configurations II and III have many points in common. For example they both require retro-reflector augmentation of the target. However, Configuration III requires that three of these reflectors be simultaneously visible to a single sensor. Configuration II needs to see only one reflector if the sensors are arranged so that their lines of sight to a single reflector are not co-planar. Also, if the sensors in Configuration II are to be used on a single reflector, it may be necessary to have them all operate on slightly different wavelengths. This could conceivably have some impact on the sensor design if heterodyne or doppler techniques were used to obtain range rate data.

An area of uncertainty in Configurations II and III is that of obtaining line-of-sight rate data. This could only be done by smoothing the angle data, and, consequently, it would require tracking of a reflector for some period of time.

Configuration III, like Configuration I, must operate in the acquisition mode, which imposes some of the previously mentioned disadvantages. However, Configuration II operates in the more accurate track mode where each sensor is tracking only a single point on the target vehicle.

The brief nature of the review of this problem precludes an indication of preference for one of the three alternate systems, just as it precludes a firm conclusion concerning feasibility or state of the art implementation requirements. However, ROM estimates of equipment weight and storage volumes were made to give an indication of the feasibility of installing such a sensor system in the SRV. For this purpose, Configuration III was selected, since it could utilize the single sensor likely to be provided for a laser rendezvous and docking system. For such a system, if already present for other purposes, only about three or four retro-reflectors would have to be provided on the DV, with a total additional weight of about 2 lb. If the sensor system were not already present on the SRV, its addition would provide a weight increment of about 30 lb, and would require an installed volume of about 2 ft^3, for a range capability of about 1 n mi. Because of likely commonality with other vehicle functions, onboard computational requirements associated with this function were not separately estimated.

H. 3. 2. 1. 2 Despin Devices

The causes and magnitudes of uncontrolled motion of a distressed vehicle have been discussed in Appendix I. Action to reduce this uncontrolled motion can be taken by either the DV or the SRV. It is also possible to postulate a scheme for despinning which, in the event of total failure of DV command systems, and/or of the DV crew, could be activated by the SRV either remotely or by sending a crew in EVA.

Three basic schemes for despinning were considered; the application of external torques, energy dissipation within the DV, and inertia augmentation. All three schemes lend themselves to pre-positioned devices within or on the DV; only the first and the third method could also be applied by the SRV.

Examples of external torques are the use of reaction control systems already provided on the DV, or the application of external thrusters attached by the SRV crew. If the size relationships between SRV and DV are appropriate, grappling mechanisms on the SRV may be able to couple the two vehicles to allow the propulsive capability of the SRV to reduce the motion.

Without provision of special equipment, energy dissipation within the DV is often available in the form of sloshing propellants or magnetic forces such as eddy forces. Such inherent dissipating processes tend to act very slowly, possibly requiring weeks to produce the desired stabilization. Special energy absorbers in the form of fluid hoops are also conceivable, which may speed up the stabilization process.

Inertial augmentation can be provided by extendable masses on booms or weights on cables (Yo-Yo System).

A brief analysis was performed to size two such feasible systems which also offer the possibility of being brought to the DV by an SRV and attached either manually by a crew or by a remote-controlled manipulator. For both systems, the characteristics of the uncontrolled DV motion must be known to reasonable accuracy to permit the sizing of the control forces and the proper locating of the attachment point. The mass-on-cable and the rocket thruster concepts were selected for analysis and were applied to a tumbling space station.

The assumptions concerning the characteristics of the space station were as follows:

a. Weight of the station .... 120,000 lb
b. Motion around the major axis of rotation
c. Rate of motion .... 4 rpm

It was also assumed that attachment aids had been provided on the station in anticipation of the need.

Figure H-17 shows the required characteristics of the two remedial systems examined.

If the tumbling mode requires despin device attachment at unpredictable positions, the concept of prepositioned despin aids is not applicable. Further study of this problem is necessary prior to the selection of any despin device.

H. 3. 2. 2 Transfer in EVA

Movement of personnel in EVA may be required for several operations of the rescue mission. During the close survey phase, the rescue crew may have to examine the exterior of the DV for symptoms of the specific emergency situation. Also, attempts may be made to communicate with the DV crew through plug-in hardwire links, read diagnostic instrumentation repeaters on the exterior, etc. Prior to entry into the DV, despinning equipment may have to be attached and entry hatches may have to be forced. If the entry hatch is occupied by a device such as an experiment module, the rescue crew may have to remove this module with the aid of tools or manipulators. If the SRV is unable to dock because docking fixtures are not available or are not compatible, transfer of the rescue crew into the DV, and their return together with the DV crew, will require EVA. If damage control work must be performed external to the DV, both the crew and equipment may have to be moved in EVA. Finally, disposition of the DV after completion of the rescue operation may require movement of personnel and equipment in EVA.

All of these activities will, in the minimum, require pressure garments for the crew. In addition, transporters will be required to propel both crew and equipment between the vehicles. Mechanical aids such as manipulator units may be required to perform operations beyond the capability of the crew. Finally, manipulator units large enough to house a crew in shirt-sleeve environment may be desirable in order to extend crew work time for difficult assignments.

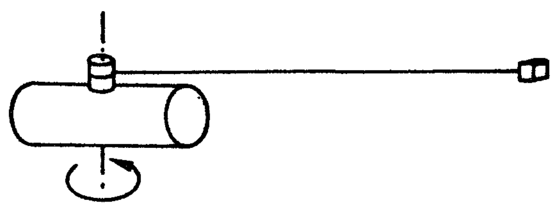
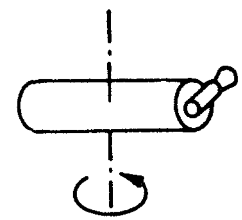
MASS ON CABLE (YO-YO)	ROCKET THRUST
 1000 FT CABLE 100 LB WEIGHT	 THRUST ~ 70 LBS BURN TIME ~ 30 MIN
TOTAL WEIGHT, LBS, 150 STOWED VOLUME, FT^3, 3	460 7

Figure H-17. Despin Concepts

This study subtask briefly reviewed hardware concepts, both off-the-shelf as well as requiring development, which may aid in such EVA activities.

H.3.2.2.1 EVA Transit

Environmental protection and life support for the crew outside of a space vehicle is currently provided by pressure garments of conventional design, with 3.5 psia of pure oxygen for breathing from either an umbilical tether or a portable life support system. Cooling is available either from the breathing oxygen in an open loop mode or from a closed loop system utilizing heat exchangers and radiators. The problem of utilizing these available garments, when SRV and DV are operating at 14.7 psia sea level atmosphere, has already been discussed in Appendix F. For reasons there stated it is likely that suit design will be changed before the IP becomes operational and that suit weights will therefore also change. For purposes of this study, however, a weight of 70 lb and a stowed volume of 4.5 ft^3 has been estimated for the standard EVA suit. A 60 ft umbilical line carrying oxygen, power, and communication from the SRV to the crewman in the suit is estimated to weigh about 40 lb. In the absence of such an umbilical, a portable life support system (PLSS) sufficient for from two to four hours of operation would weigh about 50 lb.

Astronaut maneuvering units (AMU) have been designed and developed for Gemini which combine PLSS and small rocket thruster systems in a backpack configuration to provide maneuverability over several hours of operating time. Such units, when improved, are estimated to weigh about 150 lb and require 4 ft^3 of storage volume.

Other varieties of AMU have been conceived which add mechanical assistance in the form of powered manipulators for the crew. Such a system, which can be called a space work platform, is shown in Figure H-18. This unit could also provide the mission controller, either in the SRV or

WEIGHT	500 LB
STOWED VOLUME	30 FT^3

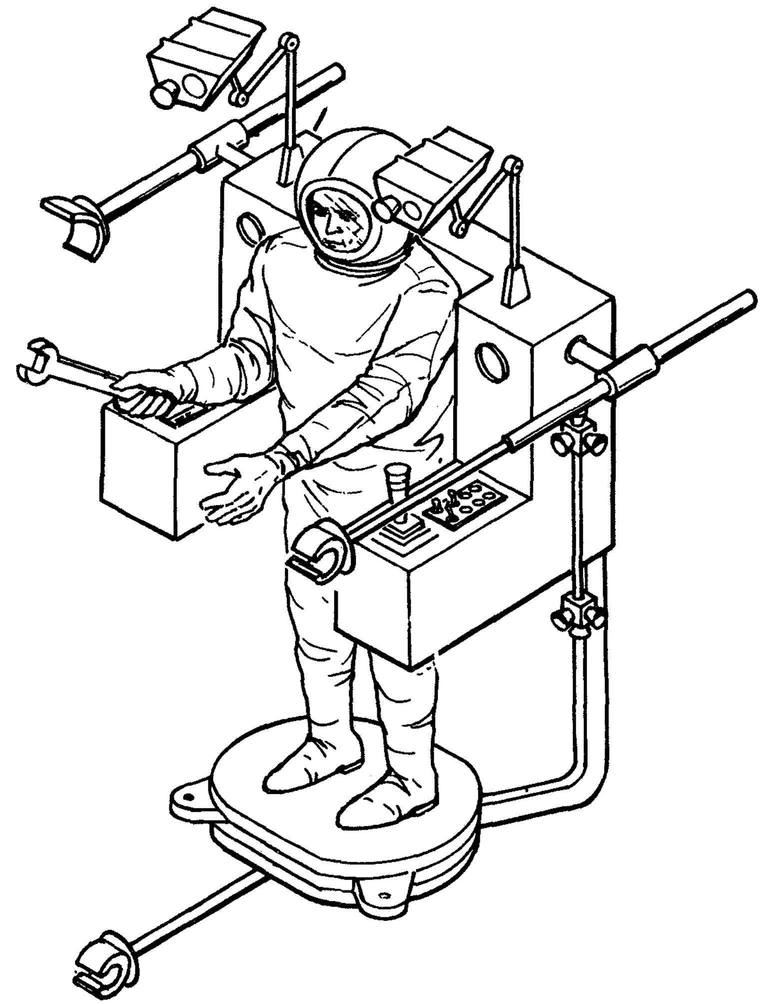
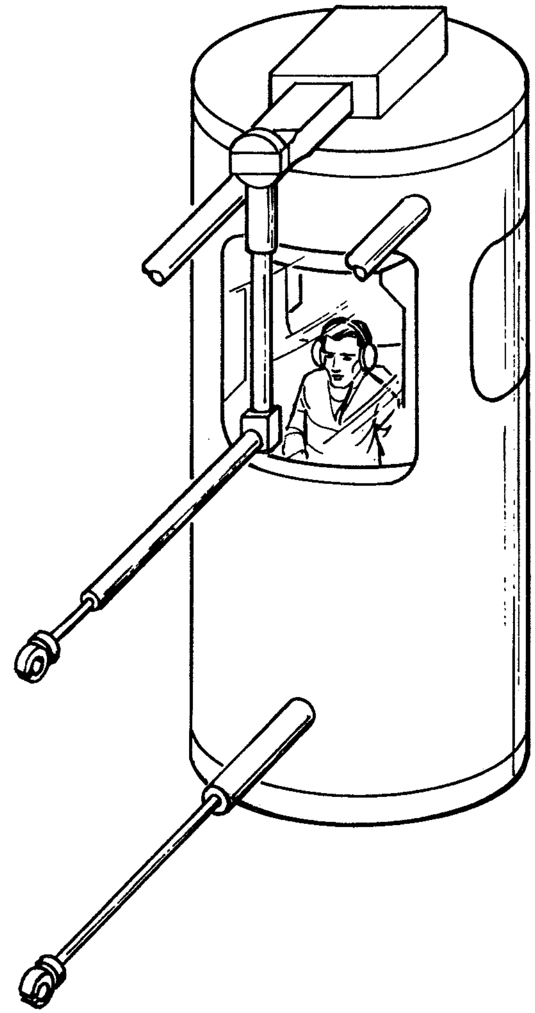


Figure H-18. AMU for SRV Crew (Platform Type) on the ground, with TV coverage of the operations to be performed and may in return supply the rescue crew with guidance from experts via an RF link in any specialized operation to be performed. The unit can carry tools and has provisions for anchoring itself to the DV so as to provide a torque-free work base for the crewman. It permits the crewman to leave the platform or to perform manual operations as well. It still, however, requires that the crewman perform in a pressure garment and thus will limit his work shift to an estimated 2 to 4 hours.

Although not truly falling into the category of an EVA device, another AMU shown in conceptual form on Figure H-19 will permit operations on or near the DV exterior with the crew in a shirtsleeve environment, and will thus allow longer work shifts. However, this unit would not allow the crewman to leave and perform some operations manually.



WEIGHT 2000 LB

STOWED VOLUME 70 FT^3

Figure H-19. Manipulator for SRV Crew with Shirtsleeve Environment

H. 3. 2. 2. 2 Entry to DV*

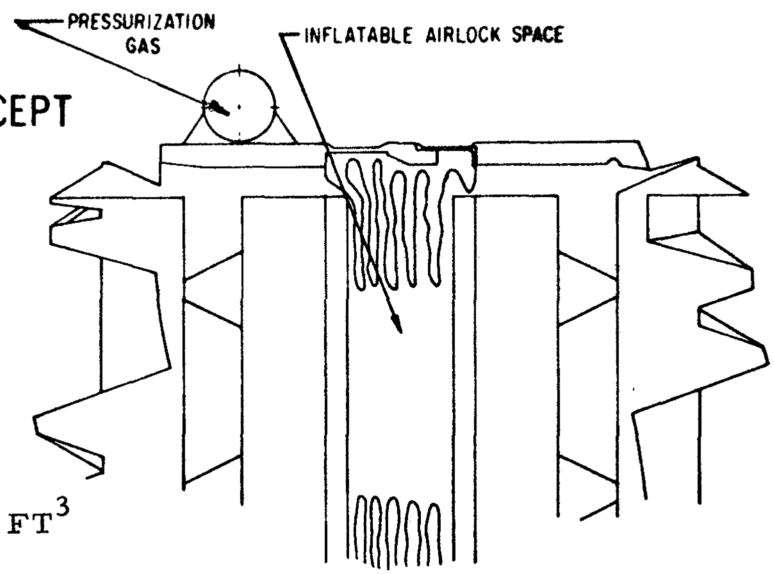
As already indicated, entry to the DV from EVA may require EVA operations to force entry hatches, the removal of modules already docked against the entry hatch, etc. The use of manipulators of either open platform or capsule type may be required in this operation. One other consideration applies in the instance when the DV hatch through which entry is to be made is not equipped with a working airlock. When entry under EVA conditions is to be made into a DV which has retained all or some of its atmosphere, and where continued retention of the atmosphere is essential, an airlock cycle must be performed either in a nominal airlock or by evacuating and repressurizing the DV compartment behind the entry hatch. If compartment pressure cycling is infeasible due to lack of functioning equipment, or due to the presence of a shirtsleeve crew, a portable device may be required which can serve as an airlock. Such a portable airlock (PAL) could be of expandable design in order to reduce stowage volume requirements in the SRV and could have other additional functions. It could, for example, be utilized between docked spacecraft to serve as an atmospheric contamination barrier between DV and SRV. Equipped with appropriate chemical spray systems, it would also prevent biological contamination of the SRV, if the DV emergency has created such a hazard. Used as a BOD or as a quarantine device it would require more extensive EC/LS provisions.

A conceptual arrangement of a PAL sized for two astronauts is shown collapsed for stowage in Fig. H-20. The flexible center section, made of material that can be folded, is extended by pressurization to a length long enough to accommodate a suited astronaut in a stretched-out position.

The PAL consists of two active ring-and-cone assemblies, an extendible cylindrical member, a cylindrical structure which encloses the collapsed flexible member, and a breathing and pressurization subsystem. The two

*This subsection is based on the work of K. G. Ludlow, Ref. H-5.

BASED ON NR DOCKING CONCEPT



WEIGHT ~1600 LB

STOWAGE VOLUME ~380 FT^3

Figure H-20. Portable Airlock

active ring-and-cone assemblies incorporate the docking mechanism and the hatches and are connected by the folded flexible cylindrical member. The airlock thus permits entry into the DV by an astronaut operating in an EVA mode or by direct transfer to the DV from a rescue vehicle docked to the opposite end of the portable airlock. A typical flexible material having the required structural and packaging properties is the Goodyear "Airmat." The PAL is extended initially by using the pressurization system which also provides the breathing atmosphere.

The docking hatches combined into the docking mechanism at each end of the portable airlock are identical in size and provide a clear 5.0 ft diameter opening for transfer of equipment. The two docking mechanisms are fastened together in the stowed position by the rigid cylindrical structural member which encloses the collapsed flexible member. The rigid cylindrical member incorporates a circumferential joint, located midway along its length, which is held together by spring loaded locks which are released either electro-mechanically or by the internal pressure used to extend the airlock into the operating position. The rigid cylindrical member also provides protection for the extensible material during stowage. Possible methods for retracting the airlock after use include telescopic tubes, cable retraction devices, extendible booms, etc. The stowed volume of the airlock is about 380 ft^3 and its weight is estimated at about 1600 lb.

H.3.2.2.3 Exit from DV

Much of what has already been discussed under transit and entry into the DV will, of course, also apply to the exit phase of the rescue mission. A PAL is as necessary to exit as to entry unless the rescue crew has been able to provide every member of the DV crew with a pressure garment, thus permitting the decompression of the DV compartment prior to exit. Pressure suits are also required if the vehicles are not docked. However, many medical situations can be postulated for a crew disabled by the emergency which may prevent dressing at least some of the DV crew in pressure suits.

Broken arms and legs are examples of such situations. In such an instance, the concept of a transfer capsule might be valuable. Such a device would also be stowed in the collapsed condition within the SRV in order to reduce storage volume requirements.

A capsule design concept for transferring men and equipment between the rescue vehicle and the DV is shown in Figure H-21. A North American Rockwell hatch design, featuring a hatch within a hatch, was selected as a representative design. The 5.0 ft outer diameter hatch corresponds to the transfer tunnel diameter used in the space station design. The inner auxiliary hatch is approximately 3.0 ft in diameter. This hatch is large enough to permit passage of a personnel carrier defined in Appendix G for transporting an injured astronaut. This inner hatch is also large enough for transporting emergency equipment into the crew transfer capsule. Modifying the North American Rockwell docking hatch to include a latch ring permits attaching the crew transfer capsule directly to the hatch, thus eliminating additional docking fixtures. This concept results in a smaller diameter attachment and reduced weight.

The transfer capsule consists of two major components, an inflatable member and a cylindrical metal shell structure approximately 36.0 inches long attached to the inflatable member. The part of the shell structure that attaches to to the DV hatch latch ring is designed to incorporate a number of docking latches located radially around the shell. These docking latches engage the inside lip of the latch ring and achieve attachment to the hatch in a manner similar to that described for the attachable docking fixture. An inflatable pressure seal is provided between the capsule and the hatch. The cylindrical metal shell structure contains a removal hatch that is mounted approximately midway inside the shell. The hatch is removable in a manner similar to the Gemini heat shield hatch. The inflatable section is inflated to a shape similar to that shown in the sketch by pressurizing the capsule with breathing atmosphere provided from high pressure storage containers.

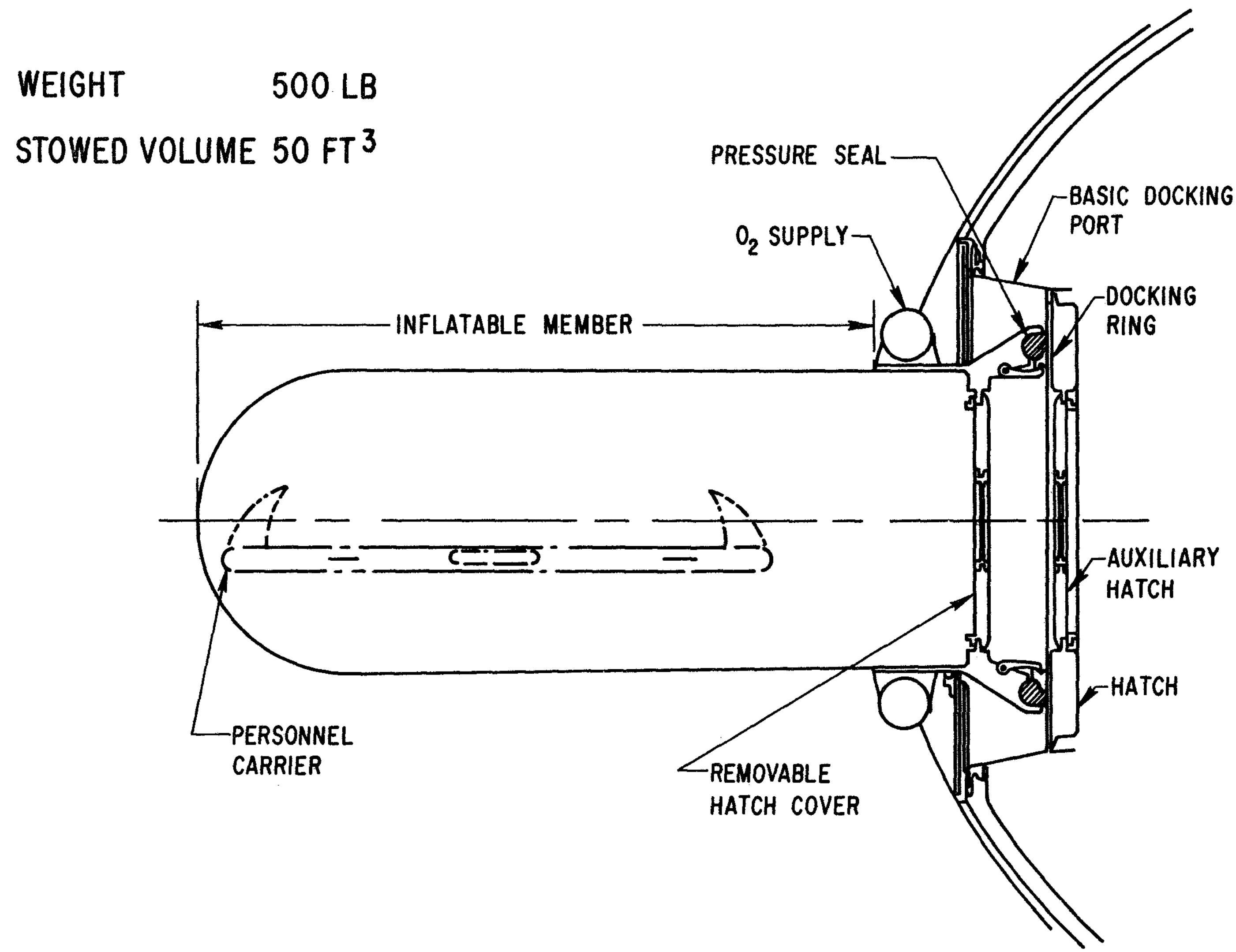


Figure H-21. Transfer Capsule for DV Crew

In the stowed position, the inflatable portion of the capsule is folded and packed inside the metal shell portion of the capsule. The stowed volume and weight are estimated at 50 ft^3 and 500 lb.

After the astronaut has been placed into the capsule, the hatches are resealed and the capsule is transported to the SRV by manipulators or by the rescue crew with AMU's. Attached to the SRV, the astronaut may be removed from the capsule or may be restricted to the capsule for a quarantine period, with life support provided from the SRV.

H. 3. 2. 3 Transfer by Docking (Ref. H-5)

The SRV may face several problems when attempting to dock to the DV. The problem of a tumbling or spinning DV has already been discussed. The use of despin devices may be effective in reducing this motion but it is likely that the motion will not be reduced to zero. This then results in the requirement that the SRV be capable of docking to a DV with some degree of residual motion, not all of which may be around a single axis of rotation. A more detailed discussion of this requirement is presented in Appendix I-3 with the most important conclusions repeated below.

The angular velocities and attitudes of the DV must be measured precisely and must be matched by the SRV. The same spin characterization system discussed earlier would be applicable here as well.

Forces and torques of docking under conditions of low residual motion are reasonable and can be accommodated with proper design.

Axial forces are reasonable for spacecraft not too excessive in weight and are similar to axial docking forces encountered in stable docking situations.

The residual DV wobble which is likely to accompany residual rotation will present a complex SRV control problem.

H. 3. 2. 3. 1 Docking Interface

A brief conceptual analysis was undertaken to determine whether SRV's could be equipped with soft docking fixtures capable of reducing the difficulty of docking to a DV with some residual wobble. The analysis was non-quantitative; stress analysis was not performed and the design was not matched to specific values of DV motion.

The soft docking fixture shown in Figure H-22 is configured to accommodate slight motions between the rescue vehicle and the DV. If the DV motions are greater than can be accommodated by the docking fixture, these motions must be reduced to a tolerable level. The concept calls for flexibly mounting the North American Rockwell docking design with a neuter docking device and a passive ring. The docking port on the DV is assumed to be a passive ring assembly. This concept could be modified into a ring/cone assembly which can be mated with another active ring/cone docking assembly to form a complete neuter docking subassembly.

Further study of this concept is required to derive methods for extending the flexible bellows toward the DV shell to provide a pressure seal and the correct stiffness at the flexible connection to minimize vehicle dynamic interactions resulting from differential vehicle motion. The weight increment of this type of docking fixture over the conventional design would be about 250 lb.

A damaged spacecraft implies the possibility of a situation where docking facilities are unavailable. If a space station is taken as an example, many of its docking ports will be occupied by experiment modules. Other ports may have logistic vehicles such as space tugs or the EOS docked to them. Finally, the emergency situation calling for rescue may have destroyed some of the ports or may have closed the passage between them and the space station compartment which the rescue crew is attempting to reach. EVA airlocks may be provided on the station but may not have been equipped with docking

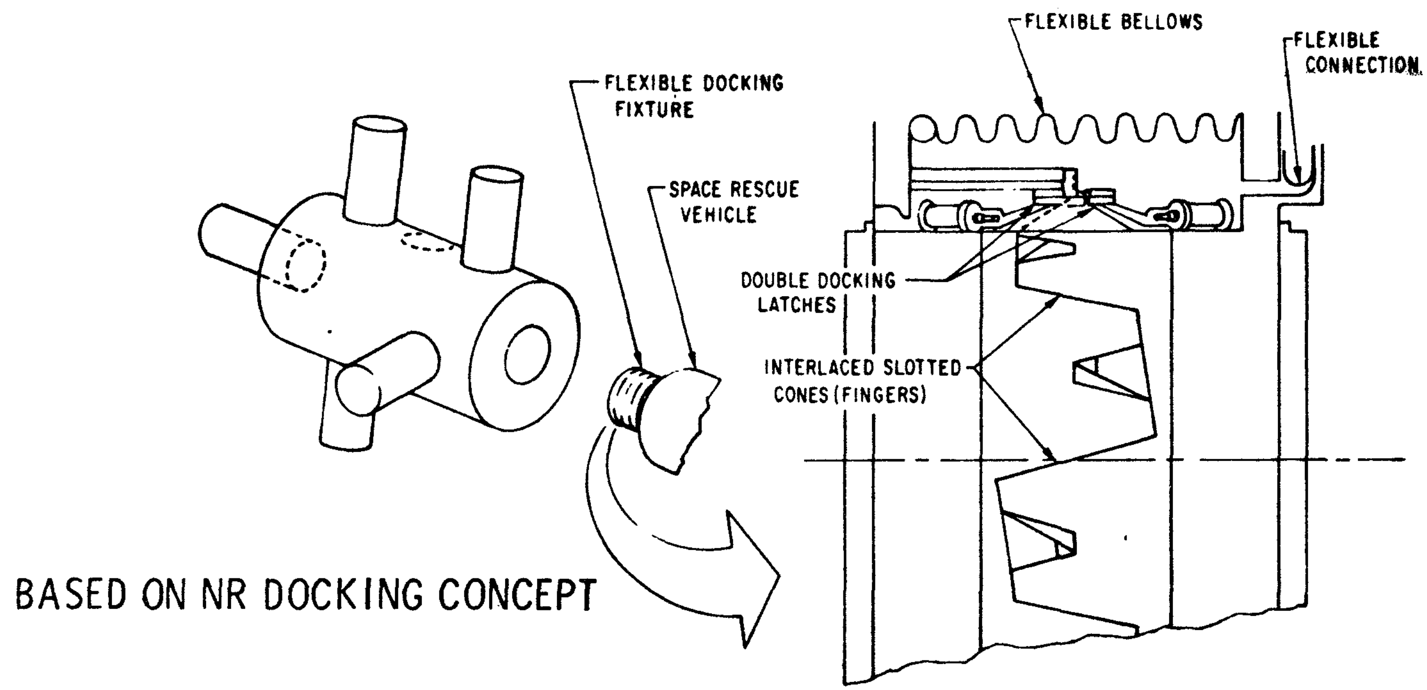
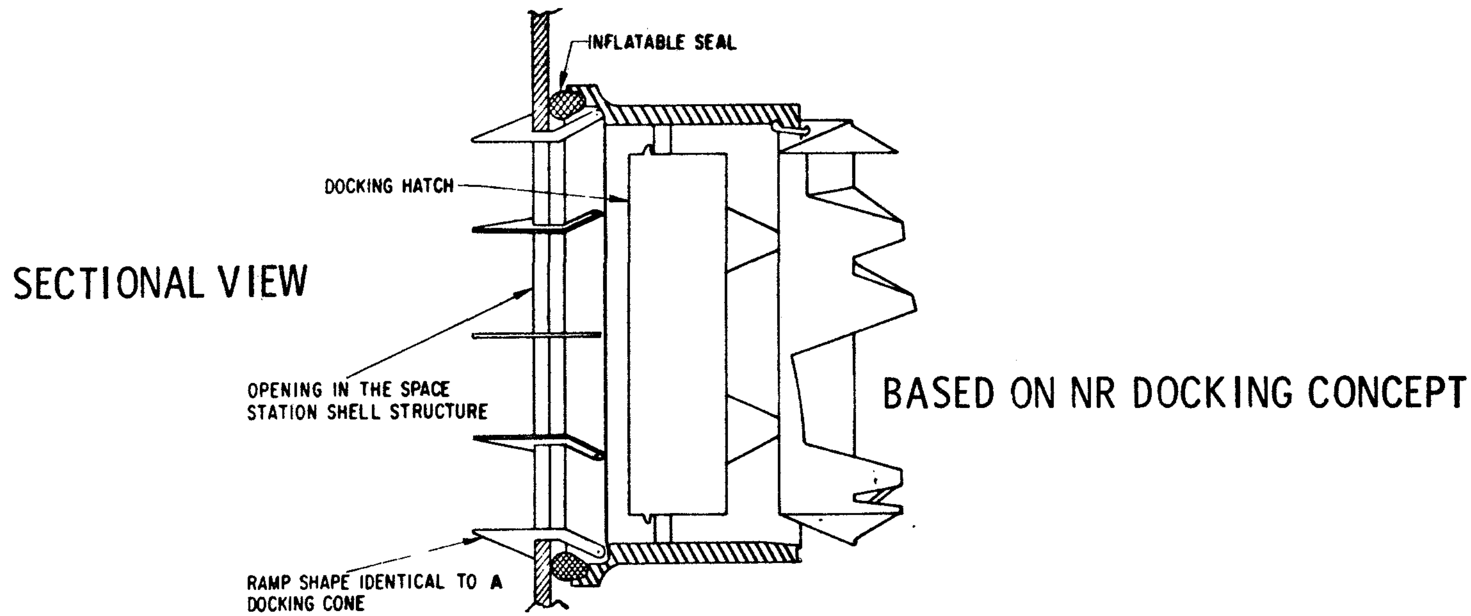


Figure H-22. Soft Docking Fixture

fixtures. The SRV may thus be faced with the necessity of creating an opening against which it could dock. In either case, that of an opening already available such as an EVA air lock, or that of an opening that must be cut into the hull, a docking fixture must somehow be placed over the opening to permit SRV docking. The concept of such a portable docking fixture was briefly investigated.

The portable, attachable docking fixture shown in Figure H-23 permits docking to a distressed vehicle via an EVA port. For purposes of this study, a 6-ft diameter opening, 12 inches larger than the standard hatch opening, was assumed. This larger opening permitted the use of the North American Rockwell docking design with minor modifications, and also permitted the use of ramp-shaped docking pawls identical in cross-sectional shape to the North American Rockwell docking cone. Space is also available for a standard 5 ft diameter hatch for transfer of personnel and cargo. The portable docking fixture is secured within the 6 ft diameter opening by the eight docking pawls located radially about the opening. The pawls are engaged initially at the pawl tips; continued movement of the fixture farther from the port opening causes the docking pawls to rotate over center about the pivot points as pressure is exerted on the ramp portion of the pawl. The pawls continue to rotate about their respective pivots until the end points of the ramps have been reached; the spring-loaded pawls then snap into place behind the DV opening, thus securing the fixture between the back face of the pawl and the docking fixture seal face. An inflatable seal between the seal face and the DV port area prevents pressure loss as the DV is repressurized. Retraction of the locking devices to permit withdrawal is provided through the use of electromechanical or completely mechanical devices.

The basic concept can also be applied to an opening specifically cut into the pressure hull of a space vehicle, providing the structure had initially been designed to permit this. Section H-3. 3. 3, dealing with damage control, provides some discussion of this point.



WEIGHS ~ 800 LB

STOWAGE VOLUME ~ 265 FT^3

Figure H-23. Attachable Docking Fixture

The weight of such a portable docking fixture is estimated at 800 lb, with a stowage volume of about 265 ft^3.

H. 3. 2. 3. 2 Atmospheric Incompatibility

Another problem which may on occasion interfere with a docking transfer is that of dissimilar atmospheres between the SRV and the DV. For example, the SRV may be at 7 psia to reduce acclimation time requirements prior to performing EVA in a 3.5 psia pressure suit. If the DV is operating at 14.7 psia sea level atmosphere, docking transfer between the vehicles requires an airlock. If such an airlock is not available behind a docking hatch on either vehicle, the compartments on each side of the docking hatch could be adjusted to match pressures and composition. If the equipment for such atmospheric changes is not available or functioning, the portable airlock already discussed in Section H. 3. 2. 2. 2 could be used. As a general principle, a SRV with slightly higher pressure than the DV is preferred to reduce chances of SRV contamination.

H. 3. 3 Damaged DV

The possibility is real that the emergency situation requiring a rescue mission has also caused damage to the DV. Such damage may require additional operations to be performed by the rescue crew before the DV crew can be aided and removed from the DV. These additional operations will involve a survey phase to determine the extent of the damage and to permit planning of the damage control effort. Operations to permit entry to the DV in the event conventional entry methods can not be used may be required as well as damage control itself. The survey phase has already been discussed in Section H. 3. 1. 2 in connection with the problem of lack of communications with the DV crew. Some additional detail concerning equipment aids for such a survey follows.

H. 3. 3. 1 Survey*

A damage survey from either the exterior of the DV or during an interior exploration of the DV would attempt to determine both the past occurrence of events as well as the current status of the DV. Past events of interest to the rescue crew relate to the incidence of fire, contamination, explosion, and decompression. Current status refers to the presence of fire, contaminated atmospheres, lack of atmosphere, and the capability of various onboard systems. Additionally, a rescue crew would wish to know whether onboard emergency systems are functioning and can be activated by the rescue crew, where the DV crew is located, and what the condition of the DV crew is. It would, of course, be preferred if the DV had been designed with sensing equipment which would record such events and the degree of the resulting damage, and which would also monitor current status. Interrogation of such sensing equipment by RF command over telemetry links would be desirable. In the event that RF communications could not be established, sensor readout repeaters located in accessible areas, such as the exterior of entry hatches, would be read visually or through plug-in readout devices as already mentioned.

Major onboard and rescue crew sensor requirements in this category are discussed below.

H. 3. 3. 1. 1 Fire Detection and Alarm

Various fire detection systems have been considered for past, current, and future spacecraft. The five most feasible, as indicated by recent NASA "Fire Hazards Steering Committee" studies, include ultraviolet (UV) detectors, correlation spectrometers (analysis of constituents, such as CO and CH_4), smoke detectors, condensate nuclei counters, and continuous wire (CW) overheat detectors. A system suitable for future programs (and currently planned for the Skylab program) involves the use of multiple UV detectors located throughout the vehicle combined with a CW overheat detector warning

*This subsection is based on the work of M. Donabedian, Ref. H-6.

circuit for wire bundles. This detection concept can be combined with a visual and audible alarm system which alerts the DV crew that some positive action is required and which records and monitors status for the rescue crew.

H. 3. 3. 1. 2 Atmosphere Contaminant Sensing

A cursory review of atmospheric contaminant sensing devices was also made. Candidate trace contaminant sensing devices useful for spacecraft application include a gas chromatograph, mass spectrophotometer, IR spectrophotometer, colorimetric indicators (chemical), and oxidation rate sensors. Based on previous studies made at Aerospace (Ref. H-7) and a literature review, the use of an IR spectrophotometer or a gas chromatograph appears to be the most attractive concept for onboard systems.

For use as a backup system or for use by rescue team members, colorimetric indicators appear to be the most attractive concept. These devices consist of two parts; a bellows-type hand operated pump which draws a sample of gas, and a gas detector tube which has a calibrated scale in $mg/meters^3$ or in percent. The presence of a toxic gas is indicated by a color change of the chemicals within the tube. A large number of tubes designed for different types of gases are available and the tubes are disposable. This concept has application to situations where a simple, portable detection system is required.

H. 3. 3. 1. 3 Oxygen and Total Pressure

Other sensing and alarm system requirements include oxygen partial pressure sensing and cabin total pressure sensing. Both visual and audible alarm systems should be included. The oxygen sensing alarm should be triggered at approximately 2.75 psia as should any significant change in total cabin pressure.

H. 3. 3. 1. 4 Radiation Monitoring

Radiation monitoring and alarms should include a variety of equipment. A particle spectrometer would normally be provided externally to monitor increases in particle flux primarily resulting from solar flares. A normal threshold level above the background would be selected to provide a visual and audible alarm to the crew of potentially hazardous increases. In addition, a portable direct reading instrument to monitor interior radiation levels is required for both onboard and rescue crew use. As a final item, passive dosimeters should be provided for each member of DV and rescue crews and worn on clothing and pressure garments to maintain a record of accumulated body dose.

H. 3. 3. 2 Entry Into the DV

The normal entry hatches and airlocks of the DV may not be available, either because of damage from the emergency situation, or blockage by objects such as experiment modules or inactivated logistics vehicles. In such cases, prior design provisions as well as special equipment brought by the rescue crew could be of assistance in gaining entry.

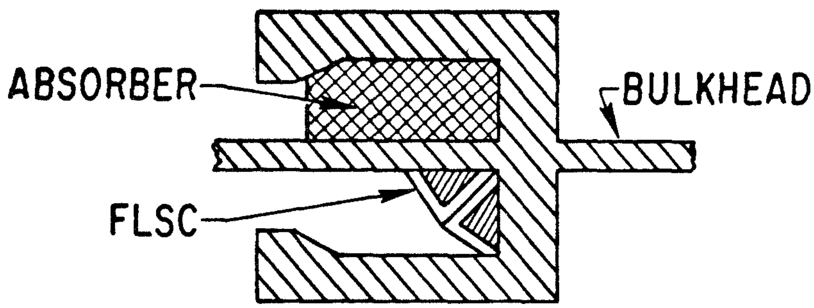
A double hatch design, such as recommended by North American Rockwell for the space station, is considered desirable from the rescue point of view. This hatch consists of an outer latch ring of 5 ft diameter. If functioning, this latching system would be activated to yield the larger, preferred opening. If DV damage has made this outer latching system inoperative, a 3 ft diameter inner hatch can be removed, offering sufficient diameter to enter and exit from the DV under emergency conditions. This approach also calls for sizing of emergency equipment likely to be brought on board by the rescue crew to a maximum dimension of 3 ft. Although the primary mode of operation for both hatches is manual, an explosive actuation mode should be provided for backup. If safety considerations make permanent installation of explosive ordnance undesirable, the design should permit insertion of the explosive actuator from the exterior of the hatch by the rescue crew.

In order to ease entry into the DV when hatches are not available, appropriate design provisions are required. Cutting through an exterior bulkhead utilizing hand tools operated by crews in EVA would be extremely difficult. Although the use of force-augmenting manipulators would assist such an operation, pre-design consideration of such a need could make it possible for a rescue crew to manually perform this operation easily and quickly. A concept for utilizing a flexible linear shaped charge (FLSC) for this application is shown on Figure H-24 (Ref. H-8). It would require bulkheads and outer walls designed for penetration by providing designated and clearly marked sections not containing service lines vital to the DV, and incorporating built-in charge holders as indicated. Both charge holder channels on either side of the bulkhead would initially be filled with coherent strips of absorber material which could be easily removed by the rescue crew from the exterior, or the DV crew from the interior. Depending upon the need, either crew would then insert an FLSC into the channel accessible to it. Activation of the charge would cut both the bulkhead as well as the channel root, permitting removal of the cut section of bulkhead. The absorber on the opposite side of the cutting charge would prevent blast and fragmentation damage to the compartment being entered.

It is estimated that, for current types of bulkhead construction, an FLSC weighing about 0.05 lb per linear foot would supply sufficient cutting action. The total added structural weight to the bulkhead would amount to about 5 lb for a 3-ft diameter opening.

This cutting method is applicable to exterior walls as well as interior bulkheads.

The equipment brought by the rescue crew depends, of course, upon knowledge of the design provisions of the DV. For the concepts indicated above, only the explosive ordnance need to be brought. Prying tools may also be useful in the unjamming of slightly damaged latching mechanisms. Drilling tools would be useful in creating sampling ports, if not already provided, in order to check the atmosphere behind the latch or to bleed down the interior compartment prior to creating the opening. Instead of a drilling tool, an explosively actuated punch could also be used, offering easier manual operation



FLSC = FLEXIBLE LINEAR SHAPED CHARGE

Figure H-24. Penetrable Bulkhead Design

and lower weight. The use of the FLSC approach, for example, would not be feasible if the compartment behind the bulkhead to be penetrated were filled with a combustible or explosive atmosphere. The pressure differential across the bulkhead should be minimal to avoid damage due to explosive decompression, and crew hazards due to rapid fragment expulsion.

H.3.3.3 Damage Control Within the DV*

Desirable items under this category include fire suppression equipment, capability for remote decompression and recompression of the primary pressurized volumes, and the capability for remote power shutdown and activation of emergency power systems by either DV or rescue crews. The most practical fire suppression equipment involves the use of a small portable (approximately 8 lb per unit) water/foam extinguishers. Remote depressurization/repressurization capability is desired to permit the rescue crew to perform necessary actions on the affected compartment from remote locations, such as airlocks or adjacent compartments, after personal safety has been assured. Typical situations requiring this type of action might be a decompression, fire, or smoke or other contamination. Remote power shutdown capability would be a significant aid in minimizing the extension of such events to other compartments.

Design provisions could be incorporated into the DV which would permit the rescue crew to power-up as well as to command operations such as described above.

Barring the ability to remotely command such operations, it remains for the rescue crew to perform them manually or with mechanical and powered aids. Firefighting would have to be performed by the portable units discussed above, if depressurization of the affected compartment were not practical. Depressurization by venting to outer space is preferred, however, and could be

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*This subsection is based on the work of M. Donabedian, Ref. H-6, and A. A. Hanson, Ref. H-8.

accomplished by manual opening of valves accessible to the rescue crew or by punching or drilling holes as already discussed in the previous section. Depressurization to outer space would deal effectively with smoke or vapor type decontamination. Nuclear radiation decontamination would require the ability to wash down affected equipment or bulkheads, and/or the cutting out and removal of radioactive components and materials. Although feasible, this approach is not necessarily easily accomplished or fully effective. Radiation decontamination would also require protection for the rescue crew in the form of portable shielding such as leaded aprons, estimated to weigh about 50 lb each.

Cutting structure, either for the purpose of decontamination or to clear a path through an area which suffered explosion damage, will require power tools developed for space application in addition to explosive devices such as FLSC.

References H-9 and H-10 report the results of design and development studies in which prototype power tools, hand tools, and kit assemblies were tested and evaluated. The power tools were electrically powered from a kit-contained battery pack, and performed such operations as drilling, hole cutting, linear sawing, and torquing. The design reported in Ref. H-9 imparted negligible reaction to the operator, and could be operated in a hands-off mode for most functions. Table H-43 lists the contents of the tool kit. (Note the inclusion of a work light.) This kit weighs about 40 lb.

Decontamination for bacterial infection requires a chemical kit, the content of which of course would be tailored to the type of bacterial infection to be expected. An allowance of 10 lb for disinfectant to be brought with the SRV is probably sufficient.

Reference H-11 reports a detailed study and experimental program for the design of a remotely operated manipulator unit (RMU) capable of performing

Table H-43. Tool Kit Contents (Reference H-9)

1. Motor Unit
2. Impact Attachment
3. Socket - 1/2 inch drive - 3/4-inch
4. Socket - 1/2-inch drive - 5/8-inch
5. Socket - 1/2-inch drive - 9/16-inch
6. Socket - 1/2-inch drive - 1/2-inch
7. Socket - 1/2-inch drive - 7/16-inch
8. Socket Holder
9. Extension Bar - 5 inches
10. Saw Attachment
11. Spare Saw Blades
12. Saw Blade Holder
13. Allen Wrench - 3/32-inch
14. Allen Wrench - 1/8-inch
15. Drill Attachment (Trepanner)
16. Saw - 5/8-inch diameter (2)
17. Saw - 1/2-inch diameter
18. Saw - 3/8-inch diameter
19. Saw - 5/16-inch diameter
20. Saw - 1/4-inch diameter
21. Needles
22. Hammer 1-1/4 pound dead blow
23. Screwdriver Ratchet Handle - 1/4-inch drive
24. #2 Phillips Head Bit
25. Short Bit - 1/4 x. 032
26. Extension Bar - 6 inches
27. Work Lights - 6.9 Watts (2)
28. Adhesive Restraint Buttons
29. Applicator Holder
30. Applicator Control Unit
31. Applicator Temperature Sensor Electronics Package
32. Storage Rack
33. Restraint Button Attachment Cables
34. Small Parts Manipulator
35. Small Parts Holder
36. Battery - 12 Volt - Silver Zinc Cells (8) - 163 Watt Hours
37. Battery Case - Pressurized to +6 psi differential
38. Astronaut Tether

maintenance, repair, and damage control operations on orbiting spacecraft. The RMU could be controlled from the SRV. This manipulator vehicle contains such subsystems as illumination, television, communications, power, propulsion, attitude control, and thermal control. It is delivered to the DV location by the SRV in a folded configuration (all appendages in stowed positions). Figure H-25 depicts the configuration and reflects small changes made to the design described in Ref. H-11 in order to configure an RMU for space rescue.

Larger, manned manipulators, already discussed in Section H.3.2.2.1 would also be useful in a damage control situation, but because of size would probably be restricted to exterior work.

Table H-44 summarizes the major items of damage control equipment and their stowed volumes which an SRV might have to carry on a rescue mission.

H.3.4 Medical Needs

A detailed discussion of incidence of illness and injury, and consequently required medical supplies and equipment, both on board and to be brought by the SRV, are provided in Appendix G in this report. This section merely summarizes the conclusions of that appendix.

The specific medical objectives of the rescue mission are to prevent deterioration of a medical problem and to permit transport of the disabled crew to the SRV. It is also intended that, if required, additional medical aid be provided aboard the SRV to enable the affected crew to survive until arrival at a safe haven where full-scale medical assistance should be available. The amount of equipment to be carried with the SRV thus depends in part upon estimates of likely emergencies, upon the available medical supplies and equipment within the DV, and also upon the degree of self-help possible by DV crew. If the DV is a space station/space base, considerable self-help should be possible unless the emergency situation has destroyed that capability.

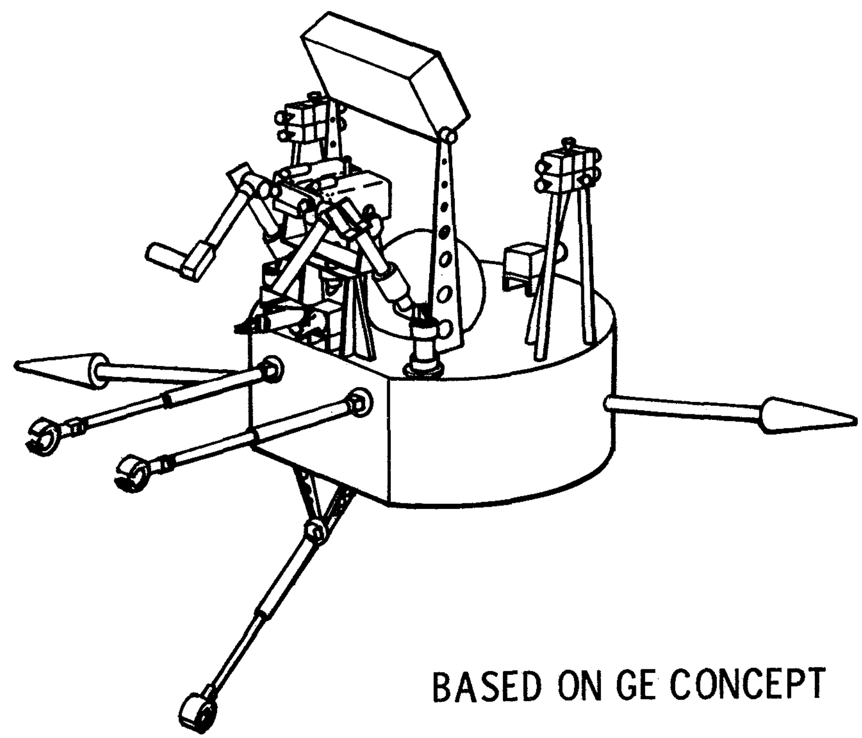

Figure H-25. Remote Controlled Manipulator

Table H-44. Damage Control Equipment

Requirement	Means	Unit Weight, lb	Stowage Vol., ft^3
Fight fire	Depressurize		
	Valves on DV	--	--
	Tool for drilling holes	40	1.00
	Extinguisher	8	0.40
Decontaminate			
Toxic gases	Depressurize (as above)	--	--
Bacteria	Chemicals	10	0.50
Radiation	Cutting and Jettisoning		
	Tool	(as above)	(as above)
	Portable shield	50	1.00
To clear passage			
Interior	Tool (as above)	(as above)	(as above)
Exterior	Manipulator (manned)	2000	70
	Manipulator (remote controlled)	1000	40

Transporter vehicles within the IP, such as the EOS, the Tug, and the Space Shuttle, will have minimal first aid capability but no effective surgical or other treatment facilities. In addition, although medical personnel may be available on the space station/space base, it is not likely that transporter vehicle crews consisting of two to three men will include a medic.

The medical equipment to be carried aboard the SRV will fall into two categories, kits which can be carried by the SRV crew into the DV and equipment and supplies which remain on board the SRV. The material to be carried into the DV will consist of essentially first aid equipment and aids such as personnel carriers for transport of injured personnel.

Table H-45 summarizes medical kit requirements and indicates those items which will remain aboard the SRV. Because of the nature of the possible illnesses and injuries, a medically trained rescue crew member would seem highly desirable. Consideration might also be given to equipment which might allow assistance from the ground in the diagnosis of medical emergencies. Diagnostic instrumentation should be developed for use by the rescue crew which either provides a direct RF telemetry link with the ground or a voice link, for the purposes of obtaining expert prognosis and treatment prescription from a medical specialist. Such equipment might be desirable whether or not medically trained personnel were included in the rescue crew.

H.3.5 Miscellaneous Equipment

In addition to the major equipment categories described above, a SRV may be required to carry a variety of miscellaneous items intended to facilitate its mission.

Table H-45. Medical Kits

Content	Unit Wt., lb
Drugs & Medication Kit	2.5
Intravenous Fluids Kit	15.0
Dressings, Packings, Bandages Kit	2.0
Suture Kits	1.0
Incision & Drainage Sets	1.0
*Dental Kit	8.0
*Tracheotomy Kit	0.5
*Surgical Kit	2.5
*Inflatable Splints	0.5
*Miscellaneous	3.0

* Remains on SRV

Note: Items to be carried onto the DV weigh about 35 lb

H.3.5.1 Extended Survival (Ref. H-6)

Survival depends, of course, upon the availability of breathing oxygen, food and water, and some degree of control of the atmospheric pressure and constituents as well as the temperature of the environment. It can be enhanced by special equipment provided by the SRV or prepositioned in the DV.

H.3.5.1.1 Portable Oxygen Source

In addition to a spacecraft's primary source of oxygen, a secondary supply for short-term usage will normally be stored aboard the spacecraft against the event of a malfunction of the primary supply. However, in certain instances an oxygen supply that can be transferred from a rescue vehicle may be required to provide additional time to the crew of a disabled spacecraft.

Oxygen can be stored as a high-pressure gas, as a cryogenic liquid or solid, or can be obtained from solid chemical sources. Some of the characteristics of each type of system will be discussed first in general terms. Specific details and various tradeoff criteria will then be examined to determine the most appropriate concept.

H.3.5.1.1.1 High-Pressure Gaseous Oxygen

In addition to the storage container weight and bulk, compressed gaseous oxygen requires substantial regulating equipment with attendant periodic maintenance, frequent quantity checks, and recurring logistics to replace the inevitable losses even though the system may not be used for weeks or months at a time. A high-pressure system also poses a fire and rupture hazard.

H.3.5.1.1.2 Cryogenic Liquid Oxygen

Liquid oxygen provides substantial weight and volume saving over a gaseous O_2 supply. In the supercritical state, it has been widely used in past manned space programs and in the subcritical state is used in military and some commercial aircraft. Cryogenic storage system requirements are extensive, including need for insulation, pressure regulation, and heat control. In addition, the losses due to tank venting which may range from one to five percent per day, become prohibitive as storage time increases.

H.3.5.1.1.3 Cryogenic Solid Oxygen

Many problems associated with the storage of cryogenic liquid oxygen can be avoided by the use of cryogenic solid oxygen. Although storage of solid oxygen has not been studied extensively, some experimental work has been accomplished on solid storage of nitrogen, argon, and carbon dioxide. That technology is directly applicable to solid oxygen.

The major advantages of solid oxygen over liquid oxygen are reduced storage pressure, higher storage density, and lower venting losses. Recent experimental studies (Ref. H-12) show that this concept is technically feasible and offers a potential for increased storage time when compared with liquid oxygen. Engineering design problems remain and are associated with pumping of the low-pressure vapor to a condition suitable for breathing purposes.

H.3.5.1.1.4 Chemical Oxygen Sources

Solid chemical oxygen sources offer appreciable weight and volume savings over liquid chemical O_2 sources in continuous flow operations and avoid the problems of cryogenic sources. In demand systems, liquid and solid chemical oxygen weight and bulk are more nearly equal. Solid chemical oxygen offers indefinite storage life and therefore a valuable logistics improvement. In some applications, it totally eliminates regulators, reducers, valves, gauges, complex containers, and system leakage maintenance problems. It offers considerable safety improvement with respect to fire. It is virtually free from pressure and contamination hazard and presents no low-temperature fluid problem.

Two types of solid state chemical oxygen sources warrant serious consideration for use in spacecraft emergency oxygen systems. These are the active sodium chlorate generators and the passive alkali metal superoxide generators.

H.3.5.1.1.4.1 Sodium Chlorate Generators

The idea of using alkali chlorate to produce breathing oxygen is not new. During World War II, the Japanese used chlorate generators for fighter plane oxygen supply. For a number of years, the United States Navy has been using chlorate candles as an emergency oxygen source in conventional and nuclear submarines (Ref. H-13).

These submarine oxygen generators are called candles because of their resemblance to conventional candles in appearance. They are dark grey cylindrical blocks compressed or cast of an intimate mixture of sodium chlorate salt and finely divided iron. Each 26 lb block is 6.6 inches in diameter and 11.4 inches long, and produces 121.8 cubic feet (at standard temperature and pressure) of oxygen gas over a period of about 45 minutes or a total oxygen mass of approximately 10 lb.

The equivalent mass of one such candle configured in small diameter cylinders would provide oxygen necessary to support 12 men for about eight hours. To initiate the process, a simple phosphorous match is rubbed mechanically against an iron starting plug embedded in the top of the candle. Because of the extreme simplicity and reliability of the system and the indefinite storage life, this approach appears to be the most attractive for portable emergency oxygen systems. The burning rate of these candles can be tailored to the desired requirements merely by changing the cross sectional area of the moulding. Contaminants produced by the reaction, such as CO, can be controlled to the necessary levels by the use of catalytic filters.

H.3.5.1.1.4.2 Alkali Metal Superoxide Generators

The second type of solid chemical oxygen supply is the passive alkali metal superoxide. Potassium superoxide has been used for many years in one-man, closed circuit, rebreather systems for use in non-breathable environments, chiefly in mines, submarines, and fire fighting applications. These materials are believed to constitute the primary oxygen supply for the Russian manned space vehicles.

These superoxides may be supplied as beds of granules, pressed discs, corrugated plates, etc., through which air containing the exhalation products of water and carbon dioxide is passed. Circulation of this expired air may be effected by lung power or by auxiliary blowers. The superoxide absorbs the water and carbon dioxide in any one of a large number of complex reactions depending upon the local condition. The gaseous product of these reactions is pure oxygen which is released into the passing air. Unless some of the water is removed from the expired air prior to passing it through the superoxide, an excess of oxygen is produced which gradually enriches the closed atmosphere.

The three principal materials that have been found to be potentially feasible are:

(1) KO_2 (potassium superoxide)
(2) Li_2O_2 (lithium peroxide)
(3) NaO_2 (sodium superoxide)

After many years of research at the Aerospace Medical Research Laboratories at Wright-Patterson AFB, Ohio, a number of development type units have been made and tested (Ref. H-14). KO_2 units utilizing pressed discs and corrugated plates weighing as little as 12 lb have been successful in controlling CO_2 and humidity while providing the necessary oxygen for one man for up to 24 hours in a sealed capsule (Ref. H-15).

H. 3. 5. 1. 1. 5 Concept Comparisons

Weight and volume comparisons of the various concepts discussed are presented in Table H-46. Basic characteristics and various advantages and disadvantages of the four basic concepts are summarized in Table H-47. The initial weight penalty per unit of oxygen stored is lowest initially for the cryogenic liquid and solid. However, due to the continuous boil-off and sublimation losses, respectively, the weight becomes prohibitive for periods beyond a few months. In such an application, the solid chemical sources become the most attractive from both a weight and storage volume standpoint. Considering all factors with emphasis on indefinite storage life, reliability, and simplicity, the sodium chlorate generators have been selected as the most attractive concept. Using this concept, a total system weight of approximately 100 lb, including 22 lb for filters and controls, will provide the oxygen necessary to support 12 men for up to 24 hours.

H. 3. 5. 1. 2 Portable EC/LS

For periods longer than 24 hours, the use of oxygen alone will be insufficient for a crew atmosphere. CO_2 removal is also required and temperature and humidity control must be provided. In addition, if the planned atmosphere for the IP vehicles is 14. 7 psia of a sea level mixture of oxygen and nitrogen, it may be desirable to maintain this atmosphere. A brief concept analysis was made to develop pertinent characteristics of a system meeting these needs and capable of being moved by the rescue crew into the DV upon demand.

The selected EC/LS system, shown schematically in Figure H-26, is a closed (i. e., processed atmosphere) shirtsleeve system. Carbon dioxide (CO_2) removal and oxygen generation is provided by potassium superoxide (KO_2) while a condensing heat exchanger (condenser/sublimator) is used for humidity and temperature control. A high-pressure air supply is provided for initial pressurization and for purging if the atmosphere is contaminated.

Table H-46. Weight and Volume Requirements for Portable Oxygen Sources

Source	Weight lb O_2/lb Source*	Storage Volume ft^3/lb O_2 Contained	Previous Application
High-pressure Gas (2,000 psi)	0.40	0.10	Aircraft O_2 cylinders
Cryogenic Liquid			
storage requirement 20 lb	0.50		Commercial converters
storage requirement 200	0.70	~0.014	Development units
storage requirement 1,000	0.80		MOL/Apollo
Cryogenic Solid	≥0.80	~0.012	Laboratory system
Solid Chemical			Submarines, mines, self contained breathing apparatus, proposed for aircraft
sodium chlorate candles	0.45	0.018	
potassium superoxide	0.34	0.072	

*Oxygen plus container weight

Table H-47. Portable Oxygen Supply Characteristics

Source	Characteristics
High-Pressure Gas	High storage container weight/volume Good reliability Requires regulators/valves/ maintenance Safety hazard
Cryogenic Liquid	Low weight/volume Average reliability Requires complex heaters/controls/ regulators Maintenance/boil-off restricts storage life Safety hazard
Cryogenic Solid	Low weight/volume Requires controls/pumps/regulators Unknown reliability Limited storage life
Solid Chemicals sodium chlorate generators alkali metal superoxides	Good weight/volume Extreme simplicity/reliability No maintenance Easily transportable Indefinite storage life Complete safety

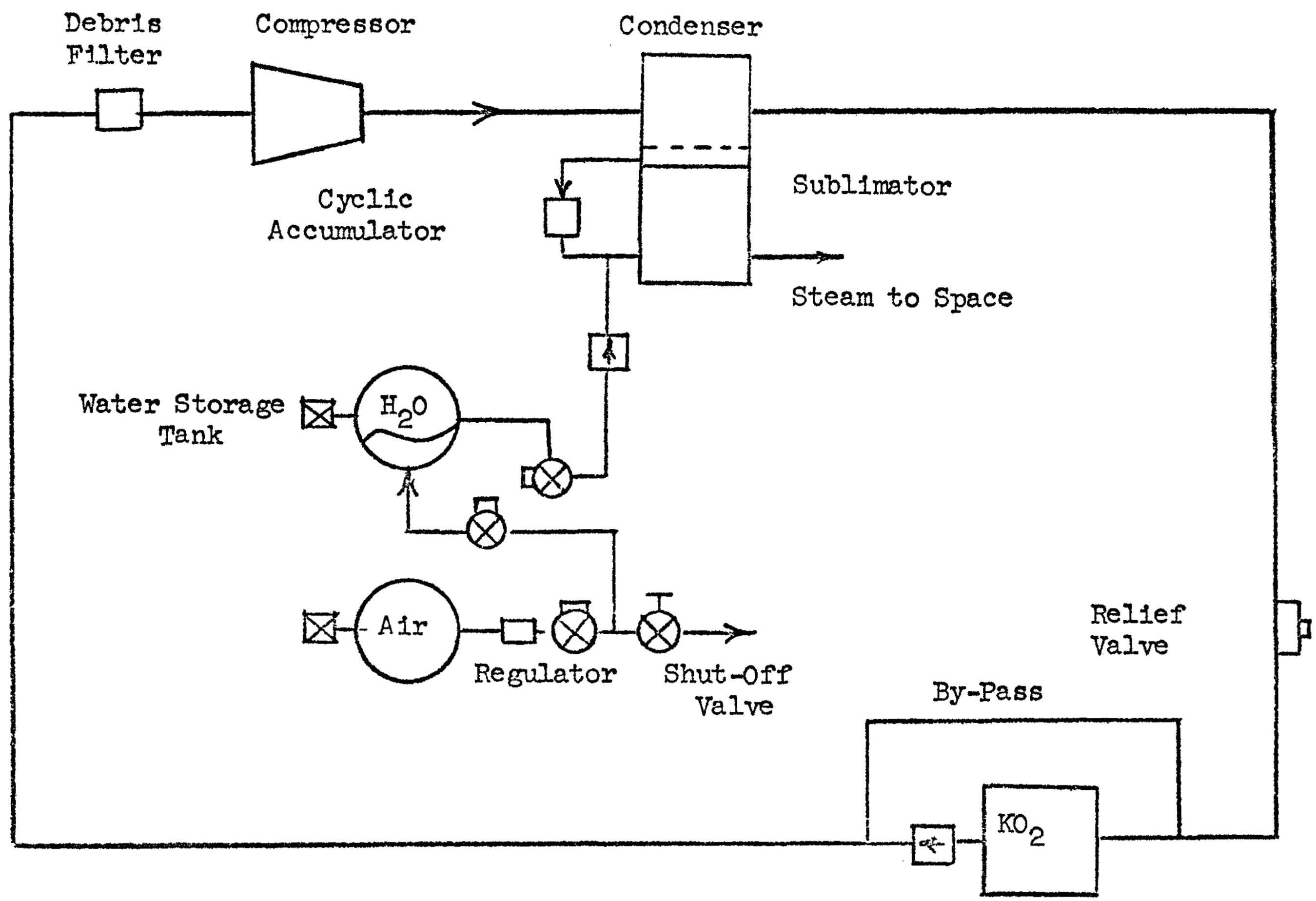

Figure H-26. Portable EC/LS System

The rationale for this system selection was based in part on a number of tradeoff studies conducted by North American Rockwell (Ref. H-16) on similar EC/LS requirements for a Space Escape Vehicle. Various types of open and closed systems were evaluated. For this type of application where a long inactive storage period may exist, the solid chemical systems are again most attractive and also are weight and volume competitive with stored high-pressure gas or cryogenic systems of this size. KO_2 and sodium chlorate ($NaClO_3$) are the two most attractive chemicals. KO_2 has the further advantages of being metabolically controlled, as water and CO_2 are absorbed in the reaction to yield oxygen, while $NaClO_3$ produces only oxygen. However, on a weight and volume basis, $NaClO_3$ has a definite advantage per unit yield of oxygen. Where only an oxygen source is required and other provisions are available for CO_2 removal, $NaClO_3$ is, therefore, preferred over KO_2.

The requirement for a self-contained portable EC/LS system that can sustain 12 men for up to 48 hours was established as a baseline. Utilizing an overall average metabolic rate of 400 Btu/hr, the total system weight, including expendables, was estimated at 475 lb. Based on an average requirement of 100 watts, the power supply utilizing silver-zinc batteries was estimated to weigh 50 lb. The entire EC/LS package, including power supply, requires a 3-ft-diam cylinder approximately 3-1/2 ft long.

Survival for at least 48 hours is aided by food and water. Based on a minimum of 3 lb/man-day of water and 1 lb/man-day of food, a total of 96 lb of provisions would sustain 12 men for 48 hours.

H. 3. 5. 2 Other Equipment Items

Another useful equipment item is a device to reduce sparking between docking vehicles or between EVA crew and vehicles being contacted.

No information was found in the literature concerning equalization of electric potentials among adjacent or mating space vehicles and/or astronauts.

However, appropriate measures had been taken in the Gemini program when the Gemini and Agena stages mated. Space vehicles typically reach a low voltage (on the order of 3 volts) as a consequence of passage through the electron plasma in orbit. In some instances, such as where the vehicle shape is elongated and/or possesses grossly irregular features, potentials as high as 200 volts can be reached. A DV with an electrical malfunction could also reach a high surface voltage. Similarly, an astronaut involved in EVA can reach a potential differing from his mother ship.

The Gemini was equipped with a dissipative element (resistor) which contacted the Agena just before docking was completed, thus equalizing the potentials. Such a unit should be provided as part of the basic SRV configuration as well. Furthermore, the astronaut in EVA should utilize such a device before coming into close contact with either the DV or SRV. It is estimated that a 15-megohm, 10-watt resistor would easily accomplish this purpose. A small kit including such a resistor and short leads and attachments or probes would weigh about 3 lb.

Other miscellaneous equipment items to be carried on an SRV are shown in Table H-48.

H. 3. 6 A Special Rescue Vehicle

The previous sections of this Appendix have discussed the special equipment requirements of a space rescue vehicle without discussing the characteristics and configuration of the SRV itself. The selection of this vehicle configuration was treated under another task of this study and considered a number of factors, including utilization of planned IP elements. However, the exploration of the equipment requirements reported in this Appendix have given clues concerning idealized characteristics of an SRV with respect to maneuvering and docking requirements, storage requirements, and operational characteristics.

Table H-48. Miscellaneous Equipment

Equipment	Characteristics	
	Unit Weight, lb	Stored Volume, ft^3
High-Intensity Portable Light	5	0.25
Flashlight	0.3	0.10
Resistor Kit	3	0.25
Personnel Carrier	10	0.75
EVA Suit	70	4.50
IVA Suit	15	1.50
O_2 Mask, Emergency	3	0.25
O_2 Mask, Full Face	4	0.25
EVA Umbilical	45	2.00

The SRV may have to operate in several mission regimes, i.e., low-earth orbit, geosynchronous orbit, and lunar orbit, and may have to dock to a variety of IP elements of varying bulk and configuration. The most desirable concept appears therefore to be one of a relatively small, highly maneuverable vehicle with propulsion capability limited to that required for terminal rendezvous and docking with the DV. This requires that the vehicle be transported close to the DV by another element of the IP such as the EOS, the Space Tug, or the Space Shuttle. In order to be transportable by the EOS, the SRV configuration must be compatible with the cargo bay of the EOS. This is probably the configuration-limiting requirement, since dimensional limitations imposed by on-orbit transportation are considerably more liberal.

The crew/cargo module envisioned for use with the EOS has similar configurational requirements and appears to offer a suitable baseline configuration for application to the SRV. How such a crew/cargo module could be modified to serve as the SRV is briefly described in the following paragraphs.

An artist's conception of the SRV is presented in Figure H-27. This vehicle is capable of performing the maneuvers necessary to dock with a DV and houses rescue equipment necessary to perform specific emergency operations. The SRV conceptual arrangement is comprised of three distinct compartments: a partially pressurized forward compartment, an unpressurized center compartment, and a pressurized aft compartment. A centrally located crew transfer tunnel extends from the forward docking fixture to the aft compartment thus allowing crewmen to enter the aft compartment when the rescue vehicle is docked to a DV by the forward docking fixture.

The forward section includes an environmentally controlled two-man crew compartment. This compartment includes visual displays (TV, sensor and instrumentation, etc.), maneuvering controls, a manipulator control console, EVA hatch, etc. In addition to the EVA hatch, another entry hatch connects to the centrally located crew transfer tunnel to provide access to either the

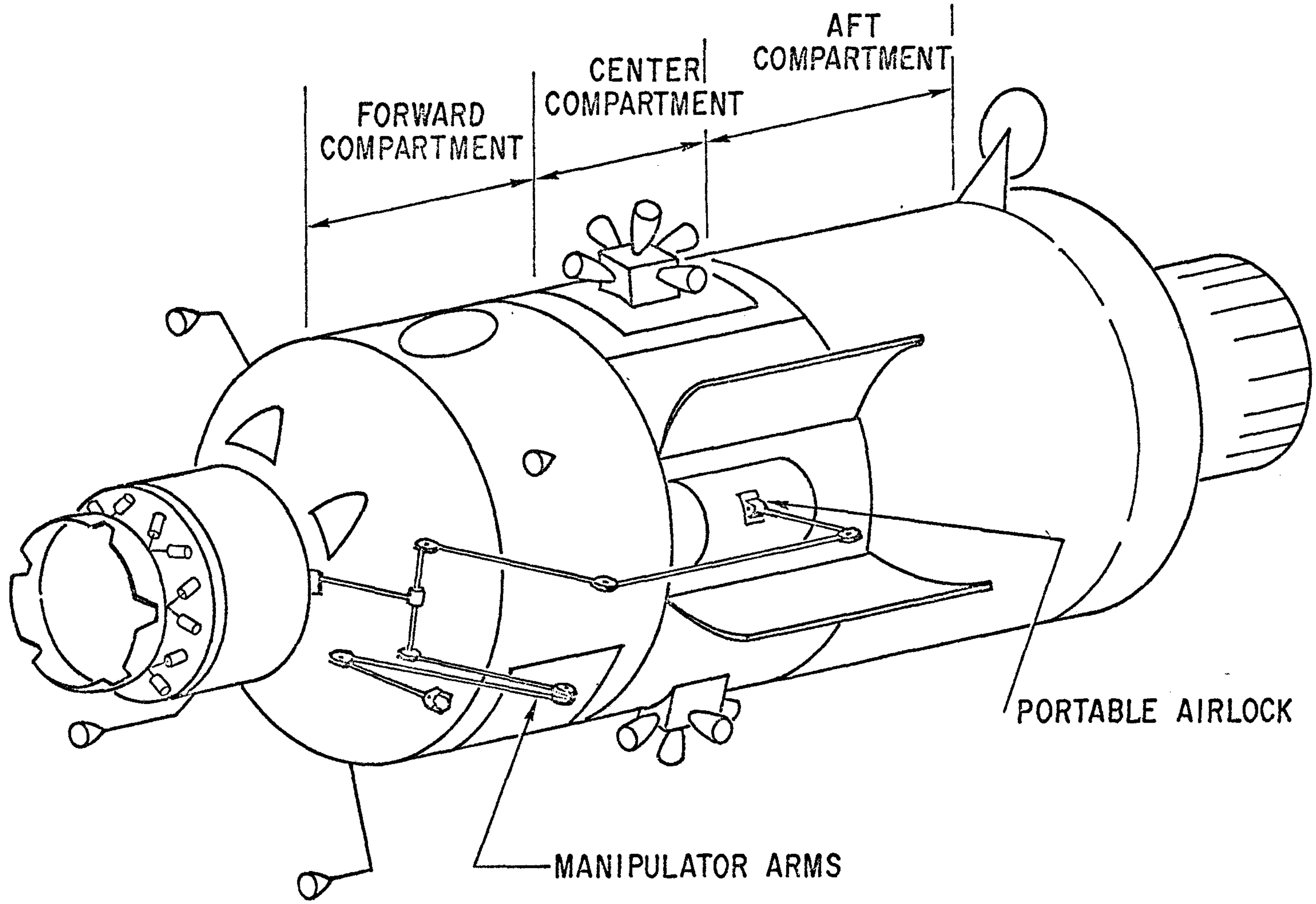

Figure H-27. Space Rescue Vehicle Based on EOS Crew/Cargo Module rear compartment or the DV, as required. The remaining unpressurized portion of the forward compartment contains the power supply subsystem components (fuel cells, etc.), life support subsystem components (O_2 and H_2 spherical containers, molecular sieves, etc.) and thermal control subsystem components (pumps, reservoirs, etc.).

The unpressurized center compartment contains retractable maneuvering propulsion nozzle clusters and the maneuvering propellant tankage. The compartment also contains separate cavities storing items of rescue equipment such as the portable airlock, fire extinguishing equipment, an attachable docking fixture, and crew transfer capsules. Hinged doors, attached to each cavity containing rescue equipment, can be opened as required from the crew compartment. The rescue equipment items could be stored therein on pallets, making removal and transfer to the DV a more manageable operation.

The aft pressurized compartment is provided with a shirt-sleeve environment and a soft docking device, medical supplies, injured astronaut restraint devices, hygiene compartment for cleansing purposes, and spare suits and undergarments, as well as recovery equipment.

The manipulator arms are attached to a ring gear on the outside of the forward docking fixture and are stowed against the front face of the forward compartment when not in use. The ring gear aligns the manipulator arms automatically by rotary motion with any pre-selected item of rescue equipment. The manipulator arms incorporate several joints which permit the arms to extend rearward to the center compartment for attaching and withdrawing the required items of equipment. The arm movements could be pre-programmed for automatic retrieval of specific items of equipment from the stowed position.

H. 4 CONCLUDING REMARKS

The various items of equipment discussed in the preceding sections of this Appendix represent the special equipment which a space rescue vehicle should carry to be prepared for any eventuality posed by a rescue mission. It is important to reiterate that event probabilities played no role in determining these requirements; in other words, all emergency situations were considered equally likely and means of countering each of them were discussed. Under these assumptions, the special equipment to be carried by a manned space vehicle serving as a rescue vehicle is summarized in Table H-49. The total weight clearly represents a considerable payload penalty to any of the projected transporter vehicles of the IP. The importance of developing rational elimination criteria for some of this rescue equipment, based upon estimates of emergency situation event probabilities and upon threshold values of these probabilities below which remedial means would not be provided, is obvious.

It can be concluded that means can be found to deal with most of the anticipated emergencies. However, the effectiveness of some of these rescue systems and devices is dependent upon the speed with which they can be applied; i. e., the response time which can be expected from a rescue mission. This time factor is difficult to estimate at this stage of the IP formulation and definition. The effectiveness of specialized rescue equipment will also depend upon the training received by the crews. A decision will have to be made whether to train all astronauts in the IP, or whether to train a nucleus of rescue specialists. Consideration might also be given to the need for language training in the context of possible international aspects of IP rescue needs.

It is also concluded that considerably more study effort should be devoted to the question of rescue equipment requirements before any final selections are made and before final decisions concerning rescue equipment development are made. In this connection it should be noted that state-of-the-art advances

Table H-49. SRV Equipment Weights for Rescue of a 12-man Space Station Crew

	Wt, lb	
Communication and Survey Equipment (various) (installed and portable)	700	
Despin Devices (2)	500	
Soft Docking Fixture (1)	250	(weight increment over standard)
Attachable Docking Fixture (1)	800	
Portable Airlock (1)	1600	
EVA Suits (4 + 3* = 7)	500	
AMU Backpack (4 + 3* = 7)	1050	
Manipulator (shirtsleeve) (1)	2000	
Transfer Capsule (3)	1500	
Sampling and Analysis Kit (1)	50	
Damage Control Equipment (various)	150	
Remote Manipulator (1)	1000	
Medical Kit (2)	100	
Extended Survival Kit (1)	500	
Tethers (Umbilicals) (2)	90	
Personnel Carriers (3)	30	
Miscellaneous	100	
Spare Provisions	100	
	11,020	

*For Rescue Crew

appear required only in the debris detection technology. The remaining rescue equipment falls into the category of current technology and requires mainly the consideration of rescue needs in the initial design of the IP elements, and the design and development of a number of items which in many cases will have application to other needs in addition to rescue.

IP hardware design should be influenced by the following factors:

- Escape by means of a bail-out device is a desirable capability because it may greatly simplify rescue.
- The ability to dock even under adverse conditions will reduce rescue equipment needs and will shorten rescue operations timelines.
- The ability to cycle cabin atmospheres will also reduce rescue equipment requirements and speed crew transfer when compared to airlock transfer.
- The ability to determine damage to the DV and the status of the DV crew from the exterior of the DV will reduce rescue hazards and rescue time.
- Vehicle and station design should provide for multiple access into the vehicles and between compartments within a vehicle.
- In bulkhead design, the need for cutting access holes should be considered.
- Vehicle design should consider the possibility of uncontrolled motion and the need to reduce such motion.
- The selection of rendezvous and docking guidance for IP transporter vehicles should also consider the needs of debris detection and spin characterization as a possible additional use for the same system.

H.5 RECOMMENDED STUDY AREAS

The primary requirement for additional studies relates to the need to establish event probabilities for the various potential emergency situations. Such studies depend upon knowledge of equipment failure probabilities, and cannot be performed until IP element design definition is available. However, parametric studies of the probability of encounter of debris as a function of distance from the DV generator of the debris, the approach vector, debris characteristics, and debris ejection velocity may now be initiated. Since debris characteristics cannot be firmly established until design definition of the potential DV has been completed, this type of analysis must remain incomplete until perhaps Phase C of the vehicle development contract. Another study area for early attention is the problem of medical emergency probability which, in a large measure, will be independent of final vehicle configuration, since most medical emergencies relate only to physiological and bacteriological considerations and past medical experience.

A parametric approach can also be taken with respect to debris detection systems which could be analyzed as a function of variable debris characteristics. Final selection of the optimum system would, however, have to await the preparation of a reasonable target model which, in turn, must await completion of vehicle design and possibly some test activity.

Recommended studies independent of the derivation of event probabilities include the derivation of damage data reporting systems. Such systems would consist of sensors combined with both automatic and demand-type data links to assure that the SRV crew, as well as ground control, would be apprised as quickly as possible of the nature of the emergency situation and the extent of damage or injury.

After fairly extensive design definition of IP elements has been completed, studies are recommended to address their dynamic characteristics under conditions of uncontrolled motion, as well as their self-damping characteristics. Data thus obtained would permit detail design studies of despin systems, both integral with the DV or brought by the SRV, and of spin characterization instrumentation.

Optimization studies should address the question of crew transfer modes under various assumptions of interference by factors such as inability to dock, residual motion, etc. The results of such studies could lead to standardization of emergency transfer methods for all IP elements.

The question of emergency entry and exit methodology deserves additional study with respect to hatch design, bulkhead design, etc. This study can be performed independent of event probabilities.

An important study area not treated in this report deals with the question of DV disposal after evacuation or rescue, and the equipment requirements which such operations would impose on the SRV.

It is also recommended that studies be made of the medical problems per se in addition to the medical event probability already discussed. Equipment requirements for ground-assisted diagnosis and prognosis, the feasibility of providing specialized medical equipment such as X-ray, traction devices, fluid administration devices, etc., should be considered.

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APPENDIX I

MISCELLANEOUS

APPENDIX I

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APPENDIX I

MISCELLANEOUS

I. 1 HAZARDS DUE TO SELF-GENERATED DEBRIS*

I. 1. 1 General

Among the emergency situations defined in Appendix A were several which could result in the generation of spacecraft debris. These situations included collision, explosive decompression, and explosion. It seemed desirable to investigate the behavior of the resulting debris because of the hazards it might pose to the distressed vehicle (DV) and to other nearby spacecraft such as a Space Rescue Vehicle (SRV). Since only a brief overview was possible within the time constraints of this study, the scope of analysis of the debris problem was restricted to an exploratory review of debris motion after ejection by the DV and the probability of debris presence as a function of ejection velocity and distance from the DV.

To thoroughly define the nature of the debris hazard would require data on particle size, mass distribution, particle velocity and vector distribution, and consideration of the secondary effects of atmospheric and gravity forces. The availability of much of this data depends on the completion of design definition of those elements of the IP which may become disabled, and the determination of event probabilities of the emergency situations causing debris ejection. It is recommended that such data be developed as soon as is feasible to allow further definition of the nature of the debris hazard.

I. 1. 2 Debris Motion

I. 1. 2. 1 Analysis

Prior work by other organizations as well as this brief analysis indicate that the possibility of a spacecraft collision with a particle ejected from the

*This section is based on the work of V. A. Chobotov, Ref. I-1.

spacecraft exists if the particle is ejected radially or in a cross-track (out-of-plane) direction. The resulting motion of the particle, to a first order approximation, is periodic in nature, implying that the particle will return to the ejecting body in either a fraction of an orbit period or after a complete period. The in-track (forward or backward) ejection, however, results in secular increase of the particle distance from the ejecting body. These effects are illustrated in Figures I-1 and I-2 (reproduced from Ref. I-2). where the positions of a mass ejected from the center of an earth-following coordinate frame (space station) are shown. The results are for a circular orbit of 300 statute miles (260 n mi) with the angle α defined as

$$\alpha = \tan^{-1} \frac{\dot{y}_o}{\dot{x}_o}$$

where $\dot{x}_o$ and $\dot{y}_o$ are the initial velocities of the ejected particle measured relative to the orbiting DV.

Additional analytic results derived in this study are given in Figures I-3 to I-5. Linearized equations for the mass motion were used to compute the distance ρ from the spacecraft of a mass ejected with 10 fps from the vehicle. These figures show the position of the mass at each quarter-orbit period for the cases of in-track, radial, and cross-track ejection, respectively.

I. 1. 2. 2 Conclusions

The analytic results lead to the following conclusions.

For Radial Ejection:

Separation is periodic in time

Maximum separation occurs in one-half orbit after ejection

Separation is reduced to zero upon completion of each orbit; conversely encounter probability is maximum at that time

Inward ejection is subject to atmospheric perturbation

For Tangential Ejection:

- Separation is always finite and is variable with time
- Separation increases with succeeding orbits

For Out-of-Plane Ejection:

- Out-of-plane separation is periodic in time
- Maximum separation occurs 1/4 and 3/4 of an orbit period after ejection
- Separation is reduced to zero every half-period; conversely, encounter probability is maximum at that time

Debris ejected radially and out-of-plane thus poses a hazard to the DV as well as to an SRV. Since the debris returns to its source with the same velocity with which it was ejected (except for perturbative forces such as for the case of radial inward ejection where atmospheric drag forces may decelerate the particle), the danger to the DV could be significant.

The debris ejected tangentially is primarily a hazard to any vehicle following in-track and trying to close with the DV for rendezvous and docking. Even if the initial ejection velocity of the debris were low, the relative velocity between an SRV trying to rapidly complete terminal rendezvous and a particle of debris could reach damaging levels.

It is concluded from the data presented that further study of the debris problem is appropriate. It is also indicated that consideration should be given to means of allowing the SRV to detect the presence of debris, to characterize its motion in order to determine the degree of hazard posed by the debris, and to avoid such hazard.

I. 1. 3 Probability of Debris Presence

The results presented above suggest that the probability of a collision with an ejection particle can eventually be computed for a given velocity vector of ejection and the volume of space occupied by the spacecraft or of a larger sphere surrounding the spacecraft. However, with the data currently available, this goal could not be attained for the general case, and only the probability of a debris particle being present in a given volume of space could be computed. For the specific case of a volume of space being occupied by a space station (i.e., the DV) the computed debris presence probability is also the probability of collision with that DV.

It is to be noted that the following analysis deals with particles ejected in a random manner, i.e., in an arbitrary direction, and thus differs from the results reported above and shown in Figures I-3, I-4, and I-5 which treat particles ejected in specified directions. The problem is much simplified if only the linearized equations of motion are used and if the probability of collision is computed at a time corresponding to one orbit period following the mass ejection in an arbitrary direction from the spacecraft. The accuracy of the results is reasonably good for a time not exceeding one orbit period but degrades considerably with time thereafter. This can be seen from the comparison of the trajectories obtained by solving exact and linearized (approximate) equations of motion. For example, Reference I-2 shows a 10% error in the altitude (radial coordinate) of a mass one orbit period later for the in-track ejection case. The in-track (or x-coordinate) error is considerably smaller, however.

I. 1. 3. 1 Analysis

The procedure for calculating the collision probability of an ejected mass particle with a sphere of radius ρ_s centered at the spacecraft can be formulated as follows.

The linearized equations of motion for a mass ejected from a circular orbit with an initial velocity V (with components $\dot{x}_o$, $\dot{y}_o$, $\dot{z}_o$ relative to the rotating x, y, z axes in Figure I-6) are given in Reference I-2 as

$$\left.\begin{aligned} x &= \left(-3t + \frac{4}{\omega}\sin\omega t\right)\dot{x}_o + \frac{2}{\omega}(1 - \cos\omega t)\,\dot{y}_o \\ y &= \frac{2}{\omega}(-1 + \cos\omega t)\,\dot{x}_o + \frac{\dot{y}_o}{\omega}\sin\omega t \\ z &= \frac{\dot{z}_o}{\omega}\sin\omega t \end{aligned}\right\} \quad \text{(I. 1-1)}$$

If $\omega t = \theta$ = the angular position of the coordinate frame (spacecraft) in orbit, then the equations (I. 1-1) can be written as

$$\left.\begin{aligned} x &= \left(-\frac{3\theta}{\omega} + \frac{4}{\omega}\sin\theta\right)\dot{x}_o + \frac{2}{\omega}(1 - \cos\theta)\,\dot{y}_o \\ y &= \frac{2}{\omega}(-1 + \cos\theta)\,\dot{x}_o + \frac{\dot{y}_o}{\omega}\sin\theta \\ z &= \frac{\dot{z}_o}{\omega}\sin\theta \end{aligned}\right\} \quad \text{(I. 1-2)}$$

One orbit period later, i.e., when $\theta = 2\pi$, the position of the mass (relative to the frame x, y, z) is given by the equation

$$x = -\frac{6\pi\dot{x}_o}{\omega} \quad \text{(I. 1-3)}$$

This result shows that the mass will be leading (negative x) the spacecraft for a backward ejection at the initial time $t = 0$ and lagging for a forward ejection at $t = 0$.

A sphere of radius $\rho_s = x$ can thus be defined as centered at the coordinate (spacecraft) origin which will not be entered by the ejected mass one orbit period later if $|\dot{x}_o| \geq \omega x/6\pi$. Consider now a given ejection velocity vector $\vec{V}$. The x component of $\vec{V}$ can be defined as

$$|\dot{x}_o| = V \cos \beta \qquad \text{(I. 1-4)}$$

where V is the magnitude of the velocity vector and β is a half cone angle measured from the x axis as shown in Figure I-7.

The $|\dot{x}_o| \geq \omega x / 6\pi$ condition will be satisfied if, and only if, $\vec{V}$ falls within the cone α described by half-angle β (either along the positive or negative x axis) and the probability of this occurring can be expressed as

$$P\left(|\dot{x}_o| \geq \frac{\omega x}{6\pi}\right) = \frac{2A_z}{A_s} \qquad \text{(I. 1-5)}$$

where

A_z = an effective area of a spherical zone defined by the cone α

$= 2\pi V^2 (1 - \cos \beta)$

A_s = an effective spherical area

$= 4\pi V^2$

assuming an equal probability of $\vec{V}$ occurring along any direction.* Thus, the probability that a mass initially ejected with a velocity $\vec{V}$ in an arbitrary direction will be outside a sphere of radius ρ_s one orbital period following the ejection is

---

*Note that V is eliminated in Eq. (I. 1-5) and can therefore be replaced by any variable.

$$
\begin{aligned}
P &= (1 - \cos\beta) \\
&= \left(1 - \frac{|\dot{x}_o|}{V}\right) \\
&= \left(1 - \frac{\omega x}{6\pi V}\right) \\
&= \left(1 - \frac{\omega \rho_s}{6\pi V}\right)
\end{aligned}
\qquad (I. 1-6)
$$

The probability that the ejected mass will be within the sphere of a radius ρ_s is then

$$
\begin{aligned}
P_{\rho_s} &= 1 - P \\
&= \frac{\omega \rho_s}{6\pi V}
\end{aligned}
\qquad (I. 1-7)
$$

This has been plotted in Figure I-8 for $1 \le V \le 1000$ fps and $\rho_s = 0.01$ to 100 n mi as a parameter for the space station circular orbit at 270 n mi altitude.

I. 1. 3. 2 Conclusions

Figure I-8 indicates that within the effective radius of a space station, i. e., between 0. 01 and 0. 015 n mi (60-90 ft), debris particles with velocities large enough to cause serious damage have relatively small individual existence probabilities. As indicated earlier, an exact analysis would probably show even lower probabilities, particularly with the passage of time after the generating event. The degree of danger to a space station or other IP element will then become a strong function of the number of debris particles which the source emergency has generated. Large numbers of particles ejected with velocities in the range of 5-10 fps could conceivably offer hazardous total probabilities of encounter with a space rescue crew operating in EVA on or near a DV. The higher the ejection velocity the lower the hazard, however, because of lower debris presence probability.

An SRV would probably be guided to a terminal rendezvous position between 1 and 10 n mi from the DV, with low thrust propulsion used to complete the docking approach. There is a very high probability of debris particles being ejected with velocities between a few fps and over 100 fps remaining within a volume of space also containing the SRV. The mitigating factor is that unless a large number of particles have been ejected, the probability of encountering debris is very low in such a large volume of space.

Further parametric analysis of DV-generated debris encounter probability is recommended. Such studies could determine probability as a function of particle size and mass and should be based on more realistic estimates of ejection velocities. Exact analysis methods, accounting for drag and gravity forces and time effects, should be used.

I. 2 UNSTABLE MOTION OF THE DISTRESSED VEHICLE*

I. 2. 1 General

In deriving requirements for special equipment and operations of a Space Rescue Vehicle (SRV), the problem of transferring a rescue crew into a DV was found to be difficult, if not impossible, if the DV was in uncontrolled motion. Particular difficulty would be faced in performing such a transfer if the DV were in a tumbling mode, that is, simultaneous rotation about more than one body axis at the same time. A brief analysis was therefore performed to determine the kind of uncontrolled motion that might be expected of IP elements and what means were available to reduce such motion to permit crew transfer.

*This section is based on the work of V. A. Chobotov, Ref. I-1.

I. 2. 2 Analysis

I. 2. 2. 1 Sources of Uncontrolled Motion

There exist several potential causes which can induce appreciable spin or tumbling of spacecraft such as the Space Station or the EOS. These are:

(1) Escaping spacecraft atmosphere

(2) Malfunctioning reaction control thruster or momentum exchange devices (reaction wheels or control moment gyros)

(3) Malfunctioning de-spin mechanism

(4) Separation from counterweight in the artificial G mode of the station/base

(5) Collision with orbiting debris, meteroids, or other spacecraft

(6) Docking impact

(7) Loss of attitude control system (power failure, etc.) in low earth orbit

(8) Movement or redistribution of masses within the spacecraft (crew or payload)

The first six causes listed above were examined in Ref. I-3 where it was concluded that each cause may induce a 3 to 4 rpm tumble in a space station. This appears to be a reasonable estimate for the Space Station as well as other large spacecraft. A detailed study of the Space Tug or EOS was not made. The seventh cause listed above is particularly significant if the spacecraft attitude control system failure occurs within the atmosphere. Tumbling will certainly result under such conditions with the spin stabilizing about the axis of maximum moment of inertia. Although the tumbling rate can have any value, a range of 1 to 4 rpm is probable, based on observed tumbling rates of spent booster stages in low earth orbits.

The induced tumble of the spacecraft may be about an arbitrary axis initially but will tend to approach pure spin about the major principal axis of the vehicle if there is any energy dissipation in the system. Such energy dissipation may be caused by internal sources (sloshing fluids, structural damping) or external sources (atmospheric friction, induced eddy currents, etc.), and will tend to decrease the vehicle nutation (wobble) as well as spin. The amount of energy dissipation may or may not be sufficient to provide a noticeable effect over a single orbital period.

I. 2. 2. 2 Reducing Unstable Motion

A tumbling or spinning spacecraft can be despun by application of an external torque, by energy dissipation within the spacecraft or by inertia augmentation i. e., the extension of booms with tip masses or the deployment of cable-connected masses (yo-yo). A rescue vehicle of a size comparable to or greater than the distressed spacecraft could also conceivably grapple the tumbling vehicle and exert a torque on the vehicle to despin it. Such a procedure, however, is not recommended for the general case because the resulting motion of both spacecraft would be very difficult to predict and control.

The amount of impulse J required to detumble or despin a spinning spacecraft can be determined from the relation

$$\begin{aligned} H &= I\omega \\ &= FR\Delta T \qquad \text{(I. 2-1)} \\ &= JR \end{aligned}$$

where

- H = angular momentum
- I = moment of inertia
- F = force (thrust)
- ΔT = burn time or time of force application
- J = impulse = $F\Delta T$
- ω = angular velocity
- R = moment arm (about mass center)

The mass properties and geometry for three typical vehicles are shown in Figures I-9, I-10, and I-11. The impulse J required to despin each of the vehicles in Figures I-9, I-10, and I-11 from a 4 rpm spin (ω = 0.419 rad/sec) about its major axes is listed in Table I-1.

If a mass unwinding from a cable (yo-yo) is used to despin the space station after being attached to it, then the required length ℓ of the cable is given by Ref. I-4 as

$$\ell = \sqrt{R^2 + \frac{I}{m}} \approx \sqrt{\frac{I}{m}} \qquad \text{for} \qquad R^2 \ll \frac{I}{m} \tag{I.2-2}$$

where m is the mass of the yo-yo, R is the radius of the unwinding drum, and I is the momentum of inertia of the spinning mass.

For a station inertia I of 4.50×10^6 slug-ft^2 and a yo-yo mass $m = \frac{100}{32.2}$ = 3.1 slugs for a 100 lb weight,

$$\ell \approx 1.2 \times 10^3 \text{ ft} \tag{I.2-3}$$

The results of the above simplified analyses suggest that a yo-yo method may be a practical means of stopping a space station or a smaller vehicle tumbling in orbit. The cable length is on the order of 1200 ft if the despin weight is 100 lb. Centrifugal force aids the unwinding of the cable and the mass can be released from the vehicle after unwinding. If the mass is not released, the system may achieve gravitational stabilization in attitude, or perform slow oscillations about the local vertical. As an alternate solution, small rockets can, of course, also be used but will probably be heavier in total weight.

I.2.2.3 Docking With Spinning or Tumbling Spacecraft

I.2.2.3.1 In-plane Docking

If a distressed vehicle has pure spin about an axis of symmetry, then the SRV could approach it in the plane of spin (co-rotate with the DV) and attempt to dock with it. The major problem in this approach is the overcoming of the centrifugal force acting on the SRV as it rotates about the DV. The order of magnitude of the forces involved is shown in Figure I-12.and demonstrates the impracticability of this approach.

I. 2. 2. 3. 2 Docking Along Spin Axis

The variation of the classical Euler angles $\dot{\theta}$ (nutation), $\dot{\phi}$ (spin), and $\dot{\psi}$ (precession) measured with respect to an angular momentum vector H of a torque-free spacecraft for the general case of unequal moments of inertia is given by

$$\dot{\theta} = H \sin \theta \sin \phi \cos \phi \left(\frac{1}{A} - \frac{1}{B}\right)$$

$$\dot{\phi} = H \cos \theta \left(\frac{1}{C} - \frac{\sin^2 \phi}{A} - \frac{\cos^2 \phi}{B}\right) \qquad \text{(I. 2-4)}$$

$$\dot{\psi} = H \left(\frac{\sin^2 \phi}{A} - \frac{\cos^2 \phi}{B}\right)$$

These equations show that only in the case of dynamic symmetry, i. e., if A = B or when two moments of inertia of a spacecraft are equal, the equations reduce to

$$\dot{\theta} = 0$$

$$\dot{\phi} = H \left(\frac{1}{C} - \frac{1}{A}\right) \cos \theta \qquad \text{(I. 2-5)}$$

$$\dot{\psi} = \frac{H}{A}$$

which indicate that $\dot{\theta}$, $\dot{\phi}$ and $\dot{\psi}$ are constant. This suggests that docking with a tumbling spacecraft having no dynamic symmetry (three different moments of inertia) would not be feasible in view of the complex nature of the motions that would result.

In the case of dynamic symmetry, however, and the presence of a docking port along or near an axis of spin, hard docking could be attempted. A schematic diagram of this technique is shown in Figure I-13 where a dynamically symmetric space station (DV) is shown precessing with an angular rate ($\dot{\psi}$) and nutating about the angular momentum vector $\vec{H}_2$ with a nutation (wobble) half angle θ. A rescue vehicle is shown matching the spin and wobble of the DV with the required centripetal force and gyroscopic torque indicated.

Assuming in Figure I-13 that $\dot{\psi}$ = 4 rpm, d = 50 ft, $\theta = 10°$, m_1 = 50,000 lb*, A_1 = 51,600 slug-ft^2, C_1 = 21,000 slug-ft^2, $A_2 = 5.53 \times 10^5$ slug-ft^2, $C_2 = 4.42 \times 10^5$ slug-ft^2, the centrifugal force F and the gyroscopic torque T are:

$$F = m_1 d \sin\theta \, \dot{\psi}^2$$

$$= 2370 \text{ lb} \qquad \text{(I. 2-6)}$$

$$T = \dot{\psi} C_1 (\dot{\phi}_1 + \dot{\psi} \cos\theta) \sin\theta - A_1 \dot{\psi}^2 \sin\theta \cos\theta$$

where $$\dot{\phi}_1 = \dot{\phi}_2 = H_2\left(\frac{1}{C_2} - \frac{1}{A_2}\right) \cos\theta \text{ and } H_2 = A_2\dot{\psi}$$

Hence $$T = -780 \text{ ft-lb} \qquad \text{(I. 2-7)}$$

Although the force F and the torque T are not excessive in this example, the requirement for precise sensing of the relative attitudes and dynamic symmetry (equal moments of inertia about the transverse axes) makes the feasibility of

*Tug of Figure I-9 is assumed half-full.

docking under such conditions questionable, if not impossible. The following conclusions apply:

(1) The angular velocities and attitudes of the DV must be measured precisely and matched by the SRV.

(2) Forces and torques are relatively low.

(3) Axial force is similar to normal requirements for docking.

(4) DV wobble is likely to occur.

(5) Wobble presents complex SRV control problems.

(6) Both the DV and the SRV must absorb docking forces, torques, and energy levels which are generally greater than under normal conditions. As a design problem, however, this is believed soluble.

I.2.3 Conclusions and Recommendations

The problem areas associated with spacecraft tumbling and SRV docking to tumbling, distressed vehicles have been briefly examined and identified. The examination of the possible tumbling causes suggested that a 4 rpm spin is a likely value for the space station. It was concluded that:

(1) Hard docking to a tumbling (spinning) spacecraft does not appear feasible because the target is likely to have complex motions not easily matched by the SRV.

(2) Self-contained despin solutions should be emphasized. The despin devices should be internally or externally activated and located to oppose spin about the principal axes. Externally attachable devices by the SRV should also be considered.

(3) The feasibility of hard docking to a tumbling DV should be reexamined if the SRV can be rotated about an axis passing through a docking port and the DV can have a docking port along each of the principal axes (or very close to them).

(4) Should spin or tumble of the DV be reduced to a relatively low value, hard docking or grappling may be attempted. The grappling and docking mechanisms should

    (a) be simple, lightweight and reliable

    (b) not damage target or SRV

    (c) have positive target capture and retention

(d) be capable of self-disengagement

(e) be operable with some misalignment between target and rescue vehicle

(f) provide for multipoint contact and large energy absorption capability

(g) have final (docked) configuration dynamically stable and controllable.

It is recommended that future effort be concerned with

(1) Determination of wobble (nutation) and spin decay times for actual IP spacecraft designs

(2) Evaluation of candidate means (external) for reducing wobble or spin

(3) Evaluation of methods for attaching grappling or despin equipment to the DV (if not self-contained)

(4) Evaluation of soft-docking designs for cases where wobble cannot be entirely eliminated

I. 3 FLY-AROUND SATELLITE INSPECTION METHODS*

I. 3. 1 General

The space rescue study indicated a requirement for surveying the DV from the SRV, particularly if communication cannot be established between these vehicles. This survey could be performed from a distance of several miles if conditions hazardous to the SRV are suspected. It might also be required within a few hundred feet or closer to the DV if detailed information on the damage status of the DV is desired. Because of the possibility that such a survey could impose rigorous propulsion requirements upon the SRV, a brief study of this problem was performed.

Visual inspection of a Distressed Vehicle (DV) in orbit by the Space Rescue Vehicle (SRV) can be performed by flying around the DV. The simplest maneuver can be an in-orbit plane inspection initiated by an impulsive radial velocity change imparted to the SRV. The SRV should initially be in a circular orbit identical to that of the DV, and should be ahead for radial outward and

*This section is based on the work of V. A. Chobotov, Ref. I-5.

behind for radial inward impulse application. The resulting trajectory will be an ellipse about the DV with a period equal to the orbital period of the DV. The ratio of the major axis of the ellipse, referenced to the initial position of the SRV, to the minor axis is 2 and its magnitude is directly proportional to the radial incremental velocity ΔV applied to the SRV.

If a faster inspection is required, it can be performed by flying around the DV in a circular motion (trajectory) at any radius, in any plane or specified maneuver time. If the fly-around time is much shorter than the orbital period of the DV, then the maneuver can be performed by application of a continuous radial thrust by the SRV equal to the centrifugal force required to maintain the circular motion desired. For the cases when the fly-around time (period) is not short compared to the orbital period, the required thrust becomes a function of time (or position relative to the DV).

I. 3. 2 Analysis

I. 3. 2. 1 Impulsive Elliptical Fly-around Maneuver*

For the in-orbit plane case, the equations of motion are (Ref. I-2):

$$x = \frac{2\dot{y}_o}{\omega}(1 - \cos \omega t) \qquad (I.\ 3\text{-}1)$$

and

$$y = \frac{\dot{y}_o}{\omega} \sin \omega t \qquad (I.\ 3\text{-}2)$$

where ω is the orbit rate, x and y are the in-track and radial relative (to DV) displacements of the SRV, respectively, and $\dot{y}_o$ is the radial impulsive velocity (relative to the DV) as shown in Figure I-14.

*This subsection is based on the work of Eggleston and Beck, Ref. I-2.

Let

$$\rho = (x^2 + y^2)^{1/2}$$

$$= \frac{\dot{y}_o}{\omega} \sqrt{4(1 - \cos \omega t)^2 + \sin^2 \omega t} \qquad \text{(I. 3-3)}$$

which states that if after a quarter-revolution ($\omega t = 90°$) ρ is to be a given value, then

$$\dot{y}_o = \frac{\rho\omega}{\sqrt{5}}$$

If, for example, $\rho = 100$ ft and $\omega = 1.11 \times 10^{-3}$ rad/sec (270 n mi circular space station orbit), then $\dot{y}_o = 0.0496$ fps. Half a revolution later ($\omega t = 180°$) the relative distance ρ will be a maximum and equal to

$$\rho_{max} = 179 \text{ ft}$$

If a maximum distance of 5 n mi is desired, then $\dot{y}_o = 8.43$ fps is the required radial impulse relative to the DV. This is also the absolute impulse, since it is given by the equation $V_y = \dot{y}_o + x\omega$ where x is assumed zero initially.

The trajectory of the SRV relative to the DV is shown in Figure I-15 for the case of an initial $\dot{y}_o = 8.43$ fps applied radially at a point 2.5 n mi ahead of the DV.

I. 3. 2. 2 Circular Fly-around Maneuver

The thrust requirements for performing a circular fly-around maneuver in orbit can be determined from the rendezvous equations given in Ref. I-2. The exact equations for the displacement of a mass particle relative to a frame x, y, z rotating at a constant angular velocity ω in a circular orbit as shown in Figure I-14 are

$$\ddot{x} - 2\omega\dot{y} + x\omega^2\left[\left(\frac{r_s}{r_f}\right)^3 - 1\right] = a_x \qquad \text{(I. 3-4)}$$

$$\ddot{y} + 2\omega\dot{x} + (y + r_s)\,\omega^2\left[\left(\frac{r_s}{r_f}\right)^3 - 1\right] = a_y \qquad \text{(I. 3-5)}$$

$$\ddot{z} + z\omega^2\left(\frac{r_s}{r_f}\right)^3 = a_z \qquad \text{(I. 3-6)}$$

Here, $r_f = \left[(r_s + y)^2 + x^2 + z^2\right]^{1/2}$, r_s is the orbit radius, and a_x, a_y, a_z are the acceleration components along the x, y and z axes, respectively. If now only in-plane motion is considered, then z = 0 and Eqs. (I. 3-4) and (I. 3-5) can be solved on a computer for a_x and a_y by letting $x = \rho \cos \alpha$, $y = \rho \sin \alpha$, where ρ is a constant radial distance of the SRV relative to the DV and α is a polar angle which may be given as $\alpha = \dot{\alpha}_o t$ as shown in Figure I-15.

An approximate solution can be obtained, however, by considering the linearized form of the rendezvous equations. These can be written as:

$$\ddot{x} - 2\omega\dot{y} = \frac{T_x}{m} = a_x \qquad \text{(I. 3-7)}$$

$$\ddot{y} + 2\omega\dot{x} - 3\omega^2 y = \frac{T_y}{m} = a_y \qquad \text{(I. 3-8)}$$

$$\ddot{z} + \omega^2 z = \frac{T_z}{m} = a_z \qquad \text{(I. 3-9)}$$

Equation (I. 3-9) describing the out-of-plane motion is uncoupled from the x and y equations and may therefore be examined separately. Considering Eqs. (I. 3-7) and (I. 3-8) first (in-orbit plane motion), let $x = \rho \cos \alpha$, $y = \rho \sin \alpha$. Then if $\alpha = \dot{\alpha} t$ where $\dot{\alpha}$ is a constant relative angular rate about the z axis,

$$\dot{x} = -\rho\dot{\alpha} \sin \alpha$$

$$\dot{y} = \rho\dot{\alpha} \cos \alpha$$

$$\ddot{x} = -\rho\dot{\alpha}^2 \cos \alpha$$

$$\ddot{y} = -\rho\dot{\alpha}^2 \cos \alpha$$

Substituting these relations into Eqs. (I. 3-7) and (I. 3-8) there results

$$a_x = -\rho\dot{\alpha}^2\left(1 + 2\frac{\omega}{\dot{\alpha}}\right) \cos \dot{\alpha} t \qquad \text{(I. 3-10)}$$

$$a_y = -\rho\dot{\alpha}^2\left(1 + \frac{2\omega}{\alpha} + \frac{3\omega^2}{\dot{\alpha}^2}\right) \sin \dot{\alpha} t \qquad \text{(I. 3-11)}$$

The in-plane (x, y plane) acceleration is then

$$a_{xy} = \sqrt{a_x^2 + a_y^2}$$

$$= \rho\dot{\alpha}^2 \sqrt{\left(1 + \frac{2\omega}{\alpha}\right)^2 \cos^2 \dot{\alpha}t + \left(1 + \frac{2\omega}{\dot{\alpha}} + \frac{3\omega^2}{\dot{\alpha}^2}\right)^2 \sin^2 \dot{\alpha}t}$$

$$\approx \rho\dot{\alpha}^2 \sqrt{\left(1 + \frac{4\omega}{\dot{\alpha}} \ldots\right) \cos^2 \dot{\alpha}t + \left(1 + \frac{4\omega}{\dot{\alpha}} \ldots\right) \sin^2 \dot{\alpha}t}$$

$$= \rho\dot{\alpha}^2 \sqrt{1 + \frac{4\omega}{\dot{\alpha}}} \qquad \text{(I. 3-12)}$$

to first order terms in $\omega/\dot{\alpha}$.

The value of a_{xy} is approximately accurate only for $\omega/\dot{\alpha} \ll 1$. The meaning of the approximate result is that the absolute acceleration a_{xy} is constant and approaches the $\rho\dot{\alpha}^2$ term, which is the relative centrifugal acceleration.

The out-of-plane circular motion is described by Eqs. (I. 3-7) and (I. 3-9) with $y = \dot{y} = 0$, $x = \rho \cos \beta$, $z = \rho \sin \beta$ where β is an angle in the xz plane. If $\beta = \dot{\beta}_o t$ where $\dot{\beta}_o$ is a constant angular rate and ρ is a constant radius as before, Eqs. (I. 3-7) to (I. 3-9) reduce to

$$a_x = -\rho\dot{\beta}_o^2 \cos \dot{\beta}_o t \qquad \text{(I. 3-13)}$$

$$a_y = -2\omega\rho\dot{\beta}_o \sin \dot{\beta}_o t \qquad \text{(I. 3-14)}$$

$$a_z = -\rho\dot{\beta}_o^2\left(1 - \frac{\omega^2}{\dot{\beta}_o^2}\right)\sin\dot{\beta}_o t \qquad \text{(I. 3-15)}$$

Therefore,

$$a_{xz} = \sqrt{a_x^2 + a_y^2 + a_z^2}$$

$$\approx \rho\dot{\beta}_o^2 \quad \text{if} \quad \left(\frac{\omega}{\dot{\beta}_o}\right) \ll 1 \qquad \text{(I. 3-16)}$$

and the time-dependent terms are neglected.

Eqs (I. 3-12) and (I. 3-16) were normalized (divided by $g = 32.2$ ft/sec^2) and plotted in Figure I-16 for different values of the period $P = 2\pi/\dot{\alpha}_o = 2\pi/\dot{\beta}_o$ with $\rho = 5$ n mi and 100 ft as parameters.

I. 3. 3 Conclusions

The results show that the required average acceleration, or thrust/weight ratio, is nearly constant in magnitude and radial in direction. The magnitude for the in-orbit-plane case is slightly higher than that for the out-of-plane case and is of the order of 0. 12 g for a 10-minute constant rotation at a distance of 5 n mi from the DV. Vehicles such as the Space Tug will thus be capable of performing this fast fly-around, particularly at distances close to the DV. For example, at 5 n mi distance, a 10-minute fly-around would require about 1900 fps of ΔV, while only 350 fps is required at 100 ft from the DV over a period of 30 minutes. Due to limited available ΔV, the EOS orbiter will have to use the impulsive, elliptical maneuver at a ΔV of about 5-10 fps which will require a full orbital period in time.

I. 4 GROUND-BASED ASCENT TIME CHARACTERISTICS*

I. 4. 1 General

The time required for a Space Rescue Vehicle (SRV) to reach a Distressed Vehicle (DV) includes time segments such as the time required to prepare the SRV prior to departure and the time required to reach the DV after departure from the point of origin. In the instance of a ground launch, the EOS serving as the SRV must be prepared for the launch. Some discussion of the duration of this pre-launch phase is given in Volume II of this report. Additional time delays are introduced by the need for waiting until the next available launch window and by the rendezvous phasing operations carried out in orbit. These ascent time delays are a function of the orbital position of the DV (its phase relative to the launch site), the orbit parameters of the DV, and the ΔV capability of the EOS.

A brief analysis was undertaken of the ascent times of the EOS as a function of ΔV available in the orbiter in a 50 by 100 n mi initial transfer orbit. The target was assumed to be in an orbit of 270 n mi altitude at 55° inclination. The DV is in a random (not subsynchronous orbit) position within this orbit when the emergency occurs and a rescue mission is requested. The EOS is assumed to be in a ready condition when such a mission is requested and can be launched whenever the next launch window becomes available. This ideal situation was assumed for the purpose of isolating the preparation and countdown times from the ascent times which depend upon orbital and flight mechanics factors and upon the ΔV capability of the ascending vehicle.

I. 4. 2 Analysis

The rendezvous mode with the lowest velocity requirement is the in-plane ascent mode where the SRV is launched when the launch site lies in the track

---

*This section is based on the work of W. A. Fey, Ref. I-6.

of the target orbit plane. This occurs twice every 24 hours; for a 55° inclination orbit and launch from ETR, the maximum time between launch opportunities is 15 hours. In the general case, the target may not be in the proper phase position in its orbit for rendezvous at that launch opportunity. An SRV phasing maneuver must be accomplished by waiting in a parking orbit (which has a different orbital period than the target orbit) for the appropriate phase relation between SRV and target to occur. Because of atmospheric drag effects, a circular parking orbit at 100 n mi altitude is about the lowest feasible and was used in this study. The orbit periods at 100 and at 270 n mi are not greatly different and therefore phasing may consume considerable time. The worst case corresponds to a change in relative phase between target and SRV of almost 360 degrees. This time, called the synodic period, is 21.6 hours for the problem under study.

More rapid phasing may be accomplished by making a direct ascent, requiring a plane change during ascent at the expense of a greater ΔV expenditure. If the SRV waits on the ground for the proper phasing to occur, approximately one target orbit period is the maximum wait required. A plane change is necessary because the launch site will not be in the target orbit plane; an orbit intersecting the target plane must be flown and a plane change to enter the target orbit made at the intersection. As an example, rendezvous with a all possible target phase relationships requires launch at any time from 0.76 hour prior to the coincidence of launch site and target plane (target northbound) to 0.90 hour after coincidence. Corresponding plane changes required are from -7.9 degrees to +8.5 degrees. In either case, a maximum increment in velocity of 3260 fps is required for the plane change. Because of the earth's rotational velocity, launches after the occurrence of launch site - target plane coincidence are more easterly than those before, thus accounting for the asymmetry in the above plane changes.

For on-orbit vehicle ΔV capabilities between those required for in-plane ascent and those for direct ascent, a hybrid technique was followed in computing ascent times. It assumed that the SRV is launched into an orbit which utilizes the maximum plane change of which the vehicle is capable. Thus, maximum use is made of the more rapid phasing associated with plane changes. The SRV ascends to a 100 n mi circular parking orbit and there completes the remainder of the phasing which cannot be achieved by a plane change because of ΔV limitations. Ascent to 270 n mi orbit is then made, and the plane change is performed in combination with the circularization maneuver at 270 n mi.

Additional features of the rendezvous procedure can be seen from Figure I-17. Lift-off from ETR is shown at (1) with burnout in a 50 x 100 n mi orbit at (2). Ascent is immediately made to 100 n mi altitude to avoid atmospheric drag effects. Circularization in a 100 n mi circular orbit is performed at (3) and parking for phasing begins. After sufficient phasing is accomplished, injection into a transfer orbit to 270 n mi altitude can be made at the next nodal crossing, (4). At (5) a combined impulse for the circularization and plane change is added. Some reduction in velocity requirement could be achieved by an optimum split of plane change at points (4) and (5) but this refinement was not considered in this preliminary study. The line of nodes where the ascent trajectory intersects the target orbit plane was selected to be 90° downrange from the launch site in order to minimize the plane change required. The desired 100 n mi altitude was not achieved by the first nodal crossing because departure from the Hohmann Transfer shown would cause an increased ΔV requirement.

In determining the SRV ΔV requirements subsequent to the 50 × 100 n mi orbit, an allowance of 100 fps to circularize at 100 n mi was included. A direct return reentry from 270 n mi was assumed, which requires 390 fps. No allowance for terminal rendezvous maneuvers was made.

The time from launch to rendezvous was determined on a worst case basis. The basic factor is the maximum time between in-plane launch opportunities of 15 hours. This time is reduced by the ability of vehicles with plane change capability to launch before or after the in-plane situation. However, an allowance must be made at each launch opportunity for the target to change its phase by 360 degrees in order to account for all possible target phases. If the entire phasing is accomplished by a ground wait and plane change the time required is 1.66 hours, which slightly exceeds the orbital period of the target (1.57 hours) because the launch site moves in the same sense as the target in its orbit. When all the phasing cannot be done on the ground the time spent in a 100 n mi parking orbit must be added, i.e., 1.47 hours for each revolution. This changes the relative phase by 24.5 degrees. Aside from the times connected with phasing, 1.93 hours were allowed for the ascent. This includes 0.11 hour from points (1) to (2), 0.71 hour from (2) to (3), 0.35 hour from (3) to (4), and 0.76 hour from (4) to (5).

No time allowances were made in this analysis for launch preparations between the declaration of emergency and rescue vehicle launch or for time required for terminal rendezvous after gross rendezvous is achieved at point (5). These items would add to the times as determined by this study.

I.4.3 Conclusions and Recommendations

The relation between velocity available in a 50 × 100 n mi orbit and the maximum time to achieve rendezvous after declaration of emergency is shown in Figure I-18. An in-plane ascent corresponds to the minimum ΔV requirement situation (1080 fps); it requires the same ΔV as ascent without consideration of phasing requirements. The time required for in-plane ascent is the maximum of all cases, 38.5 hours. If more ΔV is available, the time can be shortened from that obtained in parking orbit by substituting the more rapid phasing provided by waiting on the ground and accomplishing a plane change in orbit. A rapid decrease in time can thus be achieved. For example, if 4300 fps of velocity is available, the time to rendezvous is reduced to 18.7 hours. At this point, no wait in parking orbit is required and all phasing is accomplished by waiting on the ground. This is referred to as direct ascent rendezvous. Further increases in available ΔV serve only to increase the plane change capability and thus allow earlier launch. However, a ΔV capability of 15,000 fps only reduces the time to rendezvous to 14.4 hours.

Additional analysis is recommended to determine the rescue requirements at other points in the low earth orbit mission profile, such as in the case where an EOS orbiter had an emergency in a 100 × 270 n mi ascent orbit.

References

I-1. V. A. Chobotov, "Space Rescue Vehicle Requirements Study," ATM-71(7212-03)-4, Aerospace Corp. (November 1970). *

I-2. J. M. Eggleston and H. D. Beck, A Study of the Positions and Velocities of a Space Station and Ferry Vehicle During Rendezvous and Return, NASA Technical Report No. R-87, NASA Langley Research Center, Hampton, Va. (1961).

I-3. Preliminary Analysis of Escape from a Tumbling Space Station, Report No. SS-TR-060-4, General Electric Co., Space Division, Philadelphia, Pa. (23 June 1970).

I-4. W. T. Thompson, Introduction to Space Dynamics, J. Wiley and Sons, New York (1961).

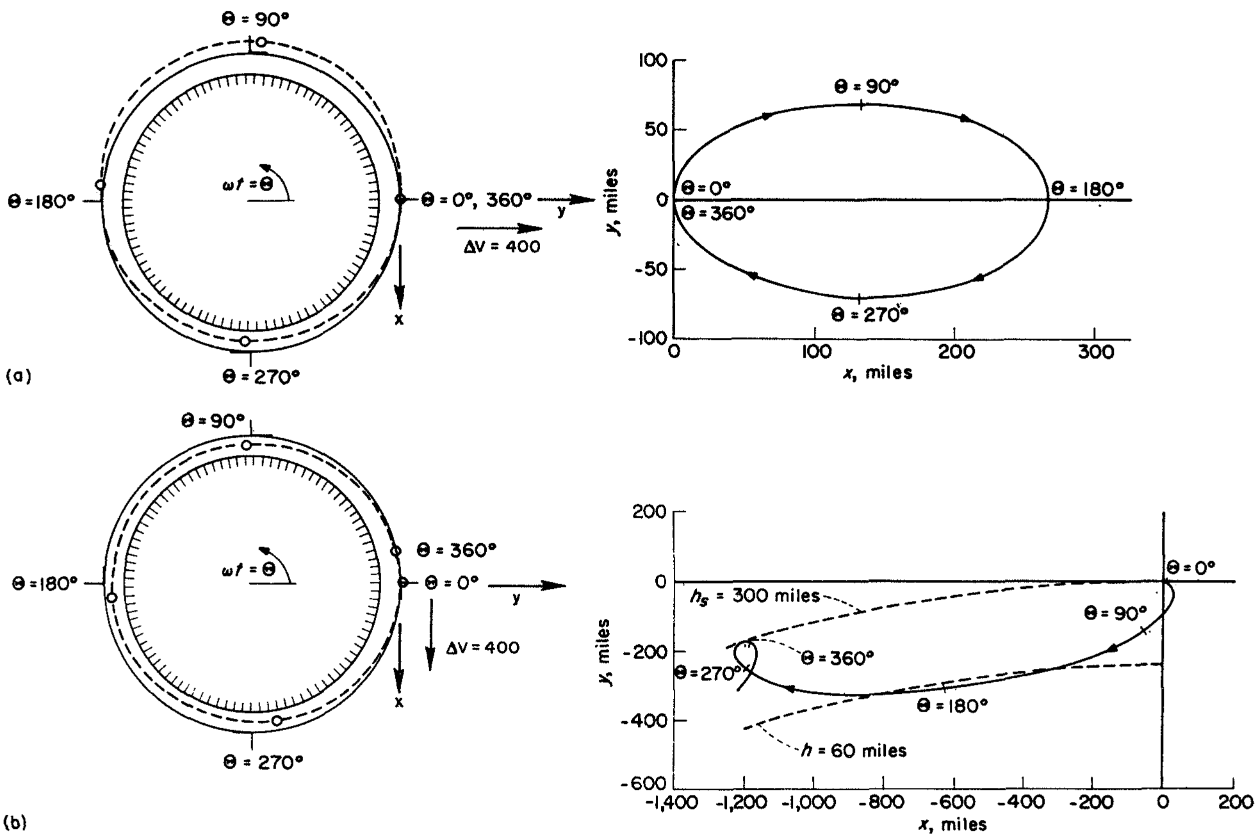
I-5. V. A. Chobotov, "Fly-around Satellite Inspection Methods," ATM-71 (7212-03)-4, Supplement 1, Aerospace Corp. (17 November 1970)*

I-6. W. A. Fey, "Ground Based Rescue from NASA Space Station," ATM-71(7212-03)-3, Aerospace Corp. (2 November 1970)*

*Aerospace Corporation Technical Memoranda (ATM's) are not available for distribution outside The Aerospace Corporation.

Table I-1. Force and Impulse Required to Despin from a 4 rpm Tumble

Vehicle	I ($sl\text{-}ft^2$)	H (ft-lb-sec)	R (ft)	ΔT (sec)	F (lb)	$J = F\Delta T$ (lb-sec)
Space Station	4.48×10^6	1.88×10^6	15	1800 (1/2 hr)	69.3	1.25×10^5
EOS (w/ 25,000 lb Payload)	13×10^6	5.45×10^6	60	1800	50.4	9.08×10^4
Tug (Full tanks)	9.89×10^4	4.11×10^4	12	180 (3 min)	19.0	3.43×10^3

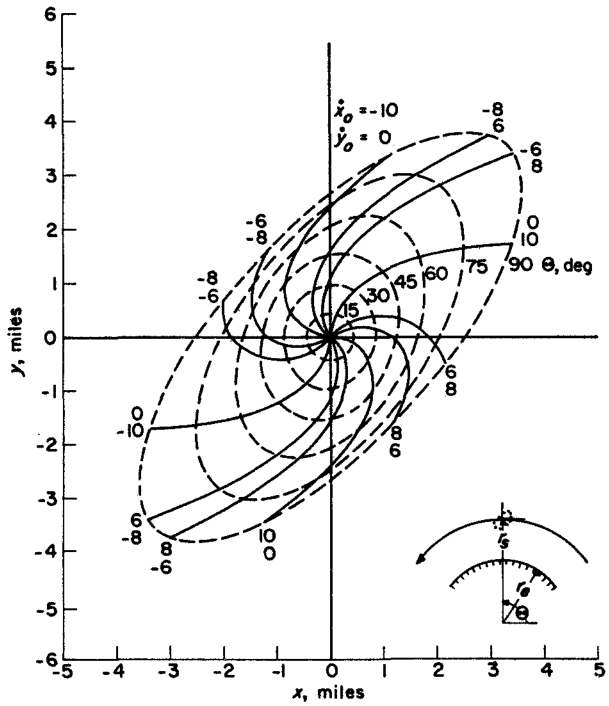


(a) $\Delta V = 400$ feet per second; $\alpha = 90°$.

(b) $\Delta V = 400$ feet per second; $\alpha = 0°$.

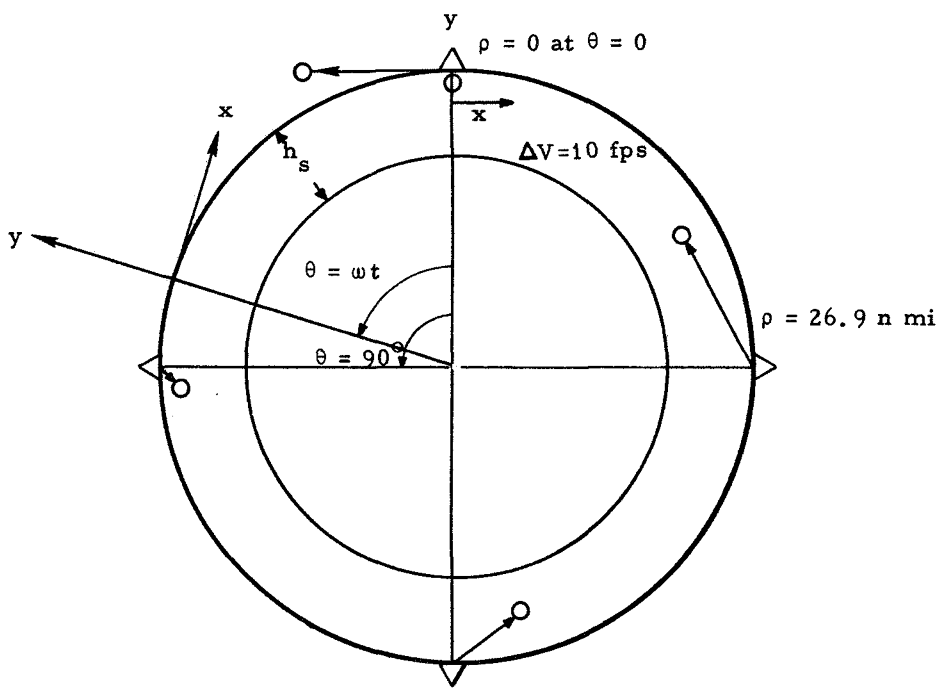
Two typical trajectories of a mass which at $t=0$ ($\Theta = 0$) was at the center of the coordinate system and had a relative velocity ΔV, which made an angle α with the X-axis. Trajectories are shown as viewed by an inertial observer (on the left) and an observer in the center of the coordinate system (on the right).

Figure I-1. Typical Ejected Particle Trajectories -- In-Orbit Plane (Reference I-2)



Trajectories of a number of point masses ejected from the center of the rotating coordinate system at $t=0$ ($\Theta=0$), each with a total relative velocity of 10 feet per second, but with different velocity components. The solid lines are discrete trajectories; the dashed lines are the contours of the positions of the masses at subsequent positions of the coordinate system.

Figure I-2. Trajectories Relative to Origin (Distressed Vehicle) vs Initial Velocity Components (Reference I-2)



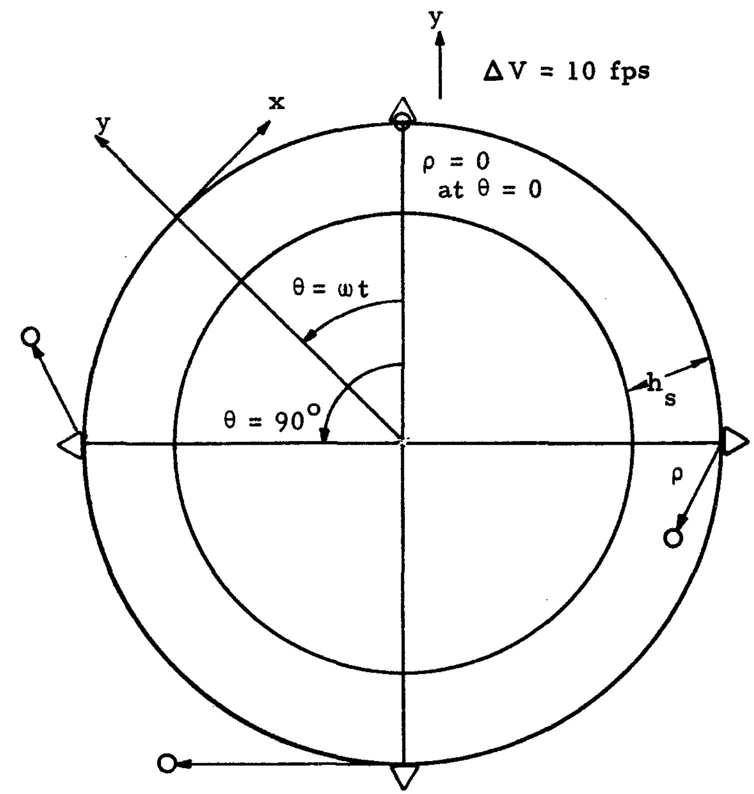
$\rho \propto \Delta V$

h_s = 260 n mi ALTITUDE

θ (deg)	0	90	180	270	360
ρ (n mi)	0	3.2	14.8	26.9	26.6

NOTE: Injection opposite to that indicated results in a change in the sign of the displacement.

Figure I-3. Particle Position History I: Following Tangential (Backward) Ejection from Space Station (ΔV = 10 fps)



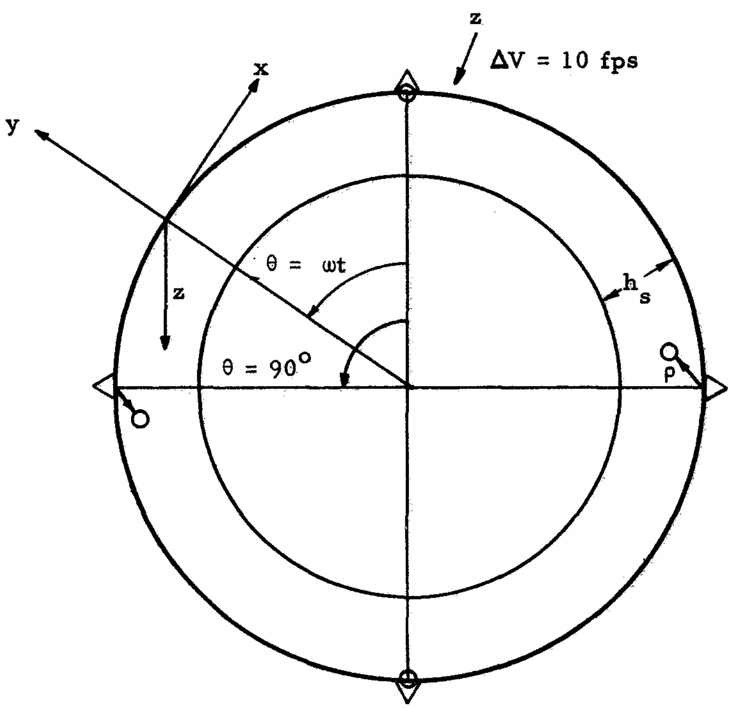
$\rho \propto \Delta V$

h_s = 260 n mi ALTITUDE

θ (deg)	0	90	180	270	360
ρ (n mi)	0	3.7	6.6	3.7	0

NOTE: Injection opposite to that indicated results in a change in the sign of the displacement.

Figure I-4. Particle Position History II: Following Radial (Outward) Ejection from Space Station (ΔV = 10 fps)



$\rho \propto \Delta V$

h_s = 260 n mi ALTITUDE

θ (deg)	0	90	180	270	360
ρ (n mi)	0	1.64	0	1.64	0

NOTE: Injection opposite to that indicated results in a change in the sign of the displacement.

Figure I-5. Particle Position History III: Following Out-of-Plane (z Direction) Ejection from Space Station (ΔV = 10 fps)

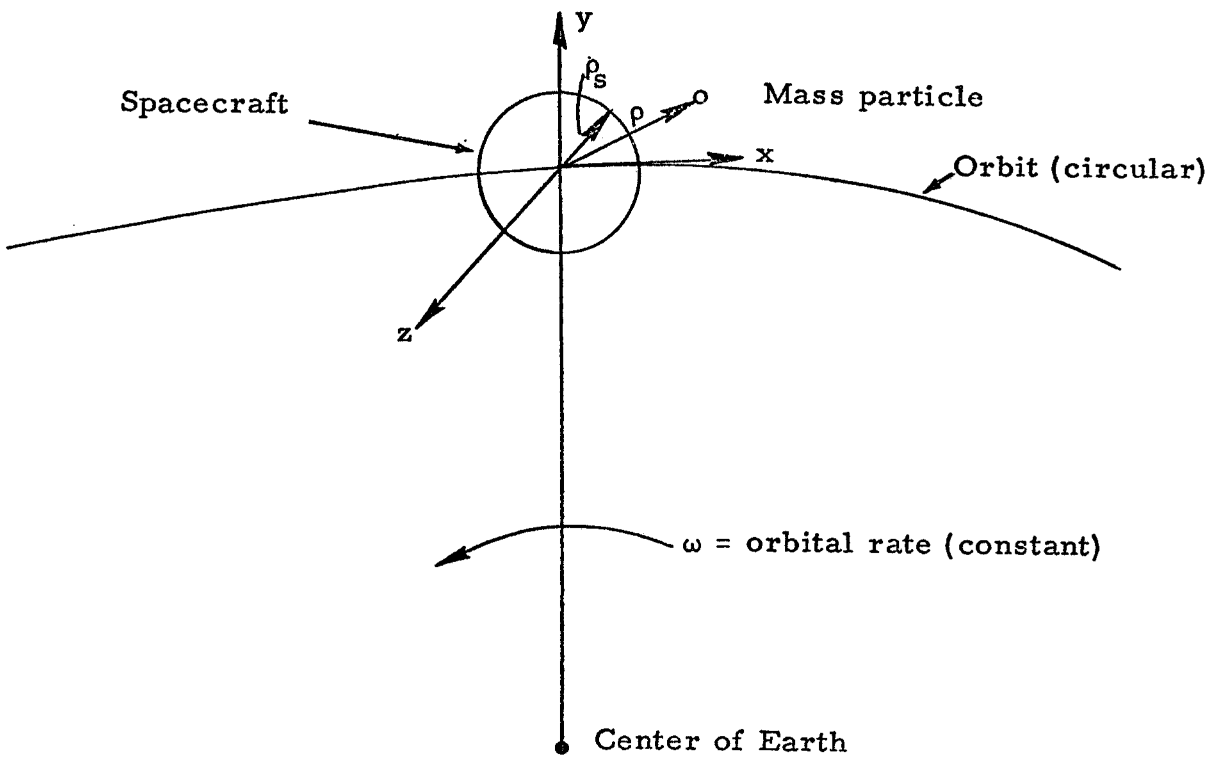


Figure I-6. Coordinate System

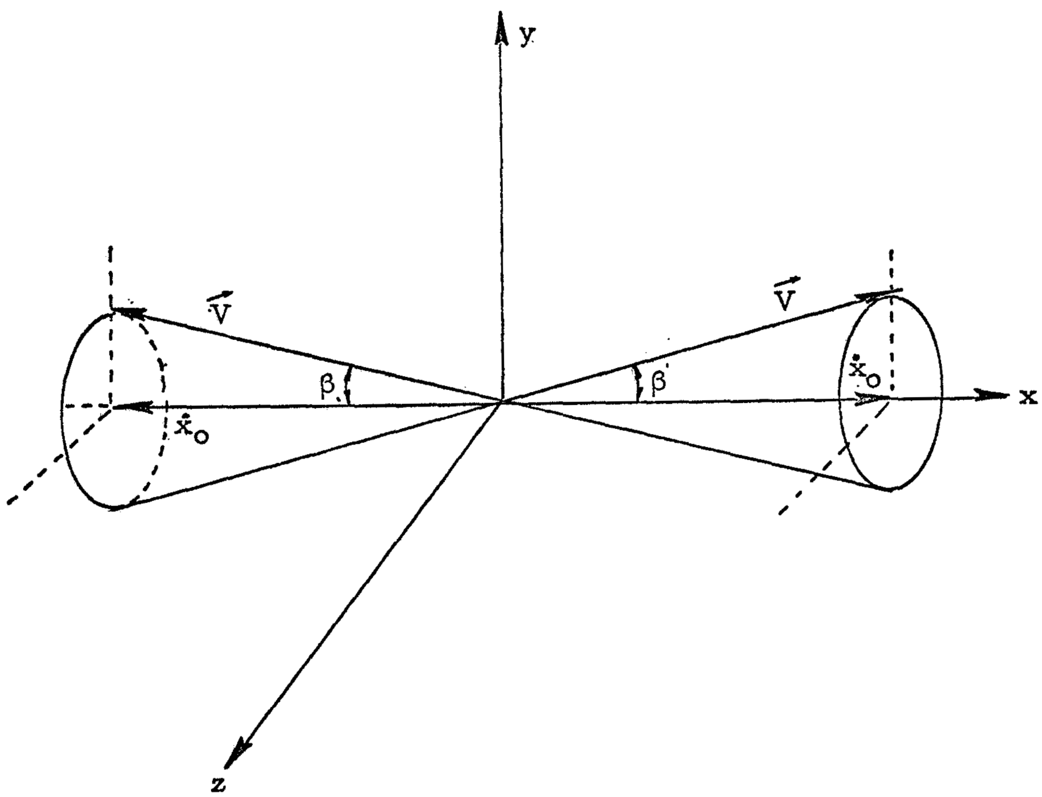


Figure I-7. Velocity Diagram

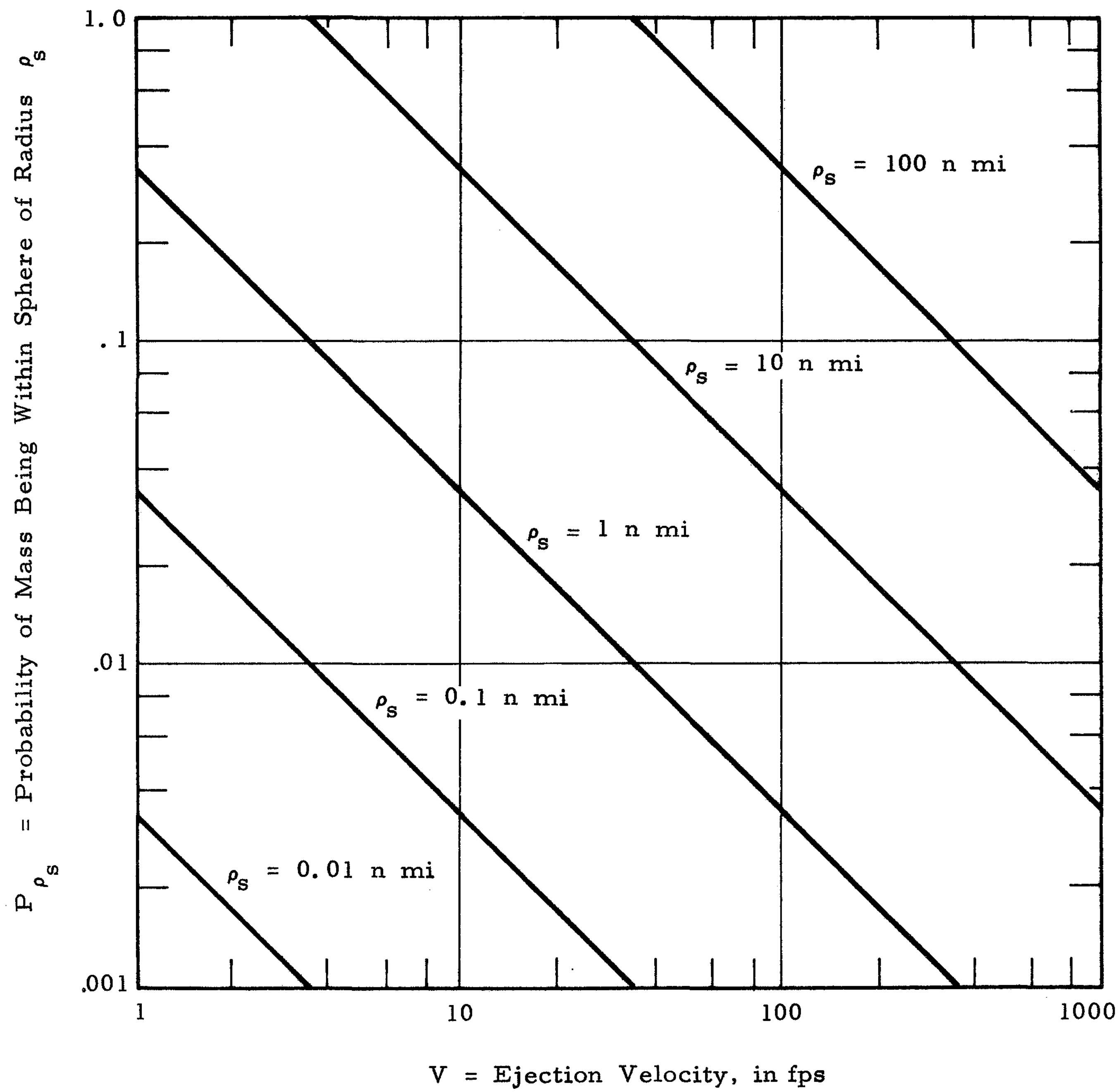
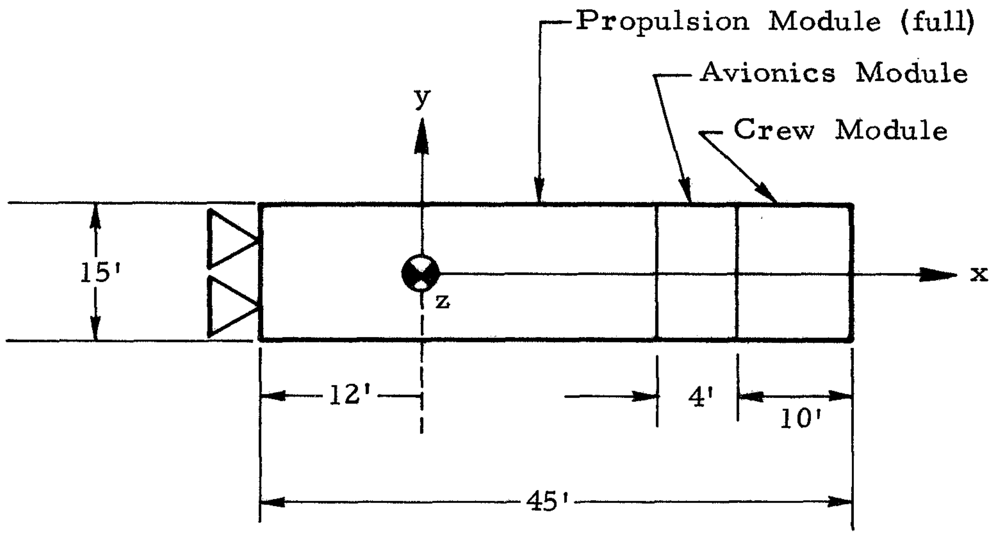


Figure I-8. Probability of a Mass Being Within a Sphere of Radius ρ_s (n mi) One Orbit Period Later if Ejected with a Velocity V in an Arbitrary Direction

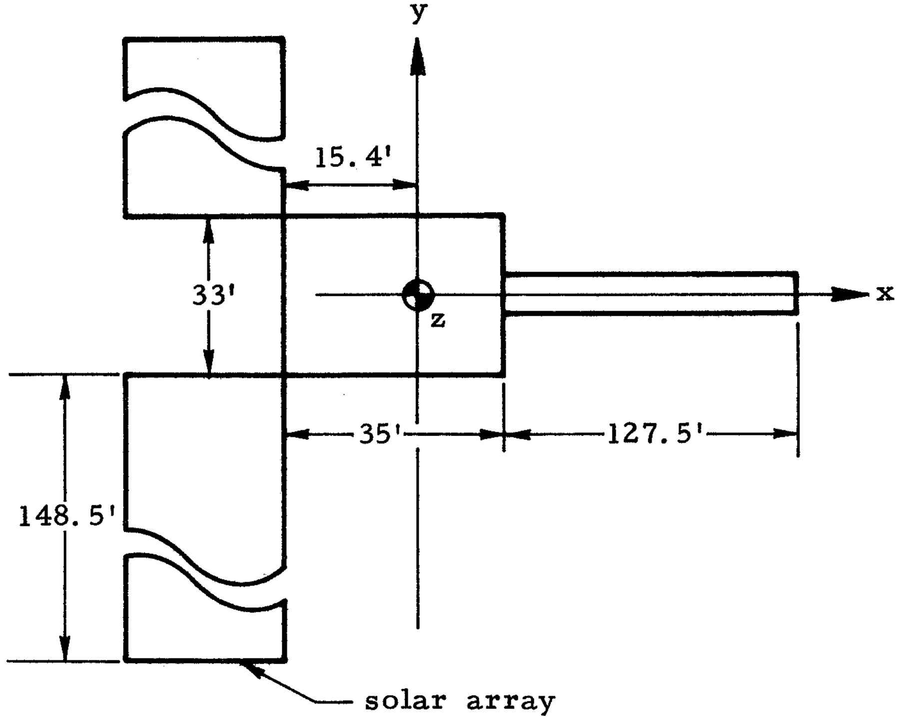


$$\text{Mass } M_T = \frac{82130}{32.2} = 2550 \text{ slugs}$$

$$I_x = 21100 \text{ slug-ft}^2$$

$$I_y = I_z = 98900 \text{ slug-ft}^2$$

Figure I-9. Mass Properties of a Typical Space Tug



With solar array:

$I_{xx} = 3.69 \times 10^6$ slug-ft^2

$I_{yy} = 1.24 \times 10^6$ slug-ft^2

$I_{zz} = 4.48 \times 10^6$ slug-ft^2

$$M_{s3} = \frac{117166}{32.2}$$

$$= 3630 \text{ slugs}$$

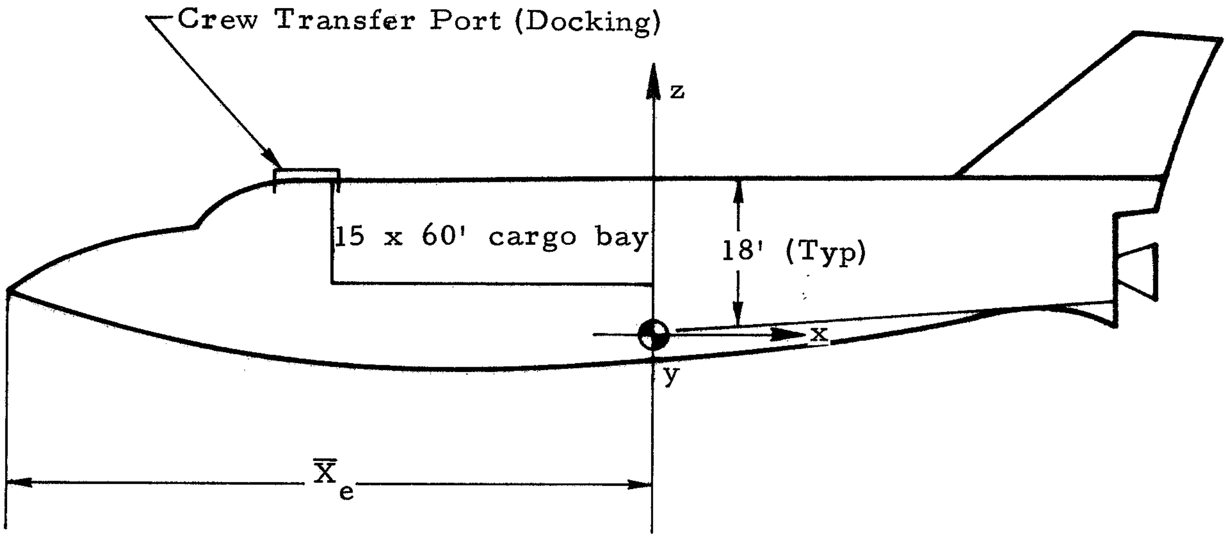
Without solar array:

$I_{xx} = 4.42 \times 10^5$ slug-ft^2

$I_{yy} \approx I_{zz}$

$= 5.53 \times 10^5$ slug-ft^2

Figure I-10. Mass Properties of a Typical Space Station



Empty

mass $M_{o_e} = 5580$ slugs

$\overline{X}_e = 103$ ft

$I_{xx} = 1.93 \times 10^6$ slug-ft^2

$I_{yy} \approx I_{zz} = 14 \times 10^6$ slug-ft^2

Full (25,000 lb cargo)

$M_{o_f} = 6380$ slugs

$\overline{X}_f = 99.5$ ft

$I_{xx} = 1.82 \times 10^6$ slug-ft^2

$I_{yy} \approx I_{zz} = 13 \times 10^6$ slug-ft^2

Figure I-11. Mass Properties of a Typical Earth Orbital Shuttle Orbiter Stage

CASE I: RESCUE VEHICLE APPROACHES IN PLANE OF SPIN (90° TO SPIN AXIS)

CONDITIONS:
- SPIN IS ABOUT MAJOR AXIS
- RATE OF SPIN - 4 RPM
- DISTANCE FROM SPIN AXIS TO RESCUE VEHICLE "CG" - 100 FEET

SRV WEIGHT	AXIAL FORCE REQUIRED	THRUST AVAILABLE
50,000#	26,800#	~ 15,000 #
82,000	44,000	~ 15,000
200,000	107,000	30-40,000

CONCLUSION: APPROACH AT RIGHT ANGLE TO SPIN AXIS IS NOT PRACTICAL AT ~4 RPM. (REQUIRES ~ 1/2 "G" TRANSLATIONAL ACCELERATION WHILE DOCKING)

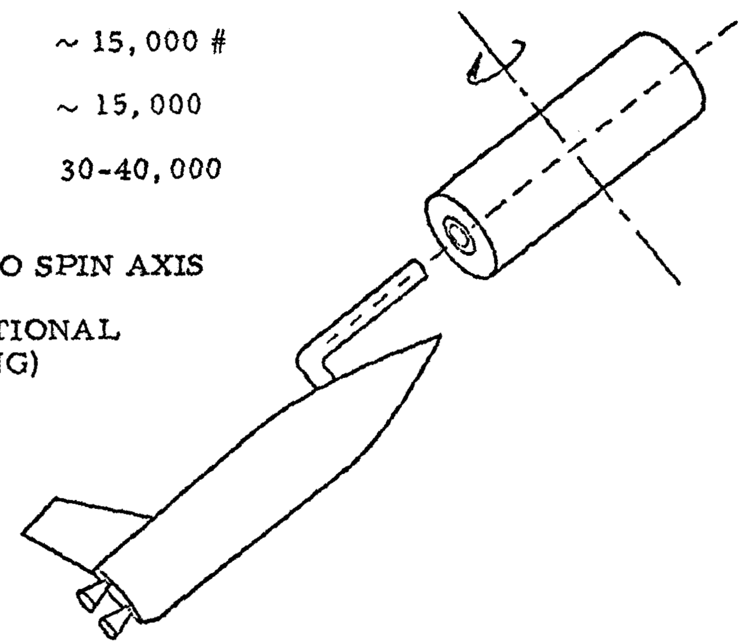


Figure I-12. Docking with a Spinning Spacecraft in Plane of Spin

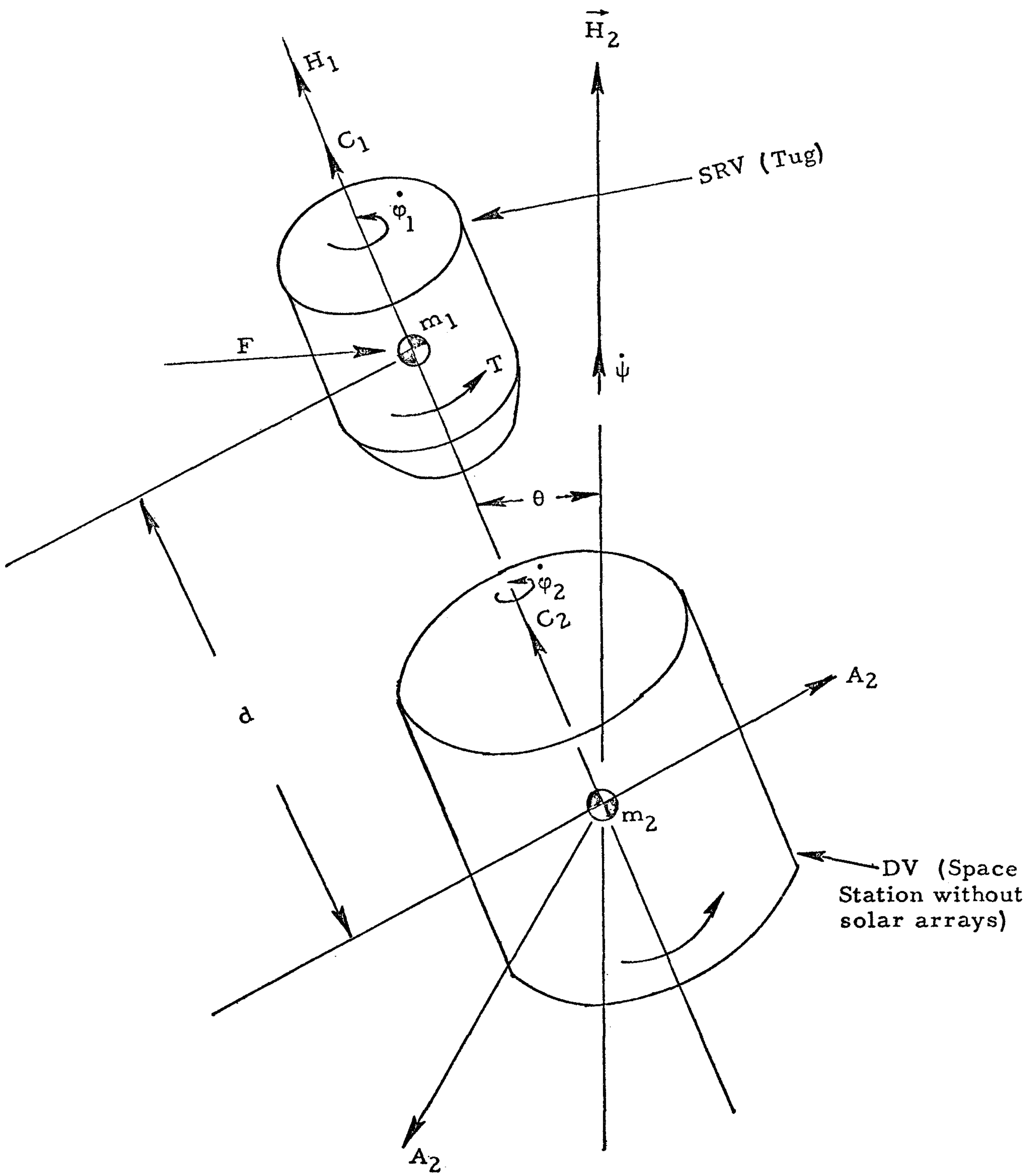


Figure I-13. Docking with a Precessing Target Vehicle

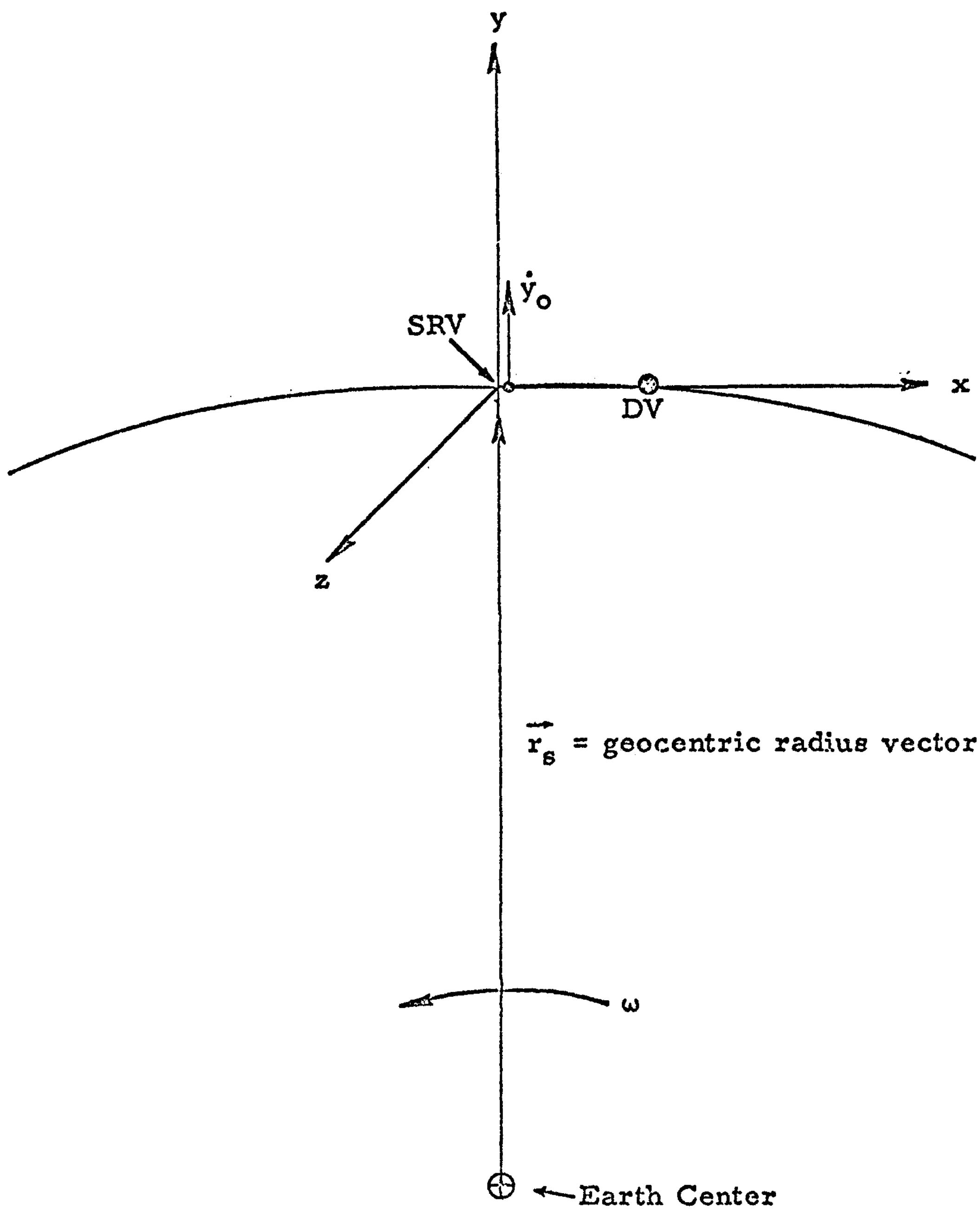


Figure I-14. Initial Position of SRV and DV for the Impulsive Fly-around Maneuver

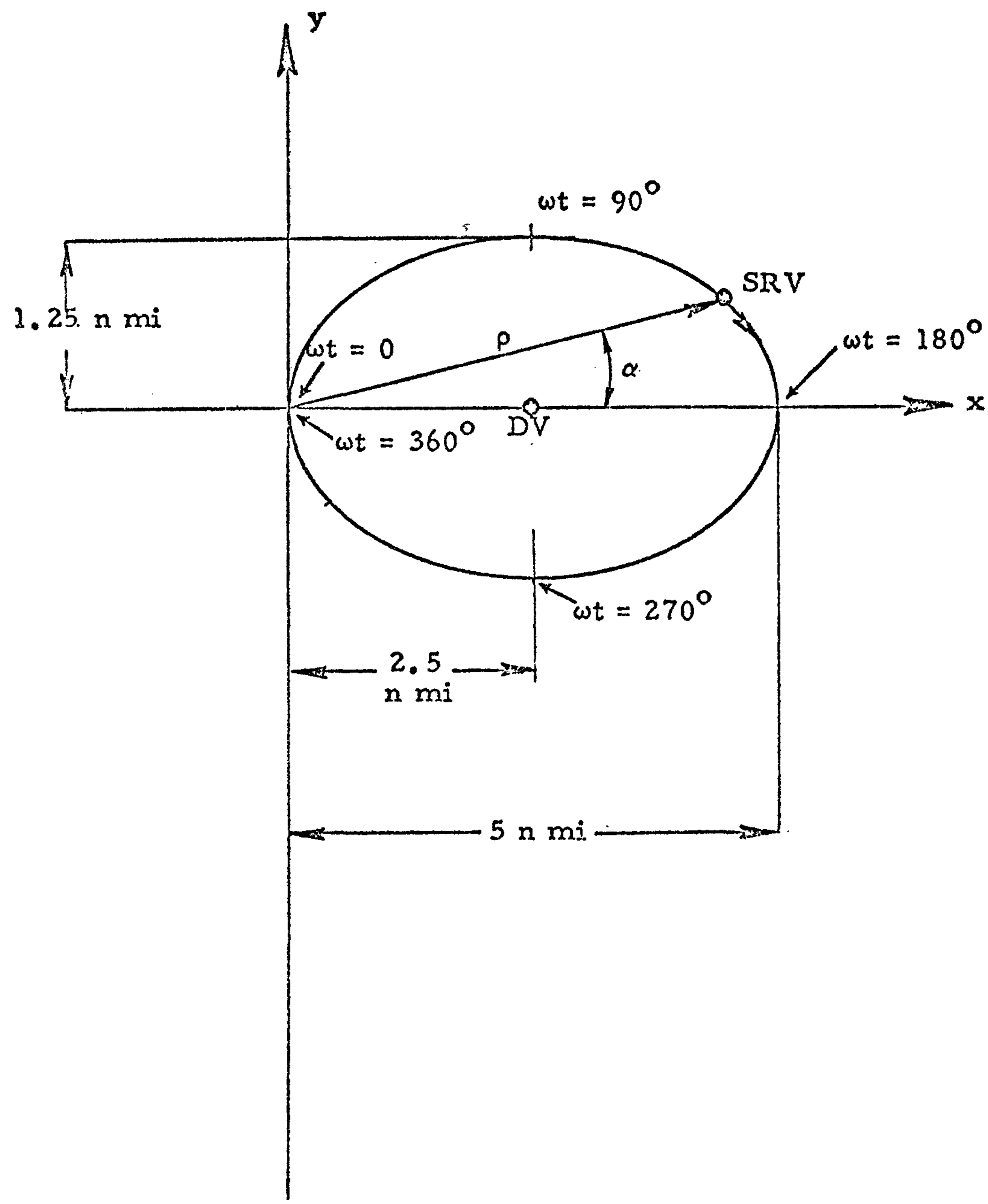


Figure I-15. SRV Trajectory for an Initial Radial ΔV = 8.43 fps and an In-track (Forward) Separation from the DV of 2.5 n mi

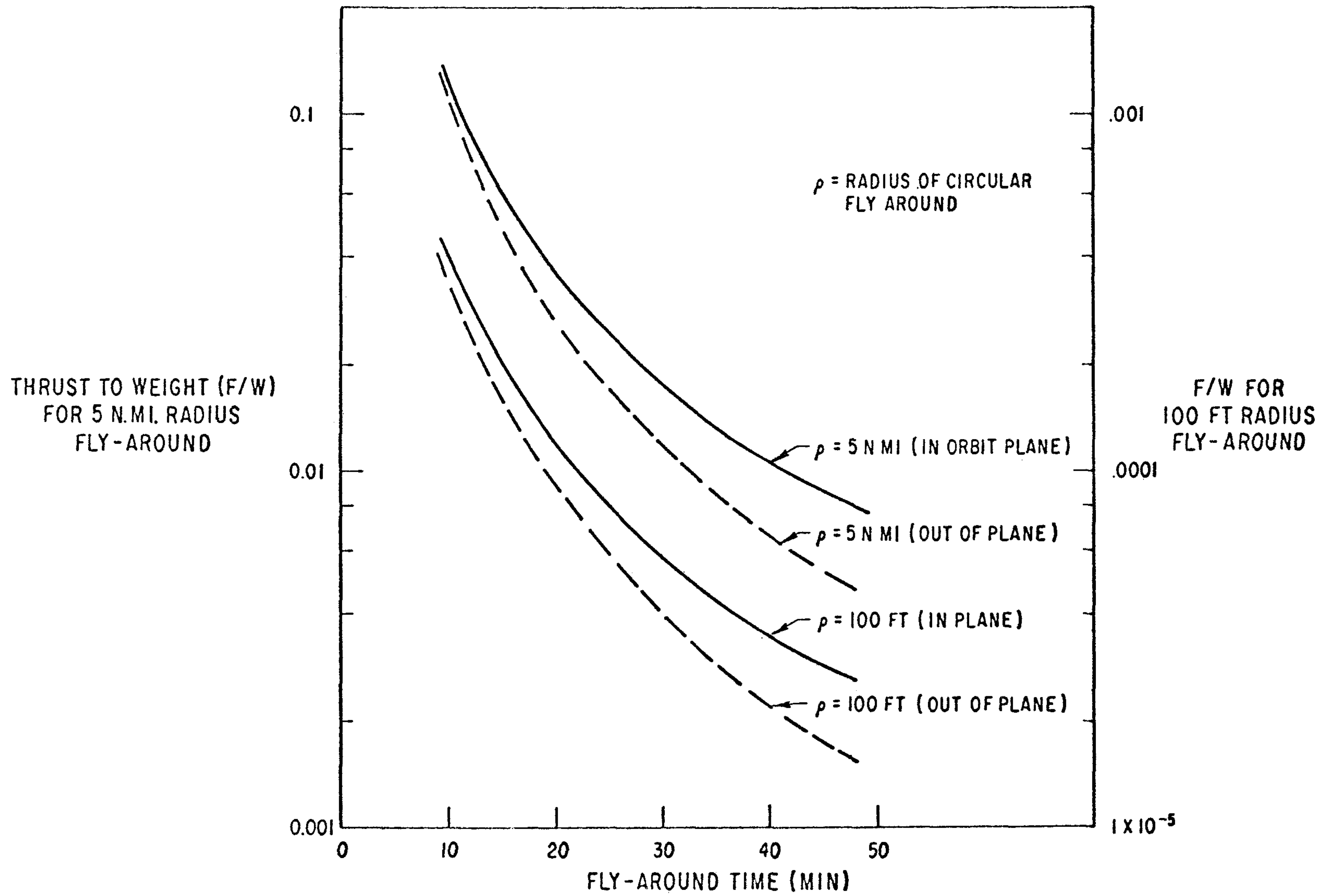
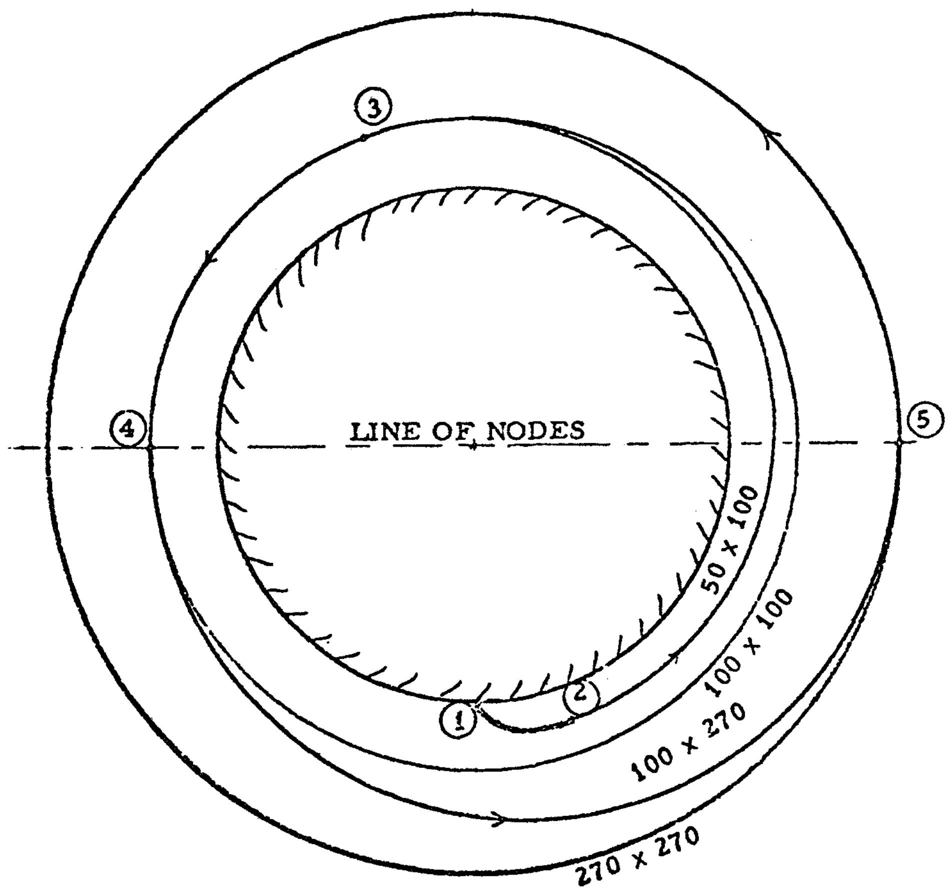


Figure I-16. Average Thrust to Weight Ratio to Fly Around an Orbiting Body (Continuous Thrusting) as Function of Radial Distance and Time Required



① LIFT OFF FROM ETR

② BURNOUT IN 50 x 100 ORBIT

③ CIRCULARIZE INTO 100 x 100 ORBIT

④ INJECT INTO 100 x 270 AFTER PARKING IN 100 x 100 FOR PHASING. INJECTION 180 DEG FROM ④ IS ALSO PERMISSIBLE

⑤ CIRCULARIZE AND MAKE PLANE CHANGE TO ENTER 270 x 270 ORBIT WITH 55° INCLINATION

Figure I-17. Schematic of Rescue from 270 n mi Circular Orbit (Inclination = 55 deg)

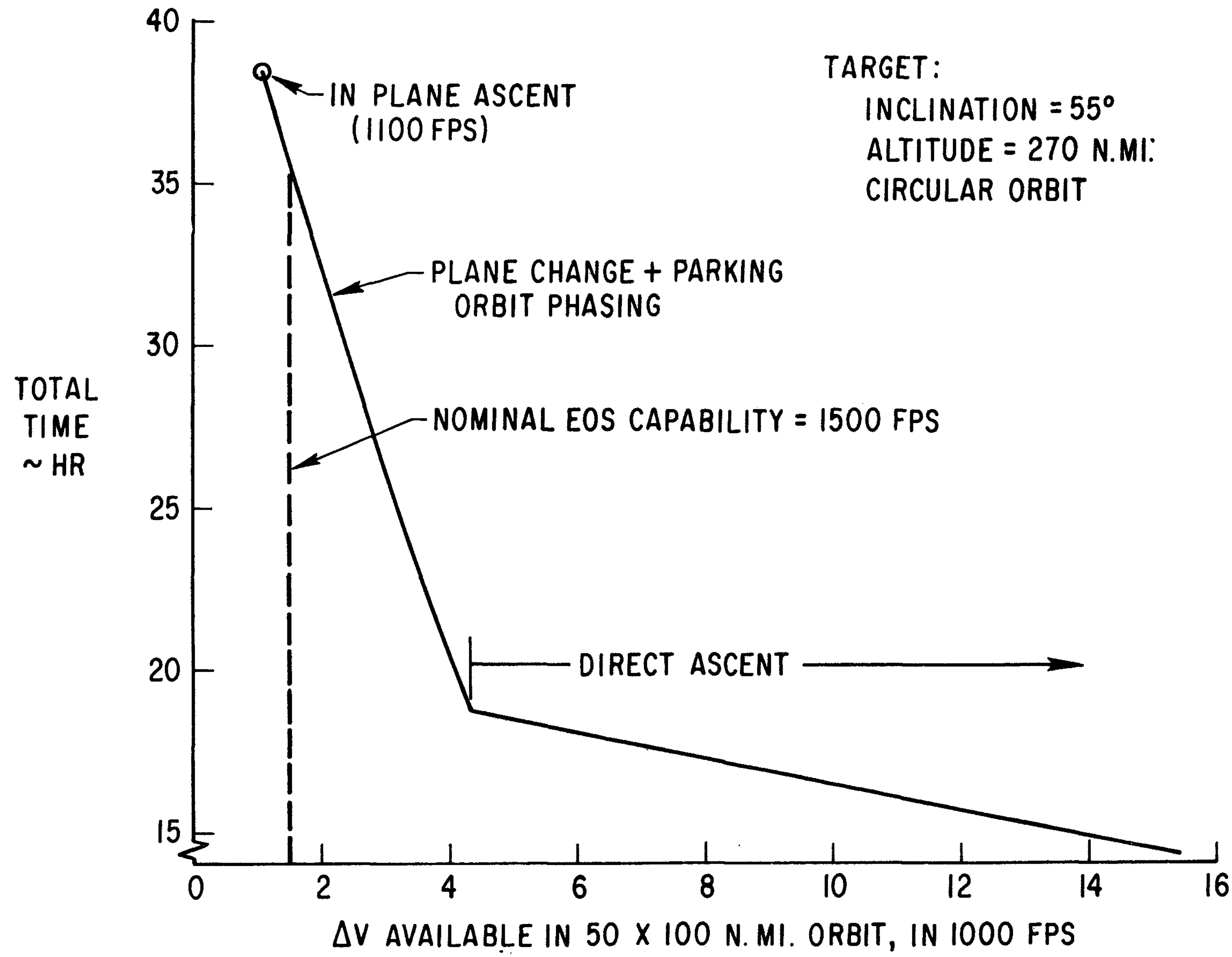


Figure I-18. Ascent and Rendezvous Time--Random Case

APPENDIX J

REMEDIAL SYSTEMS SELECTION

APPENDIX J

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APPENDIX J

REMEDIAL SYSTEMS SELECTION

J.1 GENERAL*

J.1.1 Objectives

One of the tasks of the Space Rescue Operations Study was a review of escape and rescue systems suitable for use with the manned hardware elements of the Integrated Program (IP). The objective of this task was to recommend a set of applicable remedial systems for more detailed consideration at a later time. These remedial systems were to provide techniques for resolving the emergencies identified in Appendix B, including an escape and rescue capability if necessary. The Space Rescue Vehicle (SRV) equipment requirements developed by this study and reported in Appendix H were to be used in deriving and sizing the remedial systems.

The remedial systems were to be derived in the gross sense. Order-of-magnitude estimates of size, capacity, performance capability, and development and unit costs were to be provided if readily available, but major effort was not to be devoted to detailed estimates.

This Appendix describes the procedure used in arriving at a recommended set of remedial systems, using the weight and cost estimates presented in Appendix K and the performance requirements established in Appendix E.

The terms "remedial means" and "remedial systems" will be used frequently in this Appendix. These terms are defined as follows:

> Remedial Means (RM) -- Functional or operational concepts which provide the desired relief for a given emergency situation.
>
> Remedial System (RS) -- The hardware elements and equipment which implement the remedial means concept.

*This Appendix is based on the work of E. J. Rattin and M. G. Hinton.

J.1.2 Ground Rules and Assumptions

The problem initially faced in planning the RS selection effort was the very large matrix of systems, emergency situations, and mission classes from which the most effective systems were to be selected. The 11 mission classes with which this study was concerned were discussed in detail in Appendix A and are listed below:

1. Low Earth Orbit Space Station (LEOSS) and operations associated with it
2. Geosynchronous Orbit Space Station (GEOSS) and associated operations
3. Space Tug in Low Earth Orbit (LEO) operations
4. Space Tug in Geosynchronous Orbit (GEO) operations
5. Space Tug in Lunar Orbit (LO) operations
6. Space Tug on the Lunar Surface (LS)
7. Lunar Surface Base (LSB) and Orbiting Lunar Station (OLS) operations
8. Earth Orbit Shuttle (EOS) in LEO operations
9. Space Shuttle in LO or in transit between earth and moon
10. Space Shuttle in GEO or in transit to and from LEO
11. Space Shuttle in LEO

Emergency situations resulting from a variety of hazards were discussed in Appendix B. These fall into 10 general categories:

1. Ill or injured crew
2. Metabolic deprivation due to Environmental Control and Life Support (EC/LS) failure or shortage of food and water.
3. Stranded or entrapped crew due to equipment failure, illness or injury occurring in EVA, etc.
4. Inability to communicate due to equipment failure or crew disability
5. Out-of-control spacecraft due to equipment failure or collision
6. Debris in the vicinity due to collision or failure of nearby spacecraft

7. Radiation in vicinity due to reactor or isotope power source malfunction on spacecraft
8. Non-habitable environment due to accidental decompression, contamination, or ECLS failure
9. Abandonment of spacecraft forced by equipment failure, fire, etc.
10. Inability to reenter atmosphere (EOS only) due to propulsion failure, collision, or other damage to the heatshield, control systems failure, etc.

The Remedial Means (RM) potentially applicable to the mission/emergency situation matrix resulting from the above are shown in Table J-1. These nine RM categories cover a variety of RS of varying sizes and capabilities. This makes the selection process monumental in size unless a method can be found to intensively screen the resulting matrix. Quantitative methods are limited because emergency event probabilities are not available, the IP hardware elements are not fully defined, and many of the RS are still in a conceptual status only.

It was necessary, therefore, to assume equal probability for all the emergencies that can occur, and that the RS are therefore required to handle all anticipated emergencies. Space stations are assumed to contain some medical equipment so that they could serve as interim havens for ill or injured crews prior to their return to the permanent haven of safety on earth. Space Rescue Vehicles (SRV) are assumed to be capable of being launched either manned or unmanned, as required by the emergency. If the crew of the Distressed Vehicle (DV) is functioning, an unmanned vehicle might be sufficient, and exposure of a rescue crew to possible hazards would be avoided. In some instances, as in the case of radiation hazard, an unmanned rescue vehicle may be the only permissible rescue means regardless of DV crew conditions.

Other assumptions are listed in the sections to which they relate.

J.1.3 Approach

A qualitative approach was chosen for reduction of the multi-dimensional matrix of candidate RM and RS for the reasons discussed above. This process consisted of two phases, as shown in Figure J-1. The first phase was concerned with derivation of the minimum possible number of RM that could cope with all mission classes and emergency situations under study. The second phase defined the hardware systems needed to perform these remedial functions, then reduced the number of hardware systems to the minimum number that would be able to cope with all anticipated emergencies. This second phase emphasized the use of planned or modified IP elements rather than all-new developments.

Being non-quantitative, the selected study approach relied on ranking procedures that were often based on judgment rather than measurement. The following discussion briefly summarizes this approach.

As discussed in Section J.1.2, the 10 separate emergency categories must be initially assumed as applicable to each mission class. One particular aspect of each emergency situation will be most critical for each mission class. An RM was selected to provide a solution for this most critical aspect or condition. If this RM could not also cope with the remaining aspects of the emergency situation, it was backed up by others. The remaining emergency situations were similarly analyzed for the same mission class. After all ten emergency situations had been analyzed for a single mission class, the set of RM thus derived was screened to remove duplications. This resulted in a minimum set of RM that could respond to all of the emergencies applicable to that mission class. This process was repeated for all of the mission classes. The total set of RM thus derived was then screened to eliminate duplication between mission classes. This final set of RM would be effective over the entire mission spectrum and for all of the applicable emergency situations.

The second phase of the analysis was concerned with selection of the RS matching the functional or operational concepts represented by the final set of RM. The process was initiated by defining critical requirements such as performance, size, and mission duration for the RS that matched the final set of RM. Candidate RS were then selected from planned elements of the IP, and modified where needed. Where this proved impossible, consideration was given to a new RS development to meet specific requirements. A set of selection criteria was then applied to reduce the resulting RS possibilities to the minimum number able to meet all of the functional or operational requirements of the final RM set. The remaining RS group was again screened to determine which RS could combine more than one remedial concept in a single hardware item, thus resulting in a further reduction of the candidate RS set.

Cost criteria could be used to arrive at a least-cost set. However, this procedure, although desirable, was not performed because sufficiently detailed data were not available at this time.

J.2 ANALYSIS

J.2.1 Remedial Means (RM)

J.2.1.1 RM Characteristics

In selecting remedial means from those listed in Table J-1 for application to the mission/emergency situation matrix discussed in Section J.1.2, certain characteristics were considered more desirable than others. Top preference was given to the ability to return a distressed crew directly to a safe haven. This characteristic is exhibited by the "Mission Abort" and "Bailout and Return Device" (BOR) categories.

The BOR is carried by the mission vehicle, can be detached upon need, and contains sufficient propulsion to travel to a safe haven. For example, two such havens could be postulated to exist for emergencies in LEO. A BOR designed to retro directly to earth might require a ΔV of about 300 fps. If it were planned for rendezvous with the LEOSS, it might require about 600 fps of ΔV to permit phasing, altitude adjustments, and rendezvous and docking.

The Mission Abort category of RM allows the crew to remain on board the DV while returning to safe haven, and is thus the most preferred RM. However, it applies to IP transporter elements only.

A lower ranking is given to an RM which permits the crew to abandon the DV but has no means for reaching a safe haven independently. A Bailout and Wait Device (BOW), attached to the DV, falls into this category of remedial means. It allows prompt shirtsleeve escape from a rapidly deteriorating emergency situation on board the DV. The BOW may be able to cast off and provide some separation distance between itself and the DV, but its propulsion is essentially limited to an attitude control system. To be effective, this concept requires pairing with a retrieval vehicle.

Concepts which permit aid to be brought to the DV, or which retrieve the DV crew for return to a safe haven are next in the preference ranking. Although emergencies may require such external aid if, for example, the DV crew has no means of self-help, the retrieval concept requires time for aid to reach the DV. This time may be critical in terms of crew survival. Included in this class of RM concepts is an unmanned assistance package which is shipped to the DV upon request and requires that the DV crew be able to receive the shipment and utilize its content. If, for example, damage to the breathing oxygen supply of a lunar space station results in a call for assistance, a space shuttle or a tandem space tug, using an automatic rendezvous and transfer procedure, might be sent to the station with replacement oxygen.

In addition to a supply package, such an unmanned shipment might also include an Unmanned Rescue Module (URM) to be operated by the DV crew. This concept would be employed if abandonment of the DV is required and if the crew is fit to operate the return vehicle. It might also be employed if approach to the DV is considered hazardous and the risks to a rescue crew are believed unnecessary.

The manned Space Rescue Vehicle (SRV) concept ranks last in this preference list because it represents the most complex RM. First, it may take longer to respond than an unmanned vehicle. Secondly, it requires a more capable transportation system, since it weighs more than an unmanned vehicle. And finally, it will expose additional personnel to hazard. However, this vehicle is a last resort and must be used when the preferred means cannot cope with the rescue need. For this reason, it will remain prominent in the selection matrix.

Other characteristics are also considered in the selection process. For example, the BOR and the manned/unmanned rescue and retrieval means should preferably return the DV crew directly to the final safe haven, earth. In some instances it may be necessary to use an intermediate haven such as a space station, but since the final destination will in all cases be earth, preferential ranking will be given to those RM which can reach this final haven directly.

RM selection should also emphasize speed of response to an emergency. Here again BOR and BOW rank higher than unmanned assistance or manned rescue vehicles. RM should also provide maximum speed of return to a safe haven.

The BOR and the Buddy system rank highest from this point of view because they are at the scene of the emergency when it occurs, and in most instances can immediately depart for a safe haven. Rescue vehicles sent to the DV must consume additional time in reaching it.

Finally, the RM should be able to offer aid specific to the emergency situation. Here the SRV ranks highest because it can offer manned aid, and can be equipped prior to departure with equipment required for dealing with the specific emergency, to the extent that its nature is known.

Among RM categories, the Buddy system is unique in that it exhibits mixed characteristics. It is defined as another vehicle travelling with the mission vehicle. It may simply accompany the mission vehicle as a backup, or it may carry part of the mission payload and crew. In either case, it travels sufficiently close to the other vehicle to offer almost immediate aid. The degree of aid is somewhat less than that of the SRV (except for speed of response), because it will not contain specialized rescue equipment to the same extent as the SRV. It is also somewhat less effective than the BOR, except in the case where the vehicles are joined, which is not treated here. Docking between the two vehicles may not be feasible, so that transfer may have to be by EVA whereas transfer into the BOR could be made in shirt-sleeves. The Buddy system is more effective than the BOW, since the Buddy can provide return to a haven and can also offer some manned assistance.

Another RM included in this study is the concept of a Prepositioned Aid Package (PAP). As used here, this concept applies to non-transiting vehicles such as a space station or lunar exploration site, and assumes that shelter and supplies are placed in a dormant state nearby. The PAP may consist of a BOW or a BOR placed within easy reach of the crew by EVA from the mission vehicle, or it may consist merely of crew survival equipment such as breathing oxygen for use by a crew stranded in EVA. Its only advantage over the BOW or BOR concepts is that it is not attached to the mission vehicle, and thus may escape the effects of the emergency situation to which the other RM have been subjected. The PAP concept may also be used where the mission vehicle configuration prevents the docking of a BOR or BOW.

One category of RM assumed to be present in all IP elements consists of onboard supplies and equipment of a backup nature, dedicated to emergency use only. Emergency oxygen supplies and emergency subsystems such as communication equipment would fall into this category. Since all vehicles are assumed to be so equipped, the selection process used for this study did not consider this RM as a variable.

Table J-1 places the RM discussed above into three classes representing self-help, unmanned aid, and manned aid concepts. The numbers assigned do not represent a ranking system, but are merely used to identify each RM in subsequent analyses.

J.2.1.2 RM Application

As indicated in Section J.1.3, the RM must be selected from Table J-1 for each of the 11 mission categories on the basis of being best able to respond to the most critical aspect of a particular emergency situation. If several RM meet this requirement, they are selected by giving preference to the self-help means, followed by the unmanned means, and finally the manned assistance means. The selected RM may be backed up by other RM, but only if the mission or the emergency situation requires such a backup. The assumption is made that the RM always functions as intended, and therefore requires no backup for itself. An example of a case when backup is permissible is an emergency situation involving disability of the crew, which voids their self-help capability. For example, in a "metabolic deprivation" emergency, the condition may have so deteriorated that the crew is disabled, preventing abort or use of the BOR. Other examples include the case in which a preferred RM is impractical because of mission payload constraints preventing the use of a BOR, or where the limited number of vehicles in the fleet does not permit use of a Buddy RM.

Figure J-2 provides an example of the RM application procedure. The particular emergency situation chosen, the case of a stranded or entrapped crew, shows that the critical condition will vary depending on whether the mission vehicle is a stationary space vehicle or a transporter vehicle. It was assumed here that EVA was more likely in the instance of the space station than in that of the transporter, and that being stranded in EVA was more critical than being merely trapped within the space station. The RM considered to be applicable are indicated by number codes in the three columns on the right. This code corresponds to the numbering system used in Table J-1.

If an astronaut is stranded in EVA outside a space station, the most rapid means of aid will be required, since portable life support systems have limited duration. A BOW or other temporary shelter external to the space station would be a suitable RM, as would additional oxygen supplies or PLSS-type equipment located in a position accessible to the astronaut. The PAP concept, which includes this capability, was therefore selected as the most desirable RM for this condition. Since the PAP by itself cannot return the astronaut to a safe haven, an unmanned rescue module (URM), at the least, is also required to provide the retrieval capability. The URM is not a back-up, but is paired with the PAP to form a single RM concept. If the PAP contains a BOR, the URM is not required.

When the emergency condition considered most critical involves entrapment, the implication is that a rescue crew will be required to open a path to the sealed DV crew compartment and effect the rescue. The SRV has therefore been selected as the RM for this condition. RM (1), onboard supplies and equipment, is assumed to be on board all vehicles and is therefore not specifically listed.

Similar considerations were applied to the remaining nine categories of emergency situations included in this analysis. Table J-2 shows the critical conditions selected as a function of mission class for each of the emergency situations. For the purpose of this table, as well as Figure J-3, it was convenient to combine the mission classes for shuttle in LO, GEO, or in Transit into a single class. The RM requirements of these classes are similar.

The RM selected to cope with these critical conditions are shown in Figure J-3. The number code is again that of Table J-1, and triangles have been used to indicate the preferred RM concept. The URM (7) frequently appears paired with the BOW (2) or with the PAP (4). When it is shown associated with the BOR (3), however, it is used as a backup instead of being paired. For example, in the instance of the EOS suffering a non-habitable environment, the URM would be used only if the BOR, after hardware system sizing, proved too heavy or too bulky to be carried on or within an EOS. A number of the backup situations shown in Figure J-3 were resolved during the subsequent RS analysis in which weight and size estimates were used to select applicable systems.

Table J-3 summarizes the data of Figure J-3 by listing the number of missions in which each RM is applied in the primary or desired role, and those missions in which the RM serves as a backup. It is of interest to note that the only RM which seems to have no application is (6), the "Shipped Supplies and Equipment" concept. As already mentioned, onboard emergency supplies and equipment are desired across the board (by definition). BOR is either desired or backup in all of the mission classes. The same is true for the SRV. The URM, however, seems to be required only as a backup, either by itself or paired with the BOW.

This summary indicates that performance and design requirements need to be developed for eight of the nine RM categories. Since the different missions have different performance and size requirements, a sizable matrix of requirements for RS results.

J.2.2 Remedial Systems (RS)

J.2.2.1 RS Requirements

The consideration of candidate RS and their subsequent reduction to a recommended set was semi-quantitative in the sense that precise specification of RS is not feasible at this stage of the IP development. Some quantitative information was necessary, however, to assist in the selection of preferred RS. The ability of a particular mission vehicle to accept a specific RS might depend, for example, upon the mass characteristics of the RS and upon the discretionary payload capability of the vehicle.

For the purpose of this study, the large set of characteristics which could be used to describe a specific remedial system was reduced to those listed below:

1. Crew and Passenger Capacity - Applicable to BOR, BOW, URM and SRV; also applicable where a "Buddy" is not the same as the mission vehicle
2. Response Time Limits - Applicable to those mission and emergency situation combinations for which the URM or SRV concepts were selected
3. EC/LS Sizing - A mission duration-dependent characteristic applicable to BOR, BOW, URM and SRV; also applicable to onboard emergency equipment and life support equipment contained within a PAP
4. ΔV Requirements - Applicable to BOR, URM and SRV; also of interest where a "Buddy" is not identical to the mission vehicle
5. Structural Requirements (reentry shielding, water impact, etc.) - Applicable primarily to BOR
6. Docking System Requirements - Applicable to BOR, BOW, URM, and SRV

Table J-4 shows an abbreviated listing of the critical requirements derived for the BOR. Although a great variety of requirements appear on this table, grouping of missions into classes of similar requirements is feasible and, as will be shown, can result in a reduced set of candidate BOR. Similar listings were prepared for BOW, URM, SRV and other equipment needs.

The candidate RS based on these listings are discussed in the following section.

J.2.2.2 Remedial Systems Candidates

J.2.2.2.1 Bailout and Return Systems (BOR)

Table J-5 shows the BOR selected to match the characteristics of Table J-4. The earth reentry systems are designed to apply to IP elements in low earth as well as in geosynchronous orbits, or in transit between these orbits. The relatively low weights of these BOR devices, and their proposed use in a dormant state over long time periods docked to vehicles such as space stations, led to selection of storable-propellant retro systems. Details of these systems are provided in Appendix K. The reason for evaluating three small earth reentry systems with the same ΔV capability (300 fps) was to permit exploration of several designs. The Modified Apollo CM (MAP), as indicated in Table J-5, is derived from the current Apollo command module, and is a North American Rockwell concept. The MAP with a 5000-fps ΔV capability is a candidate for GEOSS application. The XM, which represents an expandable module concept, was also proposed by North American Rockwell and was selected since it offered the most likely BOR capability for the EOS Orbiter. Because of the ascent and reentry mission mode of the EOS, an externally-mounted BOR is not appropriate, which leaves only storage within the cargo bay as a possible approach. Payload volume considerations make it desirable to consider an expandable concept, which requires removal from the cargo bay prior to expansion and rigidization of the structure. This concept does increase reaction time, and may require special provisions in the EOS to permit shirtsleeve transfer of the crew to the BOR after its deployment. The SERD, or small earth reentry device, is a Lockheed concept which differs from the MAP primarily in that it is a new design specifically created for space escape.

The BOR with space docking systems are designed to find a haven at one of the orbiting elements of the IP (space stations or OPD), and are sized for two propellant systems in order to compare weight and cost differences. Where the ΔV is very large, as in the MTCM III, the cryogenic system was arbitrarily chosen to minimize BOR weight. The assumption was made that a cryogenically fueled BOR could only be utilized in missions where resupply was frequent enough to permit replenishment of boil-off losses. Brief descriptions of the Modified Tug Crew Module (MTCM) and the individually sized Propulsion Module (PM) are provided in Volume II (Section 7) and Appendix K. The MTCM is based on space tug crew module concepts provided by North American Rockwell and Boeing. The Propulsion Module (PM) is specially sized for this application.

The BOR systems with 4000-fps ΔV capability are designed to reach a safe haven at the OLS from a vehicle in transit to the moon. The MTCM III is sized to return a crew from GEO to LEO, and can also be used between lunar orbit and the lunar surface. For example, when used with the Lunar Surface Base (LBS) it can reach the OLS even in the worst plane change case. The MTCM I is able to provide a BOR function between vehicles in the same orbit, i.e., between space station and OPD, or a space shuttle in lunar orbit and the OLS. In the latter instance, the BOR is assumed to be attached to the shuttle on arrival in lunar orbit and to remain with it until departure.

J.2.2.2.2 Bailout and Wait Systems (BOW)

Both rigid and expandable BOW systems have been sized for this study. The BOW is characterized by being attached to the mission vehicle and serving as a temporary haven. It permits shirtsleeve transfer of a crew fleeing the primary vehicle because of an emergency which makes continued operation of the vehicle impossible. The BOW may also be used in a PAP mode. The BOW has no propulsion other than an attitude control system.

The expandable design listed in Table J-6 is based on in-house studies by The Aerospace Corporation. The rigid BOW design is based on the basic Space Tug crew module shell, with sufficient subsystems to permit survival of the crew until rescued by some other vehicle.

The smaller crew capacity vehicles of Table J-6 are associated with transporter type IP elements such as tugs and space shuttles without passengers. The 15-man capacity BOW is used with transporters, such as a space shuttle carrying a full rotation crew, or with space stations. The EC/LS life is based on response time assumptions, since the BOW can provide only a temporary haven and must depend upon other vehicles to complete the RS function of returning the crew to safe haven.

Details of BOW configurations and equipment complement are provided in Volume II (Section 7) and Appendix K.

J.2.2.2.3 Space Rescue Vehicle (SRV) and Unmanned Rescue Module (URM)

Table J-7 shows the candidate RS selected under this category. In all cases except one, the basic module used is that of the Crew/Cargo Module (CCM) being considered for use with the EOS. The modifications required to convert the CCM into either URM or SRV are described in Volume II (Section 7) and Appendix K. The essential difference between these two vehicles is in the amount of special rescue equipment carried on a specific mission. The rescue need can be satisfied with URM if the DV crew (or part of the crew) are functioning, can transfer themselves into the URM, and can operate the URM. In this case, only about 1200 lb of equipment is carried on board the URM. Table J-8 shows a list of such equipment. If the rescue is to be performed in a manned mode, and if the maximum capability is to be provided, about 11,000 lb of equipment might be required, as shown in Table J-9. This latter weight was used in sizing the propulsion requirements for the SRV.

In the one instance in which the MCCM was not used, the candidate system selected was the Space Tug Crew Module with a Space Tug Propulsion Module. This vehicle, however, was used here as the standard tug, not equipped with special rescue equipment. Nevertheless, this vehicle will undoubtedly be able to respond satisfactorily to some of the emergency situations that might occur, for example, the need to abandon a DV. For this reason, it is retained in the list of candidate vehicles.

As indicated earlier, the ΔV allowances shown for each of the candidate systems relate to the mission regime for which the system is intended. The 14,200-fps figure identifies a vehicle based in GEO and returning to a LEO haven; ΔV of 18,000 fps identifies a rescue mission from OLS to LS and return; and so forth. In one instance, that of the MCCM with a Staged Tug, the actual ΔV capability available was in excess of the required 18,000 fps. The Staged Tug refers to a propulsion module of the space tug under consideration, with a gross weight of about 71,000 lb. The staging consists of two of these propulsion modules in tandem.

When the EOS is used to transport an SRV to the vicinity of a DV in LEO, the ΔV capability required is minimal, and is used only for docking or station-keeping maneuvers. The attitude control system of the MCCM is expected to provide ΔV increments of the order of 200 to 300 fps. Where a 1000-fps ΔV is shown, the vehicle is based in the same orbit as the DV and will require ΔV for phasing, terminal rendezvous, and docking maneuvers.

For some rescue situations, Appendix E shows ΔV requirements greater than those provided for in Table J-7. Vehicle sizing for these requirements showed excessively large propulsion module weights. These vehicles have not been shown on Table J-7 because of the very low probability of their eventual application.

J.2.2.3 Remedial System Selection

J.2.2.3.1 System Selection Criteria

Section J.2.2.2 indicated that the RM selection process reduced the candidate set somewhat, but left 5 BOW, 8 BOR, 10 URM and SRV, the Space Shuttle and the Buddy System in the candidate set. Further reduction is needed in order to reduce the set to an economically feasible number.

The selection criteria used in this next reduction process consisted of general criteria as well as criteria for relative ranking of systems. The general set of criteria was concerned with questions of practicality. The practicality criterion was applied, for example, when the candidate RS would reduce the basic performance capability of the mission vehicle to a degree that made its acceptance unlikely. For example, on a 50,000-lb payload mission to the moon, if 15,000 lb of payload capability was required for a BOR, this remedial system was considered impractical for that mission. In contrast, it was considered practical to attach a 15,000-lb BOR to a Space Shuttle while in either LEO, GEO, or LO in order to provide crew escape capability while in standby orbit. The BOR would be removed prior to transfer orbit injection.

Another practical consideration introduced as a criterion was that of required stowage volume. It was considered impractical, for example, to store a rigid BOR or BOW in the cargo bay of an EOS as a permanent arrangement. It was assumed that the maximum degradation in payload volume the EOS mission might tolerate would be that of an expandable structure.

The relative ranking procedure used is described in the next section of this Appendix. This ranking considered the degree of aid which the RS could offer, its reaction time, the complexity of its operation by the distressed crew, its development status, and how many other applications the RS would have within the total mission context. The state of the art represented by the RS was also considered, with current or planned IP state of the art being preferred.

J.2.2.3.2 Remedial System Ranking

Figure J-4 shows the characteristics considered in assigning the "Degree of Aid" ranking, as well as the rankings assigned to the various RS. The highest numbered rank is the preferred system. Most valued in this ranking system are the ability to respond immediately to the emergency situation, exhibited by the BOR, and the ability to return the DV crew to the final earth haven without intermediate havens. The ability to merely provide shelter while waiting for another system to retrieve the crew is valued least in comparison with other characteristics. However, the usefulness of the BOW is not to be ignored when it is the only system feasible.

Although the SRV offers many categories of aid, it ranks relatively low because of the necessarily longer response time, and time for return to haven. It is also important to note that the BOW was always assumed, for the purpose of this analysis, to be present except where the BOR or the Buddy system was listed. All other remedial systems require the BOW to assure survival of the crew in the worst-case emergency until retrieval can be accomplished.

Table J-10 is an example of the ranking sheets prepared for each mission class included in the analysis. It shows the ranking criteria used in addition to the "Degree of Aid" criterion. The "Multiple Use Factor" takes account of all the mission classes, as shown in Figure J-5. The highest rating for this criterion would therefore be 11, indicating that the candidate system can be applied to all mission classes under consideration. The reaction times shown are estimates of the actual time required, and are based on the assumed system location. In the example of Table J-10, basing was assumed to be either on the ground, or in LEO. Since the Space Tug/MCCM system cannot be launched from the ground in the cargo bay of the EOS Orbiter, the time shown assumes that the MCCM is brought into LEO by the EOS, and the Space Tug Propulsion Module is then rendezvoused and docked with it.

The "Development Status" criterion permits three levels of ranking, based on whether the candidate system represents a totally new development, can be modified from a planned IP element, or can utilize a planned IP element without modification. The latter is, of course, preferred.

The "Complexity Factor" criterion also allows three levels of ranking and measures the difficulties the DV crew might face in operating the RS. The highest ranking here would obviously go to the manned SRV because this system requires nothing from the DV crew except to communicate where possible. The BOW does require the crew to function to the extent of being able to reach the shelter, to close the hatch behind them, and to initiate operation of the emergency systems, such as EC/LS, that might be on board the BOW. The XM, on the other hand, is an expandable BOR which would require considerable activity on the part of the DV crew to remove it from its stowage area, inflate it, dock it against a hatch (if not already attached), and enter it. Entry might even require EVA in extreme cases. Finally, the crew must operate the XM to perform reentry and landing. It therefore has the lowest rating under this criterion.

"State of the Art" (SOA) is self-explanatory and has only two levels of ranking. The XM is not only a new development but also represents some possible extension in the state of the art since such devices have not as yet been developed to operational status. The other RS of Table J-10 are based on IP elements and will therefore be state of the art when the IP becomes operational.

The "Degree of Aid" criterion has been discussed previously.

For the example of the LEOSS mission class, the XM, although not state of the art and requiring new development, is considered the preferred system because it renders the highest degree of aid, that is, it has zero reaction time and returns the DV crew to earth haven directly. If the XM cannot be provided, the Space Tug/TCM or the EOS/MCCM systems would probably constitute the second choice. The latter is somewhat higher in ranking since it can provide aid of which the TCM is not capable. Because of its multiple uses, however, the Space Tug/TCM may be more readily available, and with its shorter response times is thus also a desirable RS.

J.2.2.3.3 Remedial System Application

Figure J-5 shows the results of the ranking procedure completed for all 11 mission classes. It also shows the order of the final RS in the candidate set by development status. The RM represented by the various systems are also identified on this figure by use of the same number code used in Table J-1. Applicability of the specific RS is indicated by entry of the RM concept code under the appropriate mission class heading. In one case, that of the Space Tug/TCM, the same system can function under several RM concepts.

All of the systems indicated in Figure J-5 are applicable, but some carry the further designation of "Preferred," identified by a triangle, others are "Second Choice," identified by a square.

In the case of the Standby Shuttle, which is the Space Shuttle kept in LEO in standby status, the word "Paired" appears several times. This indicates that the mission class prevents the Space Shuttle from performing the rescue mission by itself, and that it requires an SRV in association with it. This alternative mode occurs when the DV is a space station against which the nuclear Space Shuttle cannot dock, or when the DV is on the lunar surface, which the Space Shuttle cannot reach. In the latter case, Figure J-5 shows that the Space Shuttle is paired with the Staged Tug/MCCM, since a single propulsion module has insufficient ΔV capability to reach the LS and to return under the worst conditions of plane change.

Two of the RS listed have only a single mission application. These are the BOW systems designated as RBOW II and RBOW III. Although other systems are also shown under their respective mission class categories, it should be noted that none of the alternates represent BOW. In the case of the LSB/OLS mission class, a BOR is shown which could replace the BOW. In the other case, that of the Space Shuttle in LO or in Transit, RBOW III must be retained since all of the other applicable systems except the Buddy require a BOW capability for maximum effectiveness.

It is of interest that the "Preferred" systems are those functioning in the BOR mode or the Buddy mode. Another RM highly rated during the analysis of Section J.2.1, that of "Mission Abort," is still a preferred concept where feasible, but does not appear on this figure since it is not a separate hardware system. Mission abort capability is presumed to be available on those IP mission vehicles where it is meaningful.

Figure J-5 clearly shows the wide applicability of systems such as the Space Tug/TCM or the Space Tug/MCCM. It also shows that the wide spectrum of mission/emergency situations which were examined in this study can, for the most part, utilize planned or modified planned IP elements for escape and rescue. New development needs are thus reduced to the minimum. Of the two new development systems, only one, the XM, also represents new state of the art. The other new system, the MTCM I/PM, consists of a modified Space Tug Crew Module and requires new development only for the propulsion module. A more careful review of available propulsion systems than was feasible during this study may disclose current systems that would be suitable for the PM application.

J.3 SUMMARY AND RECOMMENDATIONS

Table J-11 relists the RS of Figure J-5 with their ranking characteristics added, and with estimates of both development and recurring costs. The derivation of the costs is discussed in more detail in Appendix K. It is not feasible to reduce this set further on the basis of either ranking factors or cost at the current level of definition of the IP and its elements.

The XM represents the only RS which will meet the configurational and payload restrictions of the EOS, and for that reason should be considered for development. The Space Tug/TCM and the Space Tug/MCCM have such wide application that they should also be part of the final set of RS. The Buddy system is desirable; mission planning should make allowance for this concept wherever possible, particularly in the instance of lunar missions where Figure J-5 shows this to be the preferred system for manned Space Tug/TCM application.

The cost shown for the MCCM includes that of the special equipment listed in Table J-9. The modifications to the Crew/Cargo Module are estimated to have a development cost of $175 million. A total of $75 million is estimated as the cost of developing the special rescue equipment of Table J-9. This latter cost may be reduced upon future consideration of the event probabilities of the various emergency situations postulated by this study.

A number of tradeoff studies would assist in the final selection of RS, based upon event probability data and a more definitive mission model. It would also be desirable to explore the economics of using the Buddy system for those applications where Figure J-5 suggests the application of the new design BOR, the standby Space Shuttle by itself or teamed with the Space Tug/MCCM, or the Staged Tug/MCCM.

Cost and rescue success tradeoffs should be explored for basing the Space Tug/MCCM as an SRV at space stations in LEO, GEO, and LO, versus SRV basing in LEO or on earth. In the former instance, part of the space station crew would be trained to perform rescue missions and would enter the SRV only when required, the vehicle remaining in a dormant state between emergencies. In the latter instance, a standby shuttle would be required to transport the SRV to GEO and LO, with ground basing also requiring an EOS flight. The rescue crew, if part of the LEOSS crew, would perform normal mission functions until declaration of an emergency.

Another trade of interest involves studies of the economics of developing new BOW systems instead of modifying IP elements. Because of the limited and specialized functions expected of a BOW, new development may provide a more effective remedial system without extensive cost increases.

Table J-1. Categories of Remedial Means

Self-Help	Unmanned Assistance	Manned Assistance
(1) On-Board Supplies and Equipment*	(6) Shipped Supplies & Equipment	(8) Space Rescue Vehicle with Return** Capability
(2) Bail-out and Wait Device (BOW)	(7) Unmanned Rescue Vehicle with Return** Capability (URM)	(9) Buddy***
(3) Bail-out and Return** Device (BOR)		
(4) Prepositioned Aid Package (PAP)		
(5) Mission Abort**		

* Assumed on DV to the extent permitted by payload considerations.

** To safe haven.

*** The buddy system does not require use of Identical Twins.

Table J-2. Critical Condition for Each Mission/Emergency Situation

MISSION CLASSES	EMERGENCY SITUATIONS									
	Ill / Injured	Metabolic Deprivation	Stranded / Entrapped	No Communication	Out of Control SC	Debris in Vicinity	Radiation in Vicinity	Non-Habitable Environment	Abandonment of SC	Inability to Reenter
LEOSS	Urgent; treatment not available on board	Loss of oxygen	Stranded in EVA	Inability to notify of emergency	Tumbling	Penetration of living space	Runaway reactor on board	Loss of temperature and humidity control	Crew in EVA	NA
GEOSS	Same	Same	Same	Same	Same	Same	Same	Same	Same	NA
Tug in LEO	Same	Same	Trapped without egress	Same	Unsafe Trajectory	Same	Transit into radiation field	Same	Same	NA
Tug in GEO	Same	Same	Same	Same	Same	Same	Same	Same	Same	NA
Tug in LO	Same	Same	Same	Same	Same	Same	Same	Same	Same	NA
Tug on LS	Same	Same	Same	Same	Same	Same	Same	Same	Same	NA
LSB/OLS	Same	Same	Stranded in EVA	Same	Tumbling (OLS only)	Same	Runaway reactor on board	Same	Same	NA
EOS	Same	Same	Trapped without egress	Same	Unsafe trajectory	Same	Transit into radiation field	Same	Same	Heatshield, propulsion, controls failure
Shuttle in LO, GEO, or in transit	Same	Same	Same	Same	Same	Same	Runaway reactor on board	Same	Same	NA
Shuttle in LEO	Same	Same	Same	Same	Decaying orbit	Same	Same	Same	Same	NA

Table J-3. Summary of Mission Applications

Remedial Means		Number of Applications	
		Desired	Backup
①	On-Board Supplies and Equipment	11	-
②	Bail-out and Wait (BOW)	-	9
③	Bail-out and Return (BOR)	5	6
④	Prepositioned Aid Pack (PAP)	4	-
⑤	Mission Abort	8	-
⑥	Shipped Supplies and Equipment	-	-
⑦	Unmanned Rescue Vehicle (URM)	-	11
⑧	Space Rescue Vehicle (SRV)	8	3
⑨	Buddy	8	-

Table J-4. Critical Remedial Systems Requirements for Bailout and Return (BOR)

MISSION CLASS	SAFE HAVEN	CREW & PASSENGER CAPACITY	Δ V FPS (approx.)	ECLS Life, hr	STRUCTURAL NEEDS
LEOSS	EARTH GROUND	12	300	12	WATER LANDING
	OPD/TCM		600		SPACE DOCK
GEOSS	EARTH GROUND	3-15	5000	12	WATER LANDING
	LEOSS/OPD		14,200	36	SPACE DOCK
TUG IN LEO	LEOSS/OPD	3-15	600	12	SPACE DOCK
	EARTH GROUND		300		WATER LANDING
TUG IN GEO	GEO	3-15	600	12	SPACE DOCK
	LEOSS/OPD		14,200		SPACE DOCK
	EARTH GROUND		8300		WATER LANDING
TUG IN LO	OLS	3-15	400	48	SPACE DOCK
	LEOSS/OPD		14,000	72	
	EARTH GROUND		4000	72	WATER LANDING
TUG ON LS	OLS	3-9	6000-12,000	120	SPACE DOCK
	LEOSS/OPD		20,000-26,000		
	EARTH GROUND		10,000 - 16,000		WATER LANDING
LSB/OLS	EACH OTHER	9-12	6000-12,000	120	SPACE DOCK/LS LANDING
	OLS TO LOPD		600	12	SPACE DOCK
	OLS TO LEOSS		14,000	72	SPACE DOCK
	TO EARTH GROUND		10,000-16,000	120	WATER LANDING
EOS IN LEO	LEOSS/OPD	3-15	600	12	SPACE DOCK
	EARTH GROUND		300		WATER LANDING
SPACE SHUTTLE IN LO OR IN TRANSIT	OLS	3-15	4000	72	SPACE DOCK
	LEOSS/OPD		10,000	120	
SPACE SHUTTLE IN GEO OR IN TRANSIT	GEO	3-15	6000	12	SPACE DOCK
	LEOSS/OPD		14,200	12	
	EARTH GROUND		5000	12	WATER LANDING
SPACE SHUTTLE IN LEO	LEOS/OPD	3-15	600	12	SPACE DOCK
	EARTH GROUND		300	12	WATER LANDING

Table J-5. Candidate BOR Systems

	EARTH REENTRY SYSTEMS				SPACE DOCK SYSTEMS			
	STORABLE PROPELLANT				STORABLE PROPELLANT		LOX / H_2	
	MAP* I	MAP* II	SERD*	XM	MTCM I & PM	MTCM II & PM	MTCM III & PM	MTCM IV & PM
$\triangle$V, FPS	300	5,000	300	300	1,000	4,000	14,200	4,000
ECLS LIFE, DAYS	1.5	1.5	1.5	1.5	0.5	5	0.5	5
CREW AND PASSENGER SIZE	6	6	3	3	15	15	12	15
WEIGHT, TOTAL LB	6,240	11,640	3,400	2,200	11,860	18,450	38,500	15,800

MAP MODIFIED APOLLO CM
SERD SMALL EARTH REENTRY DEVICE
XM EXPANDABLE MODULE
MTCM MODIFIED SPACE TUG CREW MODULE (IP)
PM INDIVIDUALLY SIZED PROPULSION MODULE

*COULD SERVE AS PREPOSITIONED AID PACKAGE (PAP)

Table J-6. Candidate Bailout and Wait Systems (BOW)

	EARTH MISSIONS			LUNAR MISSIONS	
	XBOW I	XBOW II	RBOW* I	RBOW II	RBOW* III
ECLS LIFE, DAYS	2	2	2	28	28
CREW AND PASSENGER SIZE	3	15	15	3	15
WEIGHT, LB	1,800	6,200	6,700	6,000	16,600

XBOW = EXPANDABLE BOW

RBOW = RIGID BOW (MODIFIED SPACE TUG CREW MODULE, IP)

*CAN ALSO SERVE AS PREPOSITIONED AID PACKAGE

Table J-7. Candidate Unmanned Rescue Vehicles and Space Rescue Vehicles (LOX/H_2 Propellants)

	URM				SRV					
	MCCM & PM I	MCCM & PM II	MCCM & PM III	TCM* & Space Tug	MCCM & PM IV	MCCM & PM V	MCCM & PM VI	MCCM & Space Tug	MCCM & EOS	MCCM & Staged Tug
V, fps	1,000	14,200	18,000	18,000	1,000	14,200	18,000	12,500	200	18,000 plus
ECLS Life, Days	2	2	7	14	4	4	14	4	4	14
Crew and Passenger Size	15	15	15	15	15	15	15	15	15	15
Payload Weight and Special Equipment, lb	1,600	1,600	1,600	0	11,000	11,000	11,000	11,000	11,000	11,000
Total Weight, lb	21,000	71,000	102,000	86,000	33,000	111,000	160,000	106,000	30,000	167,000

MCCM = Modified Crew & Cargo Module (IP)

TCM = Modified Space Tug Crew Module (IP)

EOS = Earth Orbit Shuttle

PM = Individually Sized Propulsion Module

*Can be used manned or unmanned but does not carry special equipment of an SRV

Table J-8. Recommended Equipment for Unmanned SRV

	Number	Weight, lb
AMU Backpack	2	300
Transfer Capsule	1	500
Medical Kit	1	60
EVA Suits	2	140
Tethers	2	90
Personnel Carriers	2	20
Miscellaneous	-	100
	TOTAL	1210

Table J-9. Recommended Equipment for Manned SRV

		Number	Weight, lbs
Communications and Survey Equipment		-	700
Despin Devices		2	500
*Soft Docking Fixture		1	250
*Attachable Docking Fixture		1	800
*Portable Airlock		1	1600
EVA Suits	(4 + 3 for rescue crew)	7	500
AMU Backpack	(4 + 3 for rescue crew)	7	1050
Manipulator (Shirtsleeve)		1	2000
*Transfer Capsule		3	1500
*Sampling and Analysis Kit		1	50
*Damage Control Equipment		-	150
Remote Manipulator		1	1000
*Medical Kit		2	120
*Extended Survival Kit		1	500
Tethers (Umbilicals)		2	90
*Personnel Carriers		3	30
Miscellaneous		-	100
Spare Provisions		-	100
		TOTAL	11,040

*Special rescue equipment items not likely to be developed for other applications.

Table J-10. Reducing the Candidate RS Set: Example of RS Ranking Procedure

MISSION CLASS: LEOSS

REMEDIAL SYSTEM	MULTIPLE USE FACTOR	REACTION TIME, DAYS	DEVELOPMENT STATUS*	COMPLEXITY FACTOR	SOA	DEGREE OF AID
XM	3	0	1	1	NO	△9
EOS / MCCM	4	1.0 - 2.0 +	3/2	3	YES	8
EOS	4	1.0 - 2.0 +	3	3	YES	7
SPACE TUG / MCCM	9	0.5 - 2.5 +	3/2	3	YES	4
SPACE TUG/TCM	11	0.5	3	3	YES	3
RBOW I	4	0	2	3	YES	**1

* 1 = NEW DEVELOPMENT
2 = IP/MODIFIED
3 = IP

△ INDICATES PREFERRED RS
** REQUIRES PAIRING WITH RETRIEVAL SYSTEM

Table J-11. Remedial Systems Selection Summary

	MULTIPLE USE FACTOR	DEVELOPMENT STATUS	COMPLEXITY FACTOR	SOA	DEGREE OF AID	COSTS IN $ MILLION R &D	COSTS IN $ MILLION UNIT
XM	3	1	1	NO	9	75	5
EOS / MCCM*	4 (A)	2	3	YES	8	250*	70
EOS	4	3	3	YES	7	0	0
BUDDY	– (B)	3	3	YES	6	0	(B)
SPACE TUG / TCM	11	3	2/3	YES	5/3	0	45
MTCM-1 & PM	2	2/1	2	YES	5	190	20
SPACE TUG / MCCM*	9	3/2	3	YES	4	250*	85
STANDBY SHUTTLE**	7	3	3	YES	4	0	90
STAGED TUG / MCCM*	3	3/2	3	YES	4	250*	100
RBOW I	4	2	3	YES	1	25	10
RBOW II	1	2	3	YES	1	200	20
RBOW III	1	2	3	YES	1	80	15

* ONLY MCCM NEEDS DEVELOPMENT. TO BE CHARGED ONLY ONCE.
** ALSO USED IN COMBINATION WITH THE SPACE TUG / MCCM AND THE STAGED TUG / MCCM
(A) THE MCCM ALONE HAS A MULTIPLE USE FACTOR OF 16
(B) DEPENDS UPON MISSION PHASE AND BUDDY VEHICLE SELECTED

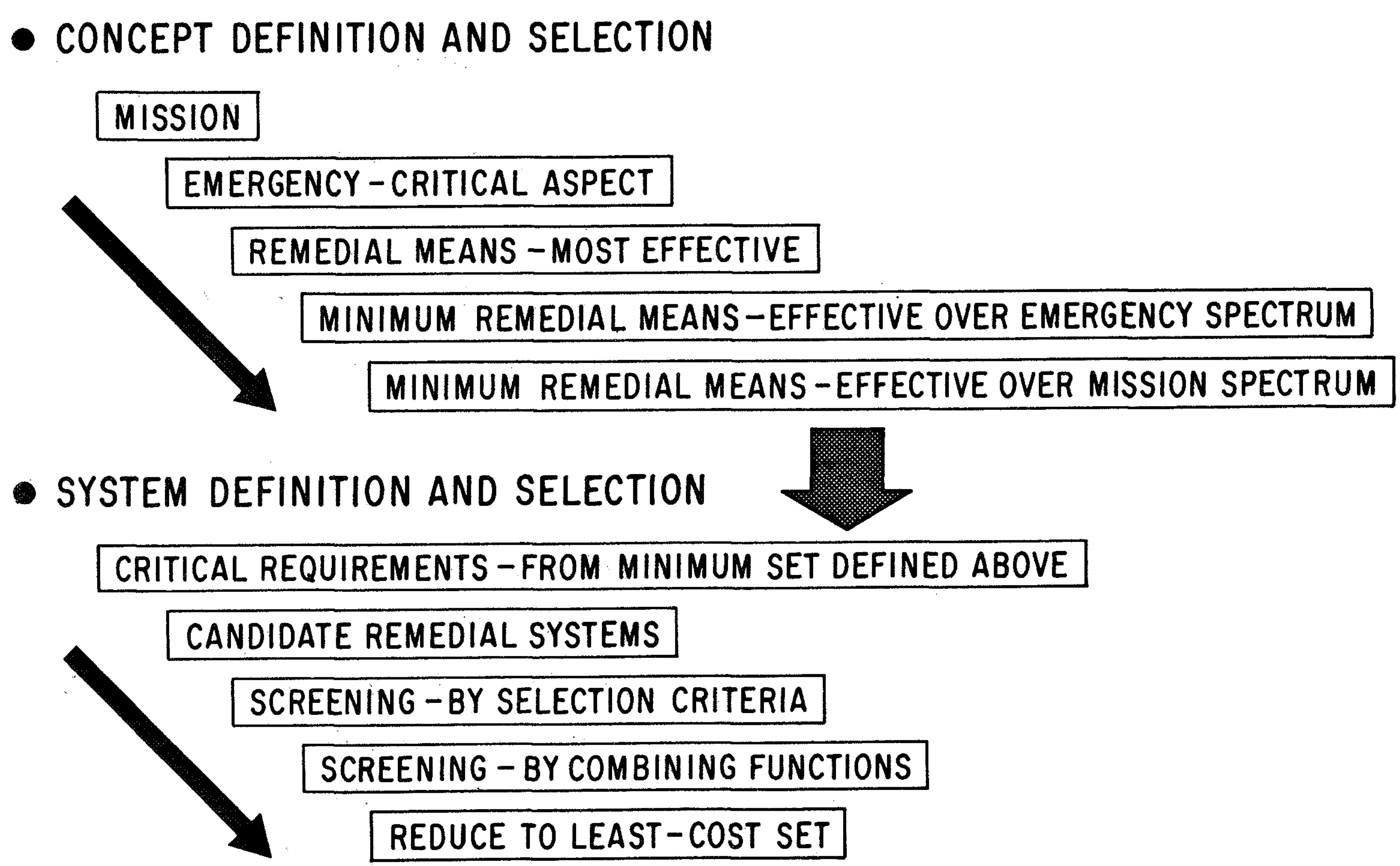

Figure J-1. RS Selection Process

MISSION CLASS	CRITICAL CONDITION	SELF HELP	UNMANNED ASSISTANCE	MANNED ASSISTANCE
LEOSS	STRANDED IN EVA	△4 PAP	(7) URM	
GEOSS	STRANDED IN EVA	△4 PAP	(7) URM	
TUG IN LEO	TRAPPED WITHOUT EGRESS			△8 SRV
TUG IN GEO	TRAPPED WITHOUT EGRESS			△8 SRV
TUG IN LO	TRAPPED WITHOUT EGRESS			△8 SRV
TUG ON LS	TRAPPED WITHOUT EGRESS			△8 SRV
LSB AND OLS	STRANDED IN EVA	△4 PAP	(7) URM	
EOS	TRAPPED WITHOUT EGRESS			△8 SRV
SHUTTLE IN LO, GEO, OR IN TRANSIT	TRAPPED WITHOUT EGRESS			△8 SRV
SHUTTLE IN LEO	TRAPPED WITHOUT EGRESS			△8 SRV

△ Preferred

(7) Pairs with (4) if latter not a BOR

(8) Is required because situation implies need for special damage control equipment carried in manned rescue vehicle

Figure J-2. Example of Remedial Means Application (Stranded or Entrapped Crew)

	EMERGENCY SITUATION CATEGORIES									
	ILL / INJURED CREW	METABOLIC DEPRIVATION	STRANDED/ ENTRAPPED CREW	INABILITY TO COMMUNICATE	OUT OF CONTROL SC	DEBRIS IN VICINITY	RADIATION IN VICINITY	NON-HABITABLE ENVIRONMENT	ABANDONMENT OF SC	INABILITY TO REENTER
LEOSS	△3 (8)	△3 (8)	△4 (7)	△3	△3	△3	△3	△3	△4 (7)	
GEOSS	△3 (8)	△3 (8)	△4 (7)	△3	△3	△3	△3	△3	△4 (7)	
TUG IN LEO	△5 (9)	(3) △9 (2) (7)	△8	(5) △9	(3) △9 (2) (7)	(3) △9 (2) (7)	△5	△5 (3) (2) (7)	(7) △9	
TUG IN GEO	△5 (9)	(3) △9 (2) (7)	△8	(5) △9	(3) △9 (2) (7)	(3) △9 (2) (7)	△5	△5 (3) (2) (7)	(7) △9	
TUG IN LO	△5 (9)	(3) △9 (2) (7)	△8	(5) △9	(3) △9 (2) (7)	(3) △9 (2) (7)	△5	△5 (3) (2) (7)	(7) △9	
TUG ON LS	△5 (9)	(3) △9 (2) (7)	△8	(5) △9	(3) △9 (2) (7)	(3) △9 (2) (7)	△5	△5 (3) (2) (7)	(7) △9	
LSB AND OLS	△3 (8)	△3 (8)	△4 (7)	△3	△3	△3	△3	△3	△4 (7)	
EOS	△5 (9)	(3) △9 (2) (7)	△8	(5) △9	(3) △9 (2) (7)	(3) △9 (2) (7)	△5	△5 (3) (7) (2)	(7) △9	△5 (7) (8)
SHUTTLE IN LO, GEO OR IN TRANSIT	△5 (9)	(3) △9 (2) (7)	△8	(5) △9	(3) △9 (2) (7)	(3) △9 (2) (7)	△5 (2) (7)	△5 (3) (2) (7)	(7) △9	
SHUTTLE IN LEO	△5 (9)	(3) △9 (2) (7)	△8	(5) △9	(3) △9 (2) (7)	(3) △9 (2) (7)	△5 (2) (7)	△5 (3) (2) (7)	(7) △9	

△ = PREFERRED MEANS

Figure J-3. Remedial Means Summary Matrix

RANK	DEGREE OF AID	SHELTER	LIFE SUPPORT	COMMUNICATIONS	MEDICAL KIT	SPECIAL ESCAPE AID	LIMITED MEDICAL AID	SPACECRAFT TRANSFER AID	MEDICAL AID	DAMAGE CONTROL	DELAYED RETURN TO INTERMEDIATE HAVEN	IMMEDIATE RETURN TO INTERMEDIATE HAVEN	DELAYED RETURN TO FINAL HAVEN	IMMEDIATE RETURN TO FINAL HAVEN
1	BAILOUT AND WAIT DEVICE	●	●	●	●									
2	UNMANNED RETRIEVAL SYSTEM	●	●	●	●						●			
3	MANNED RETRIEVAL SYSTEM	●	●	●			●	●			●			
4	MANNED RETRIEVAL AND RESCUE SYSTEM	●	●	●		●		●	●	●	●			
5	BAILOUT AND RETURN DEVICE "SPACE DOCK"	●	●	●	●							●		
6	BUDDY SYSTEM	●	●	●			●	●				●		
7	EOS	●	●	●			●	●					●	
8	EOS PLUS MANNED RETRIEVAL AND RESCUE SYSTEM	●	●	●		●		●	●	●			●	
9	BAILOUT AND RETURN DEVICE, "EARTH"	●	●	●	●									●

NOTE: ALL REMEDIAL MEANS EXCEPT BAILOUT & RETURN AND BUDDY SYSTEM ASSUME THE PRESENCE OF THE BOW

Figure J-4. RS Ranking by Degree of Aid

	Remedial Systems	Mission Classes										
	REMEDIAL SYSTEMS	LEOSS	GEOSS	TUG IN LEO	TUG IN GEO	TUG IN LO	TUG ON LS	LSB/OLS	EOS IN LEO	SHUTTLE IN LO OR TRANSIT	SHUTTLE IN GEO OR TRANSIT	SHUTTLE IN LEO
NEW	XM (3 MEN)	△3		△3					△3			
	MTCM-I/PM MCM I/PM (15 MEN)				○3	○3						
MODIFIED IP	RBOW I (15 MEN)	○2	□2								□2	□2
	RBOW II (15 MEN)							□2				
	RBOW III (3 MEN)									□2		
	EOS/MCCM (15 MEN)	○8		○8					○8			○8
	SPACE TUG/MCCM (15 MEN)	○8	○8	○8	○8	○8			○8	○8	○8	○8
	STAGED TUG/MCCM (15 MEN)						○8	○8				
PLANNED IP	EOS	○7'		○7'					○7'			○7'
	SPACE TUG/TCM (4-12 MEN)	□2 ○7'	△3 ○7'	□9 ○7'	△9 ○7'	△9 ○7'	△9 ○7'	△3 ○7'	□9 ○7'	○7'	○7'	△3 ○7'
	STANDBY SHUTTLE (FROM LEO)		PAIRED ○8		○8	○8	PAIRED ○8	PAIRED ○8		○8	○8	
	BUDDY			○9	△9	△9	△9		○9	△9	△9	○9

△ PREFERRED RS
□ 2ND CHOICE RS
○ APPLICABLE RS

Figure J-5. Remedial System Application Matrix

APPENDIX K

REMEDIAL SYSTEMS WEIGHTS AND COSTS

APPENDIX K

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APPENDIX K

REMEDIAL SYSTEMS WEIGHTS AND COSTS

K.1 GENERAL*

A number of potential remedial systems are summarized in Volume II with regard to configuration, weight, and cost aspects. The purpose of this appendix is to present the more detailed results of supporting analyses upon which the remedial system weight and cost data in Volume II are based.

The objectives of this effort were:

a. to conceptually define selected remedial systems considered appropriate for the Integrated Program

b. to provide estimates of the gross costs for development, procurement, and/or implementation of the selected remedial systems

The remedial systems considered fell into three general categories:

a. rescue vehicles

b. systems necessary or desirable to supplement or act in conjunction with a rescue vehicle

c. systems promising as alternate, independent solutions to the rescue vehicle

In the second category were such systems or devices as emergency life support systems and bail-out-and-wait (BOW) devices (lifeboats). In the third category, the single concept examined was the bail-out-and-return (BOR) (to safe haven) device.

It is important to stress that this effort was "conceptual" in nature and did not result in preliminary designs, per se. The approach followed was to "bound" the problem by selecting "reasonable" or "representative" approaches for reducing the various remedial concepts to hardware systems. Therefore, where previous results existed for any remedial device, they were utilized to the maximum extent possible.

---

*This Appendix is based on the work of M. Hinton.

One of the study ground rules emphasized that concepts utilizing selected or planned Integrated Program (IP) hardware or elements are preferred. Consequently, known or projected IP hardware characteristics were employed, where possible.

K. 2 RESULTS

K. 2. 1 Remedial System Configuration and Weight

K. 2. 1. 1 General

The following sections briefly describe the purpose, salient features (configuration, contents, gross weight), and background material (where appropriate) which were used to develop the weight estimates given for each of the remedial concept classes examined.

K. 2. 1. 2 IP Elements

Both the EOS and Space Tug have remedial system application. Inasmuch as they were treated in Volume II (Section 7), they will not be discussed here.

Two other IP hardware elements, the space tug crew module (TCM) and the crew/cargo module (CCM) used in conjunction with the EOS, were identified as potential rescue/escape devices. Their utility arises from the fact that their basic functions include the shelter and life support of crew/passengers. In addition, their basic structure can provide the basis for modified versions incorporating specific rescue/escape capabilities not present in the standard or baseline configuration.

K. 2. 1. 2. 1 Space Tug Crew Module

Within the framework of Integrated Program planning, it is proposed that a crew module (TCM) will be utilized with the space tug propulsion module (PM) to provide shelter and life support for various numbers of crew/passengers while performing numerous earth-orbit and lunar-orbit missions, including descent to and ascent from the lunar surface. Although the TCM has not been completely defined, a limited amount of definition is available from pre-Phase A design activities.

The space tug system weight breakdown is given in Ref. K-1 as:

Propulsion Module	
Gross Weight (incl. propellants)	71,000 lb
Propellants (O_2/H_2)	60,000
Crew Module	10,000
Guidance and Control Module	5,000
Total (incl. propellants)	86,000 lb

Pre-Phase A definition studies conducted by Boeing (Ref. K-2) and North American Rockwell (Ref. K-3) provide a limited insight into potential crew module configurational arrangement, subsystems, and weight allocations.

Figure K-1 illustrates a representative crew module (TCM) concept (from Ref. K-2) and, as shown, incorporates a docking port, side hatch and airlock, and manipulator arm kit, in addition to providing a habitable haven for crew/ passengers. The basic size (volume) of the TCM tentatively selected is for a 3-4 man crew performing a reasonably-long-duration space mission (~28 days). It is postulated that the TCM could accommodate larger numbers (14-15 men) for short-duration missions, particularly in an emergency situation.

With regard to subsystems and subsystem weight allocations, specific data from Refs. K-2 and K-3 are summarized in Table K-1. As can be seen, for essentially the same design considerations, the overall TCM weights are in excellent agreement from the two sources, although the distribution between subsystems is not exact. The fuel cell and O_2/H_2 consumables weights shown were not part of the reference weight statements. As the fuel cells and O_2/H_2 consumables may well be stored in (or a part of) the space tug guidance and control module, the reference TCM weight of 10,000 lb given in Ref. K-1 was considered appropriate for purposes of this study.

K. 2. 1. 2. 2 EOS Crew/Cargo Module

The present consensus is that transfer of passengers and cargo from the EOS to the space station will be effected via a crew/cargo module (CCM) which is deployed from the EOS cargo bay. Under one approach (see Figure K-2), the CCM hard-docks at one end to the station while supported by the erecting and transporter mechanism extending from the EOS cargo bay. Under another approach, the EOS can be remote from the station with the CCM being propelled (by either a space tug or CCM-integral propulsion) from the EOS to the station where the dock is accomplished.

Preliminary definitions of such CCM's were not available to define configuration details and weight breakdowns; therefore, a CCM was synthesized for the present study. In effect, the CCM, as defined herein, is comprised of a forward section which is very similar in configuration and capability to the space tug TCM, and an after section which is an enclosed cargo-carrying structure.

Table K-2 summarizes the various subsystems in the CCM and gives initial weight estimates used for conceptual design purposes. Note that both a non-propelled and a self-propelled version are included. For the latter, a type of propulsion comparable to the Apollo Service Module reaction control system (RCS) or the Manned Orbiting Laboratory reaction control system is utilized.

K. 2. 1. 2. 3 Summary

A space tug crew module (TCM) incorporating a docking port, side hatch, and airlock and weighing ~8500 lb (less crew, fuel cells and O_2/H_2 consumables) was selected as a representative baseline. It is estimated to have life support capacity for 3-4 men for 28 days or for 14-15 men for 2-3 days.

A baseline crew/cargo module (CCM) for use with the EOS was selected which had a forward section similar to the space tug command module outer shell combined with an aft cargo-carrying section. Without onboard propulsion its weight was estimated to be 11,500 lb. A self-propelled version incorporating an Apollo RCS or MOL RCS type propulsion system was estimated to weigh 14,000 lb.

While preliminary and conceptual in nature, these baseline TCM and CCM selections are felt to be sufficient for purposes of providing reference systems to be used for sizing purposes in remedial system comparison efforts.

K.2.1.3 Emergency Life Support Systems

Two different types of emergency life support systems were examined during the course of the study. The first is an assemblage of life support items carried on board a space rescue vehicle (SRV) for subsequent use in a distressed vehicle (DV), while the second is a package system to be stored on board potentially-distressed vehicles. A detailed discussion of life support subsystem selection is given in Appendix H.

K.2.1.3.1 SRV Emergency Life Support System

In conceptual terms, the SRV emergency life support system is an assemblage of items to provide (1) breathing oxygen, (2) a portable environmental control-life support system (EC/LS), and (3) spare provisions. It would be packaged in a manner to facilitate its transfer from the SRV to the DV for subsequent use in the DV.

The oxygen source is provided by potassium superoxide. The portable EC/LS unit provides for oxygen distribution, dehumidification, CO_2 removal, cooling, and power requirements. The spare provisions are limited to food and water. Table K-3 summarizes the weight and volume characteristics as applied to sustaining 14 men for a 48-hour period.

K.2.1.3.2 DV Emergency Life Support Systems

Conceptually, the DV emergency life support system is a prepackaged selected assortment of EC/LS subsystems stored on board the potentially-distressed vehicle. The subsystems are selected to be compatible with long-term storage requirements. Although termed "on-board" generically, the package in fact could be attached to the vehicle via a porthole or "plug-in" arrangement to facilitate its use, instead of physically being within the confines of the vehicle's nominal structural envelope.

To provide atmosphere supply and control, an EC/LS unit utilizing sodium chlorate candles for oxygen consumption (and leakage) is employed. Initial pressurization is provided by high-pressure (~2000 psi) bottled gaseous oxygen. CO_2 control is accomplished with molecular sieves.

Waste management is similar to the Gemini approach. Urine disposal is via an overboard dump system (with tubes, valves, and accumulator tank) while solid disposal is via a commode with a collector and blower.

Thermal control is provided by radiators, heat exchangers, and associated plumbing.

Power is provided with a battery-solar array combination.

The food provided is dried and the water is stored in tanks.

Table K-4 summarizes the resultant weight characteristics of such emergency life support "packages" for 3, 6, and 12 men for both 14- and 28-day life-support periods.

K.2.1.4 Bail-Out-and-Wait Devices (Lifeboats)

The bail-out-and-wait device (BOW) or "lifeboat" has often been suggested as a useful device to permit an otherwise effective crew to disembark (escape) from an uninhabitable spacecraft and await aid (rescue) from a remote source (ground-based or space-based). In concept then, the BOW device merely provides a habitable structure with incorporated subsystems to provide for continued survival, stabilization, and communications during the waiting period.

Based on the foregoing definition, such a device is carried on board (or attached to) the potentially-distressed vehicle (DV). Long-term storability is desired, and lightweight structure would be especially important for any vehicle having a payload-delivery function.

Those subsystems related to environmental control and life support were selected to be of the same type as previously described for Emergency Life Support Systems, as they also were predicated on long-term storability. A small storable propellant attitude control system and a simple communications system were incorporated to facilitate the later rescue operation.

As to basic BOW structure, both expandable and rigid structure versions were considered.

K. 2. 1. 4. 1 Expandable BOW (XBOW)

A similar bail-out-and-wait device had been previously delineated in Ref. K-4 for a 3-man capacity. The structural weight data of this reference BOW was scaled to 6-man and 12-man configurations. Table K-5 summarizes the resulting XBOW weight characteristics.

K. 2. 1. 4. 2 Rigid BOW (RBOW)

To synthesize a rigid structure BOW, and to stress hardware commonality, the structural shell of the space tug crew module (TCM) was selected to represent the RBOW concept. Except for the structural shell, the RBOW is identical to the XBOW in terms of subsystems selection and weight for the same number of crewmen and life support duration.

An advantage resulting from this selection is that the docking port, airlock, and side hatch, which are assumed inherent features of the TCM, are now "built in" to the RBOW.

Table K-6 summarizes the resulting RBOW weight characteristics.

K.2.1.5 Bail-Out-and-Return Devices

Two general categories of bail-out-and-return (to safe haven) devices were identified: return-to-earth and return-to-space haven.

K.2.1.5.1 Return-to-Earth BOR Devices

A considerable amount of analytical effort has been expended in the past in defining the capabilities and resultant characteristics of devices with which one or more astronauts could disembark (escape) from a distressed vehicle (DV) and reenter the earth's atmosphere to descend to an earth landing. References K-5 and K-6 summarize the most recent activity in this area.

Reference K-5 was primarily concerned with small (2-3 men) devices (rigid and expandable) for reentry from low earth orbit. Reference K-6 delineated rigid low earth orbit BOR devices with a greater capacity (3-9 men) and further explored the requirements for reentry from geosynchronous orbit for a 3-man BOR device.

The present study activity was therefore limited to summarizing this existing data base and extending it to include a broader scope. Such extensions included (1) extrapolating Ref. K-6 data to include BOR devices with up to 15-man capacity and (2) calculating propulsion system weights to enable geosynchronous deorbit (consistent with similar data in Ref. K-6 for a 3-man geosynchronous BOR device).

Table K-7 summarizes the pertinent subsystem weight breakdown data for the small (2-3 men) low earth orbit reentry devices from Ref. K-5; Table K-8 summarizes similar data for the Ref. K-6 data and extrapolations thereof; Figure K-3 is an overall summary of the data in Tables K-7 and K-8.

K.2.1.5.2 Return-to-Space Haven BOR Devices

In the return-to-space haven concept the BOR device is not faced with earth reentry requirements and is, in its simplest form, a BOW device plus a propulsion module (PM) sized to provide the necessary ΔV to permit return to a space haven from the area of distress. One special requirement is the provision of guidance and navigation equipment (and associated instrumentation, etc.) necessary to perform the ΔV maneuver and the subsequent rendezvous and docking operations.

Again, both rigid and expandable structures were considered in this application and both storable and cryogenic propulsion modules were examined.

K.2.1.5.2.1 Rigid Structure

For purposes of commonality, the space tug crew module (TCM) structural shell (including docking port, side hatch, and airlock) was selected to provide the basic habitable structure. Life support and environmental control subsystems consistent with long-term storability (as in the case of Emergency Life Support Systems) were utilized. Crew systems (seats, bunks, accessories, first aid, personal hygiene) were provided, as well as EVA equipment (suit, portable life support system (PLSS), and support equipment). Batteries were chosen to provide the electrical power for the communications, guidance and navigation, and instrumentation subsystems.

Table K-9 summarizes the resulting modified tug crew module (MTCM) weights used for the return-to-space haven BOR concept for 3-, 6-, and 12-man crew sizes and mission durations of 2 and 7 days.

K.2.1.5.2.2 Expandable Structure

For the expandable structure case (XM), all subsystems were identical to the rigid case described above, except for the structural shell. Here, the crew module (TCM) shell weight was replaced by expandable structure weights previously derived for the expandable BOW (XBOW) devices (Table K-5).

K.2.1.5.2.3 Propulsion Modules

Both cryogenic (O_2/H_2) and storable propellant propulsion modules were considered. To allow flexibility in sizing various return-to-space haven BOR devices for a multiplicity of Integrated Program requirements, the propulsion modules were merely described as a function of the crew module weight (MTCM or XM) as depicted in Table K-9 and Section K. 2. 1. 5. 2. 2.

An I_{sp} of 310 sec was considered representative of storable propellant systems and 450 sec was selected for the cryogenic (O_2/H_2) case. Figures K-4 and K-5 depict the ratio of propulsion module (PM) to crew module (MTCM or XM) weight as a function of required ΔV, assuming the propellant fraction of the propulsion module is 0.85.

K. 2. 1. 5. 2. 4 Return-to-Space Haven Summary

The overall weight of any desired return-to-space haven BOR device is then the sum of the crew module weight (MTCM or XM from Table K-5 or Section K. 2. 1. 5. 2. 2) and the properly sized propulsion module (PM) from Figures K-4 or K-5.

K. 2. 1. 6 Space Rescue Vehicles

As previously mentioned, both the EOS and Space Tug have rescue vehicle capability (Vol. II, Section 7). The present intent is to define a special space rescue vehicle (SRV) which could be transported from the earth by the EOS, or in space by the Space Tug or Space Shuttle.

Although the crew/cargo module (CCM) is as yet undefined, its basic characteristics of a crew module section plus a second cargo module section indicated that it could provide a reasonable basis for modification into a rescue vehicle.

The modifications assumed were that (1) a center section incorporates a self-contained RCS for attitude control and limited ΔV maneuvers (if the final standard CCM version is not so configured), (2) the aft cargo section is refitted to accommodate crew/passengers from a distressed vehicle (including incapacitated members transported by stretchers) and enable medical aid to be provided, and (3) that the structure is modified to accommodate a variety of special rescue equipment that may be appropriate for the rescue mission. Such equipment may include such items as portable airlocks, special transfer capsules, manipulator arms, etc.

The extent of such included equipment could well depend upon whether the rescue vehicle is manned or unmanned. If unmanned, those special equipments indicated for rescue crew use would not be necessary.

In gross, then, the space rescue vehicle is simply a specially refitted CCM. The basic weight characteristics of the previously-synthesized CCM (with onboard RCS) were assumed to apply also to the rescue vehicle, except that an 800-lb weight penalty due to structural modifications was assumed.

Table K-10 summarizes the resulting weight breakdown for the space rescue vehicle (manned or unmanned) less special equipments and crew weights, but including a nominal RCS propellant load.

K. 2. 2 Cost Estimates

K. 2. 2. 1 Introduction

Estimates of cost for the various space program elements were assembled for use in making summary comparisons of overall program costs.

Cost estimates from previous studies were used whenever possible. In many cases, however, estimates of cost were not available and were prepared using available system definitions and estimating data. In all cases, these estimates are "typical" values, representing the generic system elements involved. Because hardware definitions are conceptual, the estimates are, correspondingly, approximate.

K. 2. 2. 2 Basic IP Element Cost Estimates

Estimates of cost for the EOS, Space Tug, and Reusable Nuclear Shuttle are summarized in Table K-11. These estimates were prepared for another NASA Study currently underway at Aerospace, and are documented in Ref. K-7. The cost estimating method used for this purpose is described in Ref. K-8.

The RDT&E cost estimates shown include all engineering and development activities as well as all facilities and hardware; a minimum of three (3) flight articles are included. In addition, all engine developments are accounted therein, including the NERVA engine development for the Nuclear Shuttle. The Facilities Investment cost estimates include the acquisition of all facilities and equipment needed to operate these vehicles. For the EOS, both ETR and WTR facilities are included. Two values of unit cost are provided. First Unit Manufacturing Cost is self explanatory. The Average Unit Cost includes not only manufacturing costs but also sustaining costs such as spares, engineering, and tooling support and program management costs. Approximately 95% learning has been applied in Average Unit Costs. The cost per flight values shown are typical values which include all operation program direct and indirect costs.

K. 2. 2. 3 Projected IP Element Cost Estimates

Cost estimates for selected Projected IP Elements are shown in Table K-12. Data for the Space Tug Crew Module (TCM) and EOS Crew/Cargo Module (CCM) were obtained by making detailed program cost estimates using the weight data described in Section K. 2. 1 and the cost estimating method in Ref. K-8. Space suit, space tug manipulator kit, and maneuvering unit cost estimates are rough order of magnitude (ROM) values which were prepared after a review and assimilation of the limited amount of available and applicable data.

K. 2. 2. 4 Special Rescue Equipment Cost Estimates

A summary of selected special rescue equipment costs is provided in Table K-13. Cost estimates for bail-out devices, Modified Crew Modules, LEO BOR device, and emergency EC/LS packages were determined by multiplying element dry weight by the following factors:

RDT&E Cost	\$55,000/lb
First Unit Cost	\$ 3,000/lb
Average Unit Cost	\$ 3,450/lb

These factors were obtained from the detailed estimates made for the Space Tug Crew Module.

Transfer equipment cost estimates were made by using a typical manufacturing cost for vehicle structure (from Ref. K-8) to estimate first unit cost. RDT&E costs were developed by multiplying first unit cost by 20. The costs of other elements were determined by making ROM estimates based on judgment and available unit descriptions.

K.2.2.5 Cost Reduction via Parallel Development

All of the foregoing specific remedial system costs were predicated on the development of each item as a separate development. Since the rescue vehicle (MCCM) was proposed to be a modification of the basic crew/cargo module (CCM) and the various rigid structure bail-out-and-wait devices (RBOW's) were proposed to utilize the basic structural shell of the space tug crew module (TCM), it was estimated that if such remedial systems were developed as a parallel effort to the basic hardware development program (CCM, TCM), then the remedial system (MCCM, RBOW) development costs could be significantly reduced. Therefore, only "modification" and "special equipment" development costs should be attributed to the remedial device.

On this basis, the MCCM and RBOW parallel development costs were estimated to be as shown in Table K-14.

K.3 SUMMARY

Numerous remedial system approaches were reduced to conceptual designs and their configurational characteristics, weights, and costs were determined for a wide range of operating conditions (number of men, mission duration, ΔV requirements, etc.). The remedial concepts examined included both "onboard" and "externally supplied" systems.

It was considered feasible to use modifications to hardware being developed for other uses under the IP as a basis for certain remedial systems. In particular the space tug crew module (TCM) was utilized to configure rigid bail-out-and-wait devices (RBOW) and as the habitable portion of a bail-out-and-return-to-space-haven device. The EOS crew/cargo module (CCM) was used as the basis for a space rescue vehicle (SRV) compatible with earth orbit delivery by the EOS or space delivery by the Space Tug or Space Shuttle.

Other remedial concepts examined included (1) bail-out-and-reenter devices (from both low earth orbit and geosynchronous earth orbit), (2) expandable structure versions of the bail-out-and-wait device (XBOW), (3) emergency life support systems for "onboard" installation, and (4) a portable emergency life support system to be carried on board a rescue vehicle for later transfer to a distressed vehicle. Table K-15 summarizes the range of investigation of each remedial system, in terms of man-days capacity, and the corresponding range of remedial system weights.

Gross cost estimates occurring as a result of the development, procurement, and/or implementation of certain basic IP hardware elements and selected specific remedial concepts were also estimated to a level consistent with the concept definition.

Cost increments to provide modifications to projected IP hardware fall between $25 million and $200 million, depending upon the specific concept and the extent of changes and special equipment added.

Bail-out-and-wait devices based on utilization of the TCM outer shell were estimated to incur development costs (exclusive of TCM outer shell) of $25 million to $200 million, for a life support duration range from 24 man-days to 336 man-days, when developed in parallel with the space tug TCM development. Similarly, a rescue vehicle (SRV), developed concurrently with and based on modifications to the EOS crew/cargo module (MCCM) was estimated to require an additional $190 million in non-recurring costs.

References

K-1. Statement of Work for Phase A Feasibility and Definition Study of Lunar Orbit Space Station (6 March 1970).

K-2. "Pre-Phase A Technical Study for Use of Saturn V, Int. 21 and other Saturn V Derivatives to Determine an Optimum Fourth Stage," The Boeing Company, briefing dated 30 July 1970.

K-3. Pre-Phase A Study for an Analysis of a Reusable Space Tug, Progress Report No. 2, SD-70-188-2, North American Rockwell Corp. (7 August 1970).

K-4. Study of Manned Space Flight Emergency Concepts, ATR-68(7080)-2, Aerospace Corp. (April 1968).

K-5. Final Briefing--Conceptual Design Analysis and Technology Assessment of Space Escape Systems, PD 70-9, North American Rockwell Corp. (15 March 1970).*

K-6. Emergency Earth Orbital Escape Device Study, LMSC-A940555, Lockheed Missiles and Space Co. (31 January 1969).

K-7. Integrated Operations/Payloads/Fleet Analysis, Mid-Term Report, Volume III, System Costs, ATR-71(7231)-9, Aerospace Corp. (31 March 1971).

K-8. STS Cost Methodology, TOR-0059(6759-04)-1, Aerospace Corp. (31 August 1970).

K-9. M. Donabedian, "Emergency EC/LS System Sizing for Space Rescue Operations," ATM-71(7212-04)-4, Aerospace Corp. (31 March 1971).**

*Similar data may be found in Analysis of Required Operational Characteristics of Space Escape Systems, SAMSO TR-67-7 (November 1967).

**Not available for distribution outside Aerospace Corporation.

Table K-1. Space Tug Crew Module (TCM) Weight Synthesis (lb)

Source / Subsystem	Ref. K-3	Ref. K-2		
	4 man, 28 day	3 man, 28 day	6 man, 14 day	6 man, 28 day
Structure	3690	3087	3087	3087
Crew Systems	3320	1796	3208	3577
Crew	(800)			
Provisions	(2520)			
EC/LS	353	2173	2173	3747
EPS	676	150	150	150
Communications	18	327	327	327
Instrumentation	261	118	118	118
Controls (incl. G&N)	70	340	340	340
Misc. Equipment	195	280	340	340
Expendables (Solid)	—	180	180	200
Contingency	767	845	992	1189
Sub-totals	9350	9296	10915	13075
Fuel Cell EPS	550	550	550	550
EPS O_2/H_2 Consumables	1400	1400	700	1400
Totals	11300	11246	12165	15025

Table K-2. Crew/Cargo Module (CCM) Weight Synthesis (lb) (12 man Capacity, 2-day Mission Duration)

Subsystems \ Type		No Onboard Propulsion	Self-Propelled
Structure		5200	5200
Crew Compartment	2600		
Cargo Compartment	2600		
Crew Systems		2900	2900
Crew	2400		
Provisions	500		
EC/LS		621	621
EPS		680	680
Fuel Cells	550		
Batteries	130		
Communications		327	327
Instrumentation		188	188
Controls		190	190
Misc. Equipment		80	80
Expendables (Solid)		140	140
Contingency		1020	1020
RCS		-	550
RCS Propellants		-	2200
EPS O_2/H_2 Consumables		100	100
Total		11325	14075

Table K-3. SRV Emergency Life Support System*
(14 men, 48-hr Capacity)

Subsystem	Weight, lb	
Portable EC/LS Unit		525
Potassium Superoxide	210	
Fan and Motor	15	
Filters, Valves, Ducting	31	
Heat Exchanger/Sublimator	50	
Cooling Water and Tankage	160	
Battery Power Supply	50	
Miscellaneous	9	
Emergency Provisions		96
Food	24	
Water	72	
Total		621

*Portable system carried on board SRV.

Table K-4. DV Emergency Life Support Systems Weight Summary (lb) *

Subsystems / Size	3-man		6-man		12-man	
	14 day	28 day	14 day	28 day	14 day	28 day
Atmosphere Supply and Control	554	916	956	1603	1683	2888
Waste Management	46	51	59	64	112	122
Thermal Control	100	100	165	165	260	260
Power Supply	145	145	220	220	330	330
Food, Water Supply	287	574	574	1148	1148	2216
Miscellaneous	58	89	99	160	177	290
Packaging Structure	119	188	207	336	371	610
Totals	1309	2063	2280	3696	4081	6716

*Ref. K-3

Table K-5. Expandable BOW (XBOW) Weight Summary (lb)

Subsystems \ Size	3-man			6-man			12-man		
	2 day	14 day	28 day	2 day	14 day	28 day	2 day	14 day	28 day
Atmosphere Supply and Control	323	554	916	557	956	1603	756	1722	2680
Waste Management	40	46	51	47	59	64	60	72	77
Thermal Control	100	100	100	165	165	165	270	270	270
Power Supply	50	145	145	50	220	220	100	330	330
Food, Water Supply	41	287	574	82	574	1148	164	1148	2296
Miscellaneous	28	58	89	45	99	160	67	177	282
Attitude Control System	100	150	200	150	225	300	150	300	400
Communications	40	40	40	40	40	40	40	40	40
Expandable Structure	500	500	500	800	800	800	1250	1250	1250
Total (less crew)	1222	1880	2615	1936	3138	4500	2857	5309	7625

Table K-6. Rigid BOW (RBOW) Weight Summary (lb)

Subsystems \ Size	3-man			6-man			12-man		
	2 day	14 day	28 day	2 day	14 day	28 day	2 day	14 day	28 day
Atmosphere Supply and Control	323	554	916	557	956	1603	756	1722	2680
Waste Management	40	46	51	47	59	64	60	72	77
Thermal Control	100	100	100	165	165	165	270	270	270
Power Supply	50	145	145	50	220	220	100	330	330
Food, Water Supply	41	287	574	82	574	1148	164	1148	2296
Miscellaneous	28	58	89	45	99	160	67	177	282
Attitude Control System	100	150	200	150	225	300	150	300	400
Communications	40	40	40	40	40	40	40	40	40
Rigid Structure*	2500	2500	2500	2500	2500	2500	2500	2500	2500
Total (less crew)	3222	3880	4615	3636	4838	6200	4082	6559	8875

*Similar to Tug crew module shell; would incorporate docking port, side hatch, and airlock.

Table K-7. Low Earth Orbit BOR Devices Weight Summary (lb) (Ref. K-5)

Subsystems / Type	Rigid (2-man)	Inflatable Airmat (2-man)	Inflatable Rib-Stiffened (3-man)
Crew Weight	350	350	525
Structure	312	477	679
Guidance and Navigation	41	41	41
Crew Systems	77	77	116
EC/LS*	156	156	183
Electrical Power	168	168	168
Communications	42	42	42
Recovery System	98	98	131
Support Equipment	25	25	30
Propulsion	202	202	202
Total	1471	1638	2163
(Less Crew)	(1121)	(1286)	(1638)

*6-24 hr. orbital operation; 48-72 hr. post-landing ventilation

Table K-8. LEO and Geosynchronous BOR Devices (Rigid Structure) Weight Summary (lb) (Ref. K-6)

Size and Type / Subsystems	3-man		9-man		15-man	
	LEO Return	GEO Return	LEO Return	GEO Return	LEO Return	GEO Return
Crew Weight	726	726	2178	2178	3630	3630
Structure	1479	1929	3582	4660	5000	6500
EC/LS	364	364	957	957	1600	1600
EPS	225	225	374	374	550	550
Communications	52	52	52	52	52	52
Guidance	-	200	-	200	-	200
Crew Systems	-	-	288	288	440	440
Reaction Control	51	51	88	88	125	125
Landing Systems	150	150	350	350	530	530
Retro-Propulsion	295	3640	840	9150	1160	13630
Total	3372	7337	8709	18297	13087	27257
(Less Crew)	(2646)	(6611)	(6531)	(16119)	(9450)	(23627)

Table K-9. Modified Crew Module (MTCM) Weight Summary* (lb)

Subsystems \ Size	3-man		6-man		12-man	
	2 day	7 day	2 day	7 day	2 day	7 day
Structure**	2500	2500	2500	2500	2500	2500
Crew/Crew Systems	1323	1338	2646	2676	5192	5352
Crew	(603)	(603)	(1206)	(1206)	(2412)	(2412)
Provisions	(162)	(177)	(324)	(354)	(648)	(708)
EVA Equipment	(558)	(558)	(1116)	(1116)	(2232)	(2232)
EC/LS	460	710	600	980	850	1500
EPS (Batteries)	150	150	150	150	150	150
Communications	50	50	50	50	50	50
Instrumentation	100	100	100	100	100	100
Guidance and Navigation	200	200	200	200	200	200
Miscellaneous	100	100	100	100	100	100
Contingency	488	515	635	676	914	995
Total	5371	5663	6981	7432	10056	10947

*For use with propulsion module (PM) as a bail-out-and-return to space haven device.

**Similar to tug crew module shell; would incorporate docking port, side hatch and airlock.

Table K-10. Space Rescue Vehicle (SRV) Weight Summary* (lb)

Subsystems \ Size	12-man 14 days		12-man 28 days	
Structure		6000		6000
Fwd. Crew Compartment	2600			
Aft. Aid Compartment	3400			
Crew Systems		1650		1800
Crew	-		-	
Other	1650		1800	
EC/LS		3190		6381
EPS (Fuel Cells, Batteries)		680		680
Communications		327		327
Instrumentation		188		188
Controls		190		190
Misc. Equipment		80		80
Expendables (Solid)		140		140
Contingency		1375		1580
RCS		550		550
RCS Propellants		2200		2200
EPS O_2/H_2 Consumables		700		1400
Totals		17270		21516

*Less any crew and special rescue equipment on board rescue vehicle.

Table K-11. Basic IP Element Costs (millions of 1970 dollars)

	RDT&E (Nonrec)	Facilities Invest (Nonrec)	Unit Cost		Cost/Flight		
			First Unit Mfg.	Avg. Unit Total* (typical)	Operations	Amort.	Total
EOS	9290	500	566	650	6.3	2.4	8.7
Space Tug							
Non-lander	590	30	13.0	15	0.8	0.4	1.2
Lander	680	30	16.5	19	0.9	0.5	1.4
Reus. Nuclear Shuttle	2100	80	51	59	16	4	20

*Includes manufacturing costs, spares, engineering, tooling support, and program management costs.

Table K-12. Projected IP Element Costs (millions of 1970 dollars)

	RDT&E (Nonrec)	Unit Cost First Unit Mfg. (Recurring)	Unit Cost Average Unit Total* (Recurring)
Space Tug Manipulator Kit	90	5	6
Space Tug Crew Module (TCM)			
Basic (3 men, 28 days)	457	24.5	28.2
Space Shuttle Crew/Cargo Module (CCM) (12 men, 2days)			
Non-Propelled	394	18.7	21.5
Self-Propelled	439	20.2	23.2
Space Suit			
Soft	40	1.0	1.2
Hard	50	2.0	2.4
Astronaut Maneuvering Unit			
Back Pack	25	1.0	1.2
Platform	50	2.0	2.4
Enclosed	175	9.0	10.3
Remote Control	120	6.0	7.0

*Includes manufacturing costs, spares, engineering, tooling support, and program management costs.

Table K-13. Special Rescue Equipment Costs (millions of 1970 dollars)

	RDT&E	Unit Cost	
	(Nonrec)	First Unit Mfg. (Recurring)	Average Unit Total* (Recurring)
Portable EC/LS System	24	1.3	1.5
Transfer Equipment			
Transfer Capsule	5	0.25	0.29
Portable Air Lock	13	0.65	0.75
Portable Docking Fixture	7.5	0.38	0.44
Soft Dock	7.0	0.36	0.42
Space Rescue Vehicle			
Modified CCM (MCCM)	568.0	29.0	33.4
Bail-Out-and-Wait Devices			
Rigid 12-man, 2-day (RBOW I)	164	8.7	10.0
Rigid 12-man, 28-day (RBOW II)	342	18.7	21.5
Rigid 3-man, 28-day (RBOW III)	219	12.0	13.8
Modified Crew Module/BOR Device			
Basic Module (MTCM)	300	16.4	18.9
Propulsion Module (PM)	30	1.0	1.2
LEO BOR Device (XM II)	75	4.1	4.7
Emergency EC/LS Packages			
3-man, 14-day	39	2.1	2.4
3-man, 28-day	49	2.7	3.1
6-man, 14-day	64	3.5	4.0
6-man, 28-day	82	4.4	5.1
12-man, 14-day	104	5.7	6.5
12-man, 28-day	132	7.2	8.3

*Includes manufacturing costs, spares, engineering, tooling support, and program management costs.

Table K-14. Special Rescue Equipment Development Costs -- Parallel Development (millions of 1970 dollars)

Space Rescue Vehicle	
Modified CCM (MCCM)	190
Bail-Out-and-Wait Devices	
RBOW I (12-man, 2 days)	25
RBOW II (12-man, 28 days)	200
RBOW III (3-man, 28 days)	80

Table K-15. Remedial Systems Weight Summary

Type of System	Capacity Range	Weight Range, lb (Less Crew)
Portable Emergency Life Support System	14-man, 2 days	620
Emergency Life Support Systems (Installed On Board)	3-man, 14 days to 12-man, 28 days	1,300 - 7,000
Bail-Out-and-Wait (Expandable-XBOW)	3-man, 2 days to 12-man, 28 days	1,200 - 7,600
Bail-Out-and-Wait (Rigid - RBOW)	3-man, 2 days to 12-man, 28 days	3,000 - 9,000
Bail-Out-and-Re-enter, LEO Expandable	2 to 3 men	1,300 - 1,700
Bail-Out-and-Re-enter, LEO Rigid	3 to 15 men	2,700 - 9,500
Bail-Out-and-Re-enter, GEO Rigid	3 to 15 men	6,600 - 24,000
Bail-Out-and-Return (to Space Haven)	3-man, 2 days to 12-man, 7 days	5,000 - 11,000*
Space Rescue Vehicle (modified CCM)	12-man, 14 days to 12-man, 28 days	17,000 - 22,000**

*Does not include propulsion module weight

**Does not include weight of any special rescue equipment

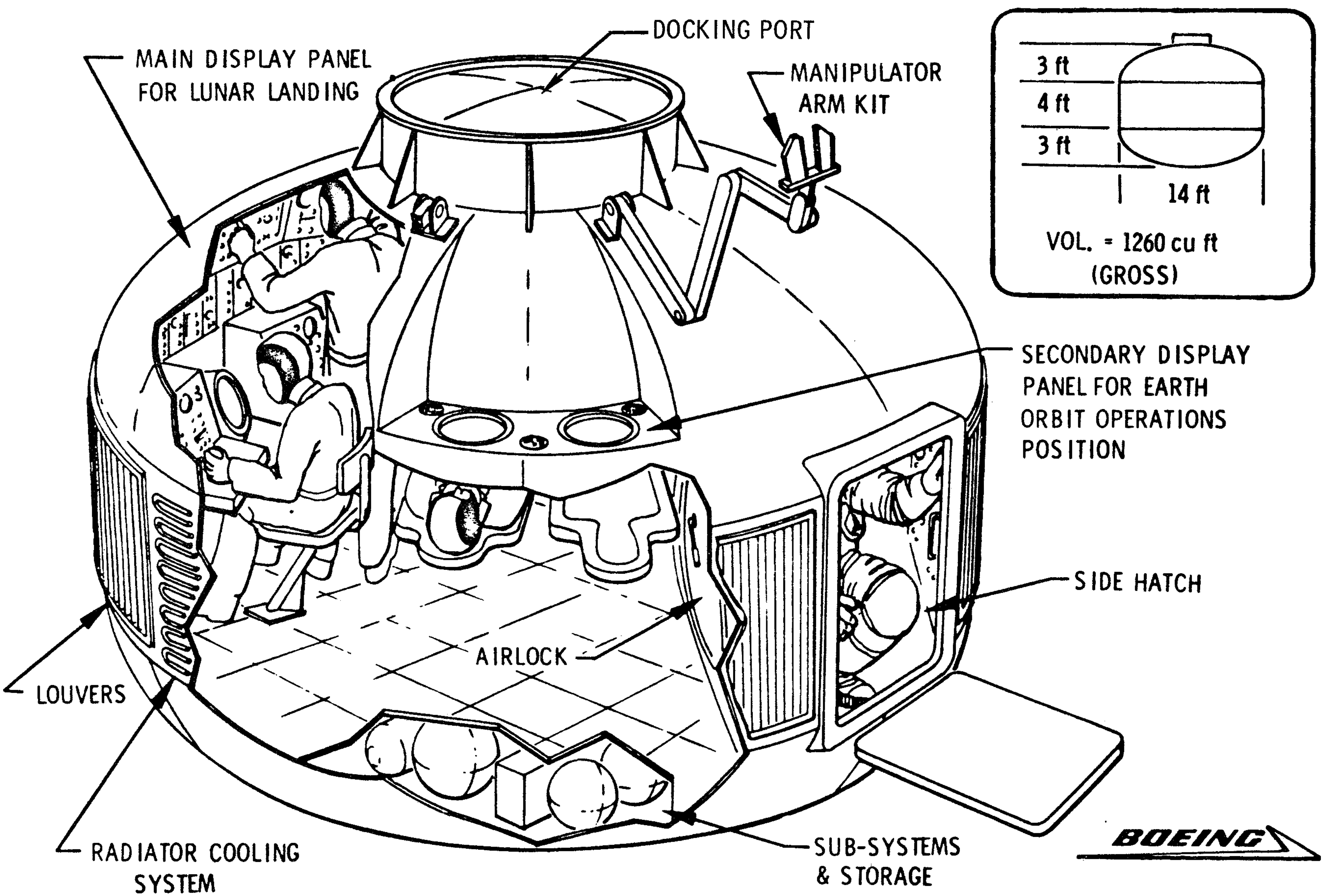

Figure K-1. Representative Space Tug Crew Module (TCM) Concept

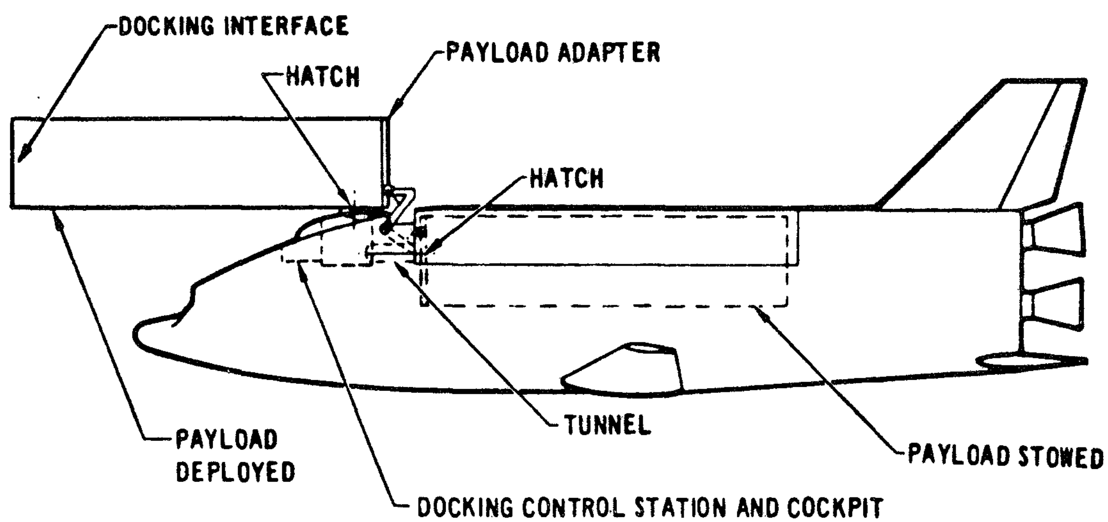

Figure K-2. Earth Orbit Shuttle (Orbiter Stage)

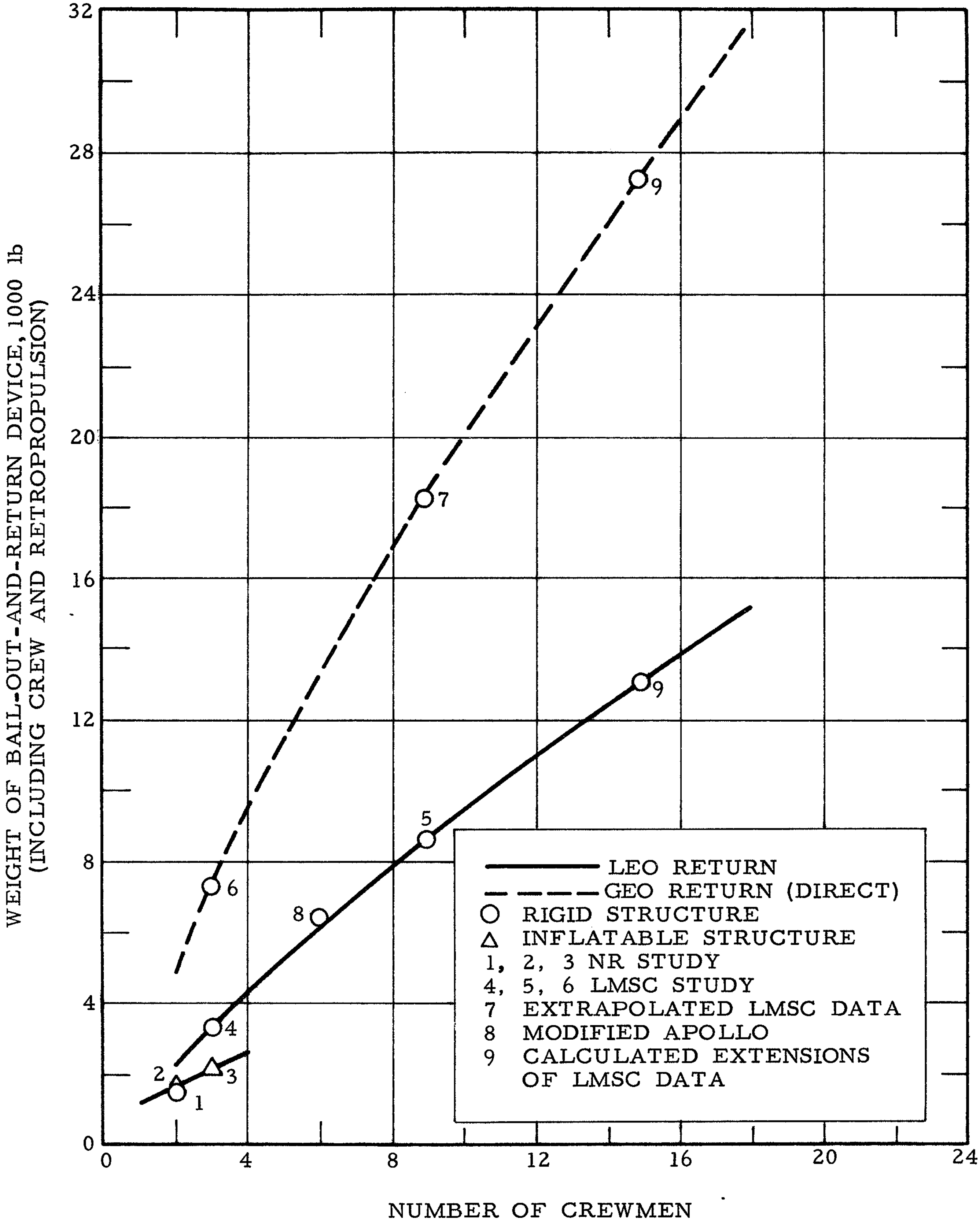

Figure K-3. Weight Summary for Bailout-and-Return Devices (24-36 hr EC/LS Duration)

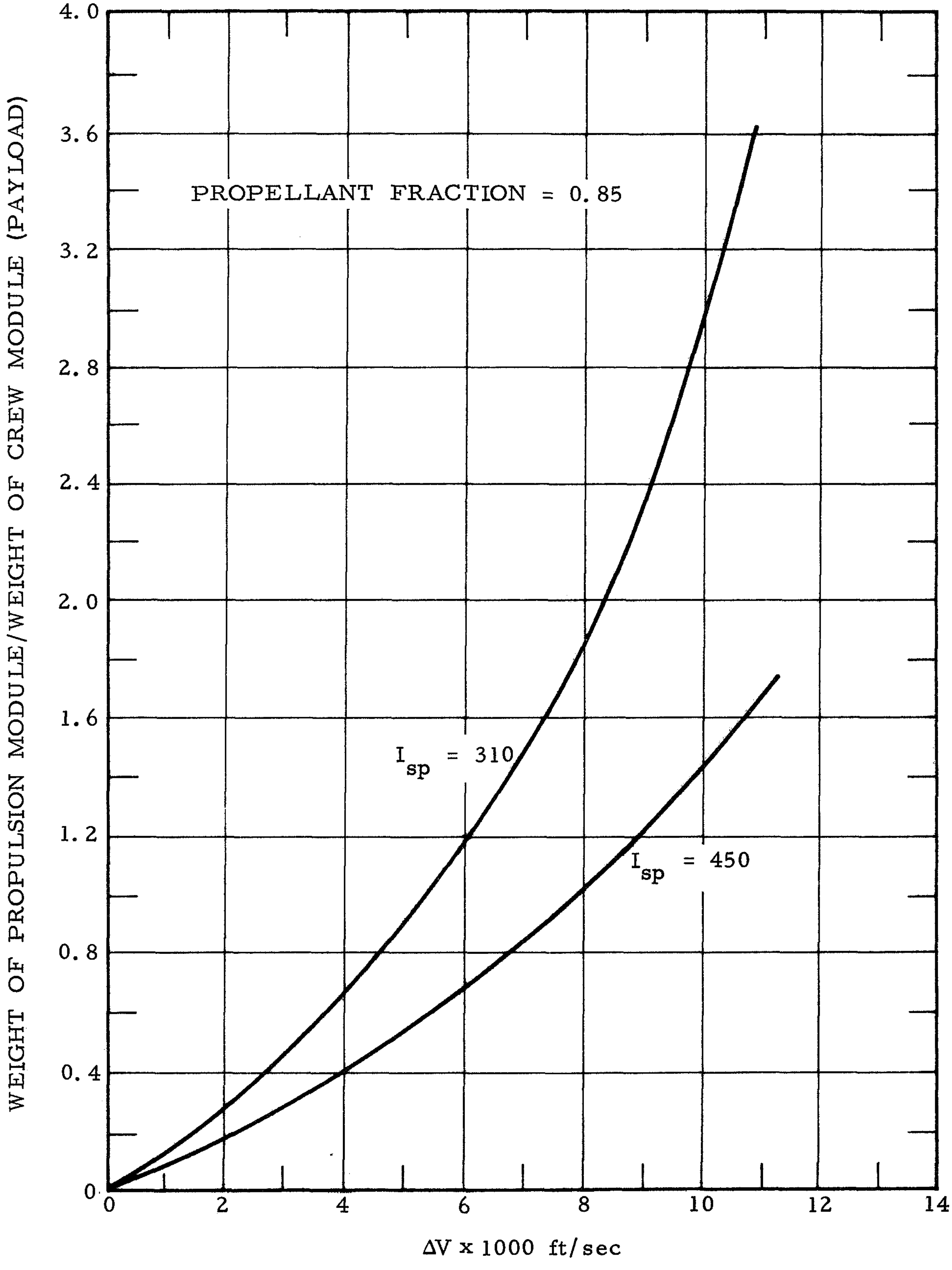

Figure K-4. Propulsion Module Weight Summary (ΔV from 0-10,000 ft/sec)

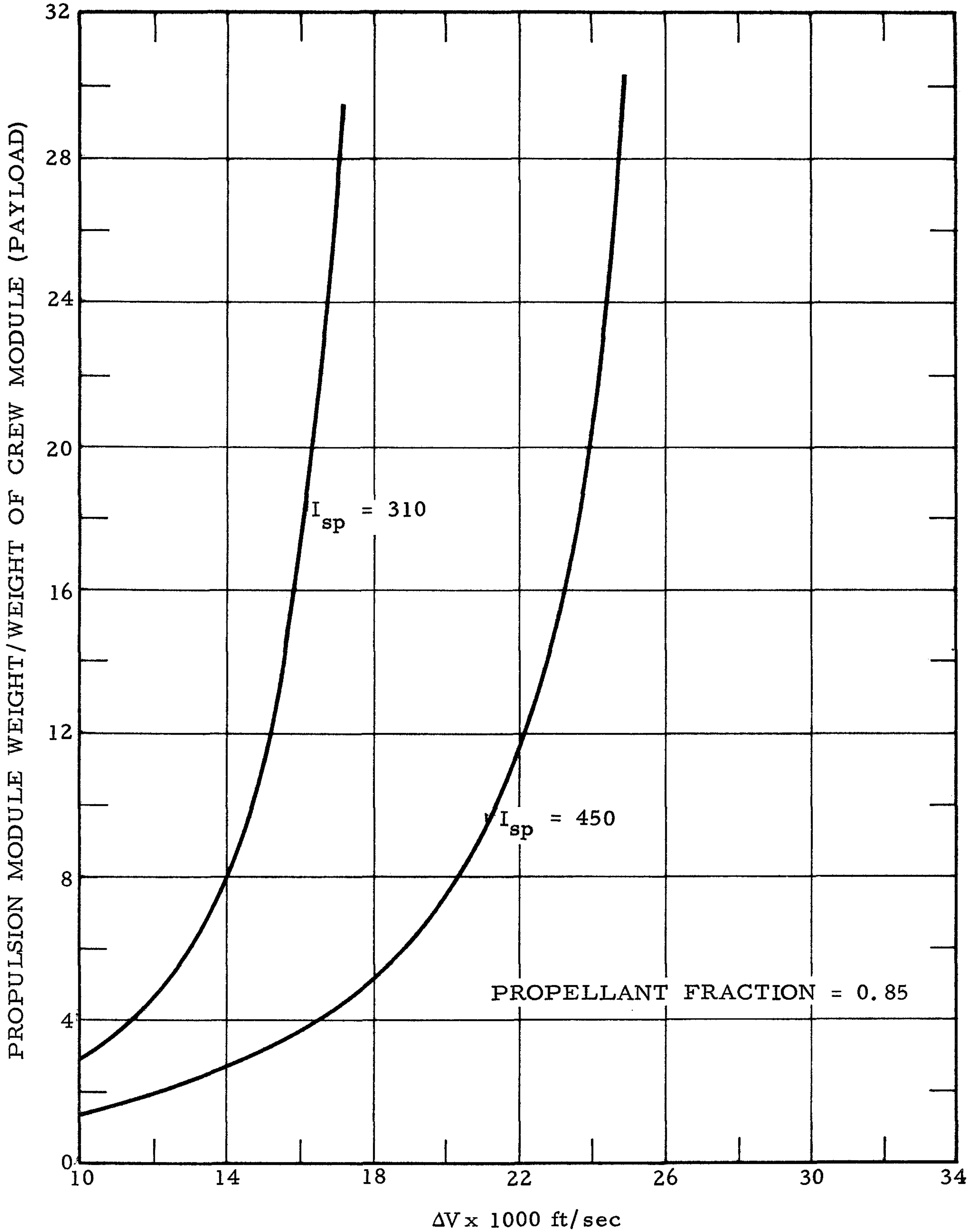

Figure K-5. Propulsion Module Weight Summary ($\Delta V \geqq 10,000$ ft/sec)

APPENDIX L

GLOSSARY OF ACRONYMS

AL	airlock
AMU	Astronaut Maneuvering Unit
BOD	Bail-out Device (BOW or stranded BOR)
BOR	Bail-out and Return device
BOW	Bail-out and Wait device
CCM	Crew/Cargo Module
CM	Command Module (Apollo)
CONUS	continental United States
CW	continuous wire (heat sensing devices)
DV	Distressed Vehicle
EC/LS	Environmental Control and Life Support system
EOI	earth orbit injection
EOS	Earth Orbiting Shuttle vehicle
EOSS	Earth Orbiting Space Station
EPS	electric power system
ETR	Air Force Eastern Test Range, Patrick AFB, Fla.
EVA	extravehicular activity
FLSC	flexible linear shaped charge
GEO	geosynchronous orbit
GEOSS	Geosynchronous Orbit Space Station
HT	Hohmann Transfer (minimum energy transfer)
HTI	Hohmann Transfer injection

IP	Integrated Program (NASA Space operations proposed for the post-1980 period)
IR	infrared
IVA	intravehicular activity
LEO	low earth orbit
LEOI	low earth orbit injection
LEOSS	Low Earth Orbit Space Station
LO	lunar orbit
LOI	lunar orbit injection
LS	lunar surface
LSB	Lunar Surface Base
LWIR	Long-Wave Infrared Detection and Acquisition System
MAP	Modified Apollo Command Module
MCCM	Modified Crew/Cargo Module of the EOS
MEM	Mars Excursion Module
MMV	Manned Mars Vehicle
MTCM	Modified Tug Crew Module (Space Tug)
NERVA	nuclear engine for rocket vehicle application
OLS	Orbiting Lunar Station
OPD	Orbiting Propellant Depot
PAL	portable airlock
PAP	Prepositioned Aid Package
PL	payload
PLSS	Portable Life Support System
PM	Propulsion Module

RBOR	Rigid Bail-out and Return Device
RBOW	Rigid Bail-out and Wait device
RCS	reaction control system
RDF	radio direction finder
RF	radio frequency
RDT&E	research, development, test, and evaluation
RM	Remedial Means
RMU	Remotely Operated Manipulator Unit
ROM	rough order of magnitude
RS	Remedial System
SB	Space Base
SC	Spacecraft
SERD	Small Earth Reentry Device
SRCC	Space Rescue Control Center (on the ground or in orbit)
SRV	Space Rescue Vehicle
SS	Space Station
TCM	Crew Module associated with Space Tug
TEI	trans-earth injection
TLI	trans-lunar injection
TM	Transfer Module
URM	Unmanned Rescue Vehicle
UV	ultraviolet
ΔV	vehicle velocity increment required for a specific mission maneuver
WTR	Air Force Western Test Range, Vandenberg AFB, Calif.

XBOW	Expandable Bail-out-and-Wait device
XM	Expandable Reentry Module
YAG	yttrium aluminum garnet (radiation detection element material)