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Space Rescue Operations

Volume II: Technical Discussion

Prepared by SYSTEMS PLANNING DIVISION

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12 MAY 1971

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

Contract No. NASW-2078

Systems Engineering Operations
THE AEROSPACE CORPORATION

Aerospace Report No.
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SPACE RESCUE OPERATIONS

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STUDY OF SPACE RESCUE OPERATIONS
Volume II: Technical Discussion

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ACKNOWLEDGMENT

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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.

VOLUME II

CONTENTS

VOLUME II

CONTENTS (cont.)

VOLUME II

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*Pertinent References are given in the individual Appendices of Volume III.

VOLUME III

CONTENTS

TABLES

TABLES (cont.)

FIGURES

FIGURES (cont.)

FIGURES (cont.)

1. INTRODUCTION

1.1 BACKGROUND

The need and feasibility of aiding distressed space crews have been of concern since the initiation of the manned United States space program. Many proposals have been made and numerous suggestions have been offered on concepts to reduce the hazards of space flight. Both preventive and remedial techniques have been considered. Since launch vehicle capability initially limited spacecraft to essential mission equipment, safety depended on the reliability and redundancy of mission equipment and the selection of preferred mission operational modes. Special provisions or equipment for crew rescue or escape, except in the case of launch abort, have not been provided.

The missions being considered under the Integrated Program are vastly more complex and of much longer duration than any previously flown. Many vehicles and passengers not trained as test pilots will be involved. New hardware designs and operating concepts are being introduced, and a large increase in flight frequency is anticipated. A review and updating of previously accepted space flight safety considerations are clearly appropriate.

The Aerospace Corporation has been actively involved in the problem of manned space flight safety and because of this experience was selected to perform this study.

1.2 STUDY OBJECTIVES

The objectives of the study were:

a. Assess the gross hazards to crew and passengers of the post-Skylab missions proposed under the Integrated Program.

b. Evaluate possible escape or rescue operations and devices for assuring crew and passenger survival.

c. Provide a technical perspective from which desirable safety-oriented actions can be identified.

1.3 STUDY SCOPE

All manned phases of the Integrated Program were considered. Included were low earth orbit missions, geosynchronous missions, lunar orbit and landing missions, and possible planetary missions. Although both mission and hardware definitions are still in the preliminary phase, the currently available information was used wherever possible.

Flight phases occurring within the earth's atmosphere were excluded from consideration. Also, no assessment was made of the relative probability of occurrence of the identified emergencies.

1.4 STUDY PLAN

1.4.1 Definitions

The following definitions were adopted:

> Emergency - An emergency is that situation resulting from the occurrence of a hazard which threatens the life or well-being of crew or passengers and which requires action to be taken to resolve or alleviate the situation.
>
> Remedial System - A remedial system is a system capable of resolving the emergency situation by providing crew and passengers with a safe haven and includes the techniques of escape and rescue.

1.4.2 Approach

The principal steps in performing the study were:

a. Review available NASA mission and hardware element planning for each mission regime

b. Identify the hazards which lead to emergency situations requiring remedial action

c. Assess available contingency planning

d. Examine selected operational factors introduced by the Integrated Program

e. Determine the operational and equipment requirements of a Space Rescue Vehicle

f. Identify and compare the relative effectiveness of feasible remedial concepts for dealing with the identified emergency situations

1.4.3 Evaluation Criteria

A number of criteria were considered in evaluating the potential utility and attractiveness for implementation of the various remedial concepts examined. They included:

a. The degree or extent of aid rendered by the remedial concept. In this regard, a number of potential needs were addressed:

    (1) habitable shelter

    (2) life support

    (3) communications function

    (4) medical aid

    (5) crew transfer capability

    (6) crew retrieval capability

    (7) completeness of the remedial action; i.e., whether the action is an intermediate one which merely alleviates the emergency or is a final action totally resolving the emergency.

b. Reaction Time - Both the speed of response to the emergency and the speed of return to a safe haven were considered.

c. The extent of required participation by the crew or passengers of the distressed vehicle in the remedial operations.

d. The development status of the remedial system. In this regard, hardware was given preference if either planned or projected for the Integrated Program.

e. The state of the art of the remedial system.

f. The feasibility of multiple-use. Remedial systems having application to more than one Integrated Program mission were given preference.

g. Practicality of use.

h. Extent of nominal mission payload reduction.

1.4.4 Resources/Data Base

The study was intended to build on and update the results of previous studies relevant to the issue of Integrated Program space flight safety. Therefore, a large number of NASA and contractor technical reports, documents, briefings, etc., were reviewed in the course of the study. References to those specific reports actually utilized or relied upon are given throughout this report in the pertinent section to which they apply.

2. MISSION MODEL AND HARDWARE DEFINITION

2.1 GENERAL

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

a. 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 experiment delivery. In fact, early flights are expected to involve experimentation aboard the Orbiter.

b. Space Station Modules with application as

   (1) Low earth orbit space station
   (2) Synchronous earth orbit space station
   (3) Low earth orbit space base
   (4) Orbiting lunar station
   (5) Lunar surface base
   (6) Mars exploration spacecraft

c. A Tug for cargo transfer in

   (1) Earth orbit
   (2) Lunar orbit
   (3) Between lunar orbit and lunar surface

d. A Space Shuttle, either chemical or nuclear powered, for cargo transfer between low earth orbit and

   (1) Geosynchronous orbit
   (2) Lunar orbit

e. An Orbiting Propellant Depot for use in

   (1) Earth orbit
   (2) Lunar orbit

2.2 SUMMARY OF INTEGRATED PROGRAM PLAN

The foregoing Integrated Program missions and hardware elements are summarized pictorially in Figure 1. Also shown is the unmanned Saturn V (Int-21) and various unmanned planetary probes which were not part of the present study. A more complete discussion of Integrated Program mission and hardware details is presented in Appendix A.

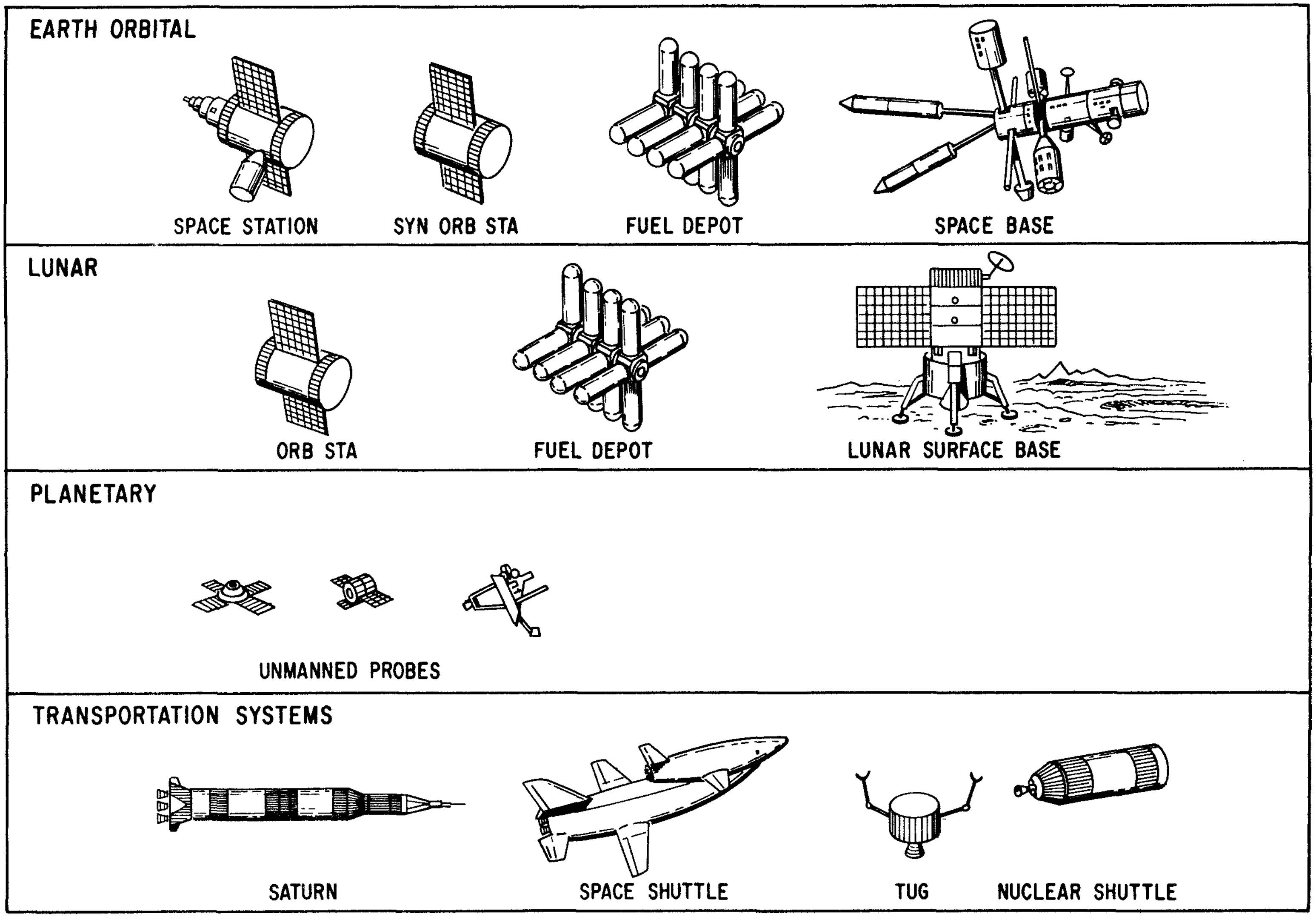


Figure 1. Integrated Program

3. HAZARDS ANALYSIS

3.1 GENERAL

An extensive review was made of the hazard studies conducted by many investigators. These studies were frequently restricted to single hardware elements or single missions, and numerous terms were employed to describe space flight hazards. Nevertheless, when reduced to causative factors, similar hazards (summarized in Figure 2) have generally been identified by the different investigators. Analysis revealed that these same hazards may also be anticipated for the Integrated Program missions and hardware. This conclusion is not unexpected inasmuch as similar subsystems, similar space environments, and similar human limitations are involved.

3.2 EMERGENCY SITUATIONS

Identification of hazards is a necessary step in defining emergencies. However, it is the emergency situations themselves which space rescue operations must consider. Hazards analyses have usually neglected to make a distinction between hazards and emergency situations. A summary of the emergency situations resulting from the identified hazards applicable to the Integrated Program missions and hardware is given in Figure 3.

Each item listed does not necessarily apply to all program elements. For example, a radiation source must be aboard a disabled spacecraft to cause radiation in its vicinity following an accident. Also, inability to reenter from space is an Orbiter problem only, since it is the only hardware element with planned reentry capability. Therefore, applicable remedial solutions need be provided only for the specific Integrated Program hardware and activity which produce the emergency being resolved.

- 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 2. Combined Hazards Listing

- 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 3. Summary of Emergency Situations

3.3 SUMMARY

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

a. a habitable haven for the rescued crew
b. medical aid (facilities and service) for ill or injured personnel
c. life support for extending crew survival
d. communication with the distressed crew during the rescue operation
e. emergency power during the rescue operation
f. transportation from the scene of the emergency to a final haven of safety

It can also be seen that a Space Rescue Vehicle (SRV) coming to the aid of a distressed vehicle (DV) may need the following capability:

a. collision avoidance with debris generated by the DV
b. radiation protection from DV sources
c. ability to dock with a disabled vehicle
d. ability to arrest the motion of a tumbling vehicle
e. ability to retrieve personnel from EVA and from a DV where docking is not possible

A more detailed discussion of the hazards analyses and emergency identification analyses is presented in Appendix B.

4. CONTINGENCY PLANNING

4.1 BACKGROUND

There is, as yet, no separately documented, overall safety plan for the manned phases of the Integrated Program. However, an extensive examination of all available NASA and contractor documents was made and revealed numerous references and guidelines for crew and passenger safety. Although specific references may not be found for each mission and hardware element, a "de facto" plan clearly exists. Its intent is to be able to deal with any contingency when it happens.

4.2 GENERAL 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. It is proposed that rescue capability be provided for both earth orbit and lunar missions. Missions will be designed to allow Earth Orbit Shuttle (EOS), Tug, and Space Shuttles to be available for this purpose. For the 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.

A detailed discussion and summarization of the specific remedial and preventive plans proposed to date for the Integrated Program are presented in Appendix C.

4.3 SUMMARY

Current plans are as yet incomplete and must remain dynamic, changing as the missions and hardware elements become more clearly defined. It is to be noted that at the present time, 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 coordinated planning between interfacing major hardware elements.

There are, as yet, no escape or rescue provisions specified for either the Earth Orbit Shuttle or the manned Tug (nor for the Space Shuttle).

5. RESCUE VEHICLE REQUIREMENTS

5.1 GENERAL

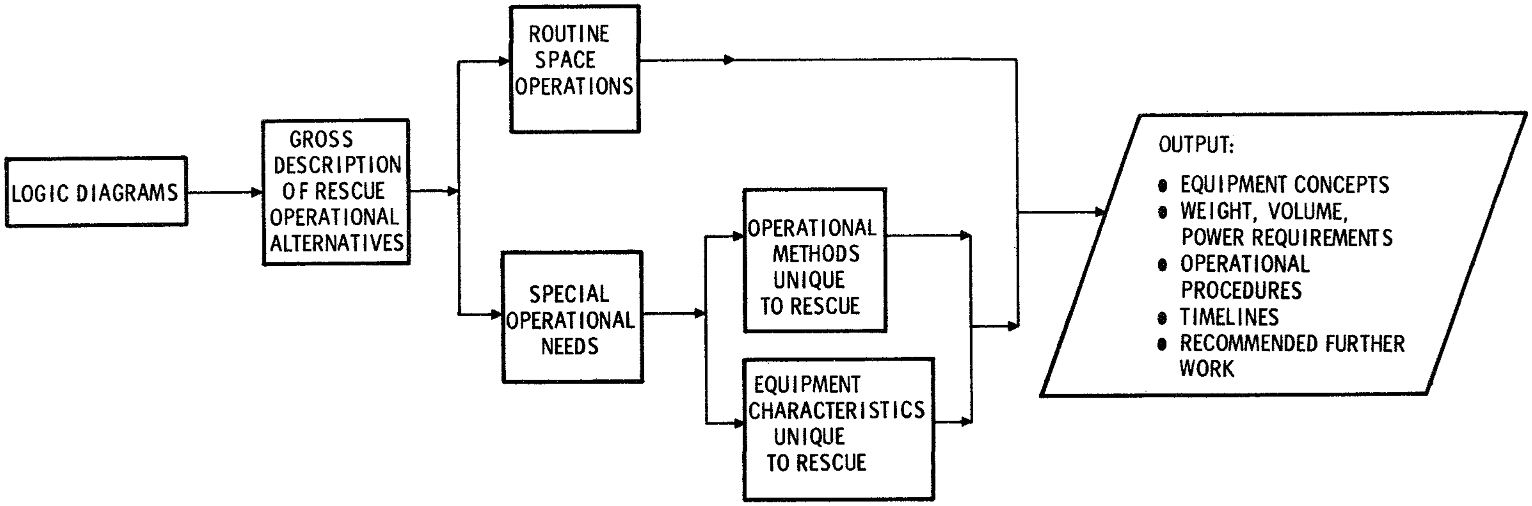
Most studies treating rescue vehicles have, in the main, been concerned with gross configurational definition and with the performance and operational considerations of launching and providing a rescue vehicle at the scene of the emergency. Little, if any, attention has been directed toward determining the specific operational steps to be taken upon arrival in the vicinity of a distressed vehicle, and what special capability or equipment a rescue vehicle might need. It has been generally assumed that once a "rescue vehicle" has arrived on the scene, it could accomplish its intended objective.

The purpose of this phase of the study was to examine the period commencing with the arrival of a Space Rescue Vehicle (SRV) in the vicinity of a distressed vehicle (DV) and ending with the departure of the SRV to a final haven of safety. Thus, a clearer understanding and assessment of the operational steps and attendant equipment requirements involved in the space rescue operation for potential Integrated Program emergencies can be provided.

5.2 METHOD OF APPROACH

Figure 4 illustrates the specific approach followed in performing this phase of the study.

Logic diagrams were prepared which described the gross operational alternatives facing an SRV when it arrives in the vicinity of a DV. The specific emergency situations considered were those previously identified in Figure 3. From these operational alternatives, non-routine space operations were further examined via logic diagrams to define those operational methods and equipment characteristics which were unique to space rescue operations. Based on this definition of requirements, a variety of special equipment concepts and operational procedures (including timelines) were delineated.



- LOGIC DIAGRAMS DEVELOPED FOR ALL RESCUE OPERATION PHASES

Figure 4. Approach Used in Determining Space Rescue Vehicle Requirements

As an example, Figure 5 represents the top flow diagram of rescue operations in the general case. An SRV arriving in the vicinity of a DV (point Ⓐ) may be faced with the need for data acquisition. For its own safety, the presence or absence of DV-generated debris or radiation needs be verified before the SRV can safely proceed to close rendezvous with the DV. The DV may be mute and unable to communicate with the SRV, requiring the SRV to perform surveys and inspections of the general area as well as of the DV before proceeding further.

As a next operation, it may be necessary to de-spin the DV prior to proceeding with the rescue mission.

The DV crew could be within the DV or have bailed out with a Bail-Out-Device (BOD). If within the DV, the rescue crew (RC) may be required to board the DV (via docking or EVA) to perform operations within the DV (damage control, medical aid, repair, etc.) and transfer the DV crew to the SRV. The rescue is completed by returning the DV crew to a permanent haven.

If the DV crew is in a BOD, the primary operational task is to transfer the DV crew to the SRV.

In addition to the above operations, it may be necessary for the RC to either dispose of or secure the DV by shutting down various equipments (nuclear reactors, etc.), adjusting the orbit of the DV for later disposal, or initiating a controlled reentry of the DV for system disposal purposes.

From these gross operational alternatives, further detailed logic diagrams were prepared for each alternative approach to the level necessary for the definition of specific methods and equipment characteristics. A more complete discussion of these logic diagrams and the resultant operational methods and equipment details is presented in Appendix H.

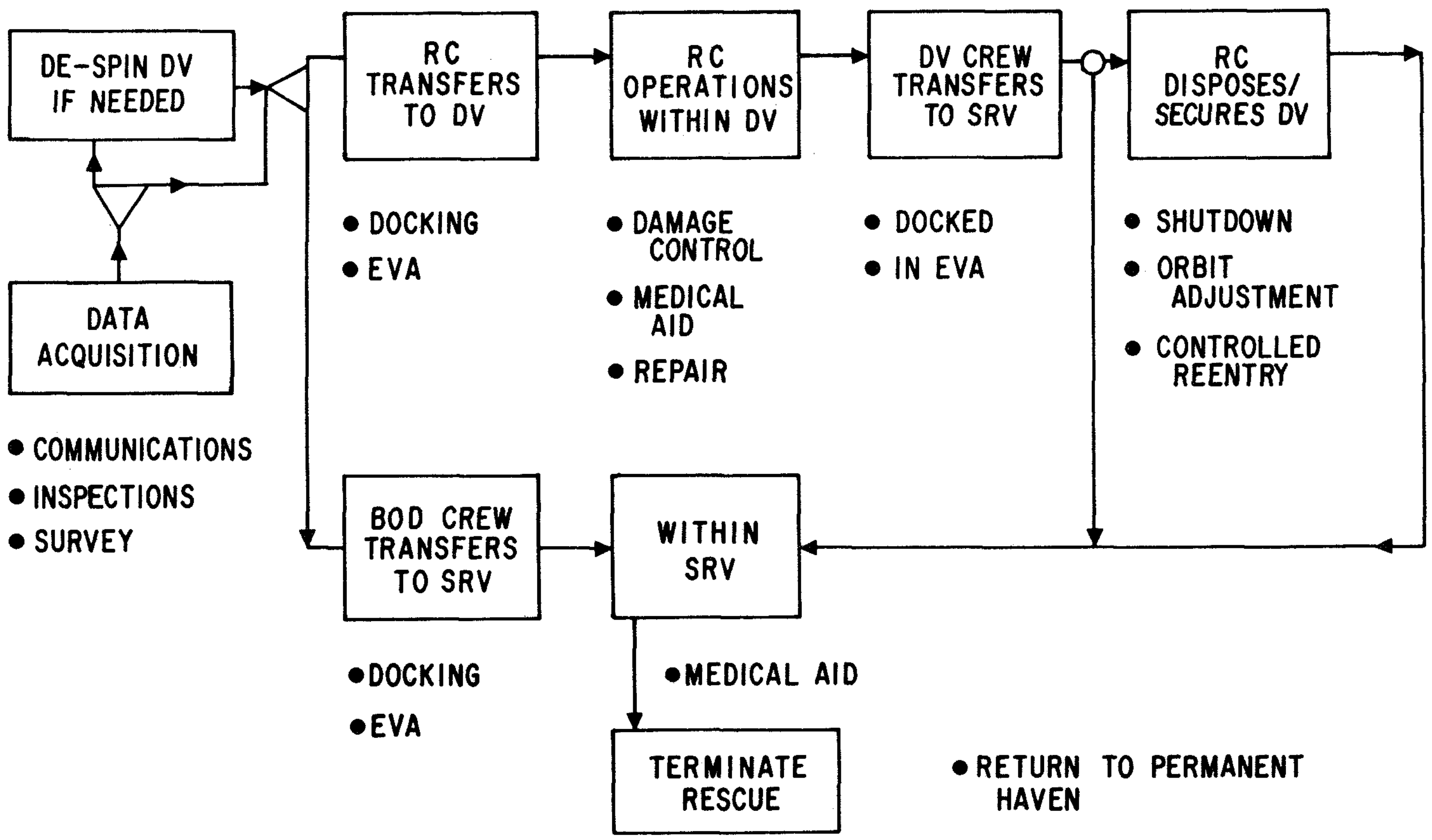


Figure 5. Rescue Operations, Top Flow Diagram

5.3 SELECTED STUDY AREAS

5.3.1 Introduction

As might be expected, detailed examination of the rescue alternatives to the wide range of emergency situations identified in Figure 3 resulted in the definition of a similarly large number of potential rescue vehicle operational procedures and special equipment requirements. Those requirements associated with (1) hazards to the SRV, (2) crew transfer difficulties, and (3) rescue delays are discussed in this section. A more comprehensive treatment of these areas and discussion of other potential SRV operational and equipment requirements are presented in Appendices F, G, H, and I.

5.3.2 Hazards to the Space Rescue Vehicle

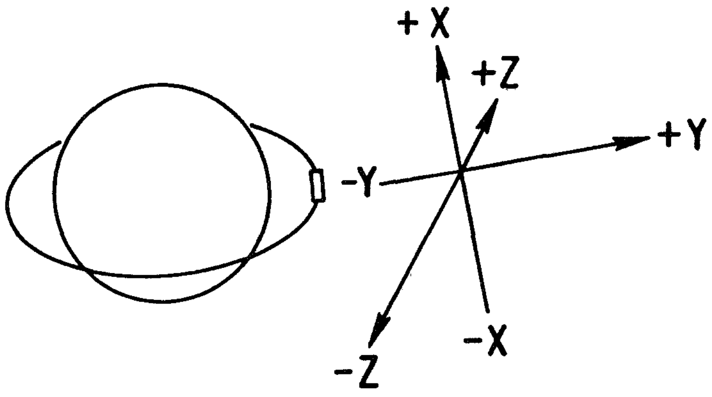
5.3.2.1 Debris Generated by DV

The possibility of an explosion on board the DV as the hazard which caused the emergency led to the conclusion (in Section 3) that some of the DV-generated debris could be in the vicinity of the DV when the SRV later approached the DV to render aid. If so, such debris could definitely constitute a hazard to the SRV itself.

In order to substantiate this possibility, a simplified first-order analysis of the resultant trajectory and motion characteristics of debris ejected from an orbiting vehicle was performed (see Appendix I-1). The analysis results indicated that (1) debris ejected radially from the DV returns to the source (DV) once each DV orbit, (2) debris ejected tangentially never returns to the source, and (3) debris ejected 90° to the orbit plane returns to the source twice each DV orbit. Figure 6 summarizes these results.

Thus, collision between an arriving SRV and DV-generated debris is a definite possibility, and the ability to detect and avoid such debris is a desirable SRV capability. A brief assessment of detection equipment (Appendix H) indicates that long wave infrared (LWIR) and laser radar systems have potential for

DV GENERATED DEBRIS



DEBRIS EJECTED	RETURNS TO SOURCE
RADIALLY (Y AXIS)	ONCE EACH ORBIT
TANGENTIALLY (X AXIS)	NEVER
90^0 TO ORBIT PLANE (Z AXIS)	TWICE EACH ORBIT

CONCLUSIONS:

- COLLISION BETWEEN SRV AND DV GENERATED DEBRIS POSSIBLE
- DEBRIS DETECTION BY SRV DESIRABLE

Figure 6. Debris Hazards to SRV

providing this capability at reasonable weight, volume, and power requirements. Further, these laser radar systems may be applicable to the rendezvous and docking function as well.

5.3.2.2 Uncontrolled Radiation

Another potential hazard to an arriving SRV is uncontrolled radiation. Nuclear reactors have been proposed as power system sources for the space station/ base. Nuclear isotope sources have also been considered for certain experiments, as well as for power-generation systems. In addition, a nuclear rocket engine is the propulsive source of the reusable Nuclear Space Shuttle. Malfunctions of either reactor or isotope sources in a DV could result in uncontrolled radiation of the neutron, alpha, beta, gamma, and x-ray types. The general requirement exists, therefore, for an SRV to have sensory systems able to perform radiation detection and diagnostic functions. Desirable capability would include (1) determining a safe approach corridor to a DV and (2) determining the nature and source of the particular nuclear malfunction and its probable effect on the DV, SRV, and rescue crew during rescue operations.

A variety of nuclear detection equipment which has potential application to this problem area already exists. For detection surveys upon arrival of the SRV at the scene (distances up to 10 n mi), neutron detectors (proportional counter), alpha detectors (proportional counter), and gamma and x-ray detection (collimated scintillation counter) may be applicable. For closer detection surveys of or within the DV, portable versions of proportional counters or Geiger counters (for gamma, x-ray, and beta radiation) may be appropriate. (See Appendix H for details).

5.3.3 Crew Transfer Difficulties

As mentioned in Section 5.2, the general requirement of crew transfer occurs frequently in a rescue mission. If the DV is stabilized (no undesirable vehicle motion) and if the standard docking provisions of the DV are operative, the transfer of crew between the DV and SRV could be accomplished via a routine docking and transfer operation.

On the other hand, if the DV has motion sufficient to preclude the docking maneuver, or if the DV docking mechanisms are damaged or inoperative, it may be necessary to perform the transfer by EVA.

In some cases, such as a crewman injured to the extent that he cannot be placed in a suit for EVA transfer, special equipment may be necessary to either effect an EVA transfer or to enable an otherwise infeasible docking transfer. A summary of the study results pertaining to these transfer problems is presented in the following three sections. A comprehensive discussion of the crew transfer problem is presented in Appendix H.

5.3.3.1 Undesirable Vehicle Motion

The potential hazards of explosion, vehicle collisions, and reaction control system malfunctions could result in spinning or tumbling of a DV. Preliminary estimates (Appendix I-2) indicate that large spacecraft, e.g., a space station, could have residual spin rates up to 4 rpm. Pure spin, however, is unlikely. It would probably exist only if the DV attitude control system was still functioning or after the elapse of a long time.

Prior to any attempted physical contact between the SRV and DV, it would first be necessary to characterize the DV motion. The DV spin rate and axis of rotation and nutation (wobble) rate and angle would have to be known. One possible method for such DV motion characterization requires at least three retro-reflectors suitably positioned beforehand on the outer shell of the DV (at a weight penalty of 2 lb) and a scanning laser radar and computer system on board the SRV (at a weight of approximately 30 lb and a volume of approximately 2 ft^3). Such a system would have an effective range of approximately 1 mile.

If an SRV attempted to dock with a spinning DV in the plane of spin, an SRV thrust-to-weight ratio of approximately 0.5 would be required because of centrifugal force effects. This is not feasible for Integrated Program vehicles (EOS, Space Tug), because they do not have thrusts of this magnitude.

If, for docking purposes, an SRV approached a spinning DV along the spin axis, the centrifugal force problem is avoided. However, the SRV and DV docking ports must both be on the axis of spin, and even then the docking torques would be greater than normal. Further, a docking port located in the spin axis is unlikely except in the case of an intentionally rotating space system.

If the DV motion was not pure spin (i.e., contained "wobble"), a complex SRV control problem occurs in attempting to match the wobble pattern of the DV. Therefore, the feasibility of approach along the spin axis is also questionable unless the motion of the DV can be reduced to an acceptable level.

Means for reducing undesirable DV motion to acceptable limits for docking or EVA transfer involve, of course, either the activation of some momentum transfer device on the DV itself or a built-in tumbling-arrester system in the SRV. The latter approach has often been mentioned as a desirable SRV capability, but no known practical schemes have been evolved to date for vehicles of the size envisioned for the Integrated Program. Examples of the former approach include a mass on a cable (yo-yo) or a rocket system, either appropriately emplaced beforehand on the DV or attached by an SRV crew at the scene of the emergency (in EVA or manipulator-assisted operations).

For the case of a 120,000-lb space station with motion at 4 rpm about its major axis of rotation, a yo-yo system consisting of 1200 feet of cable and a 100-lb weight would be adequate (total weight about 150 lb, total stowage volume about 3 ft^3). Alternatively, a rocket thrust system with approximately

70 lb thrust and burning approximately 30 minutes could also reduce the DV motion (total weight about 460 lb, total stowage volume approximately 7 ft^3).

5.3.3.2 Inability to Dock

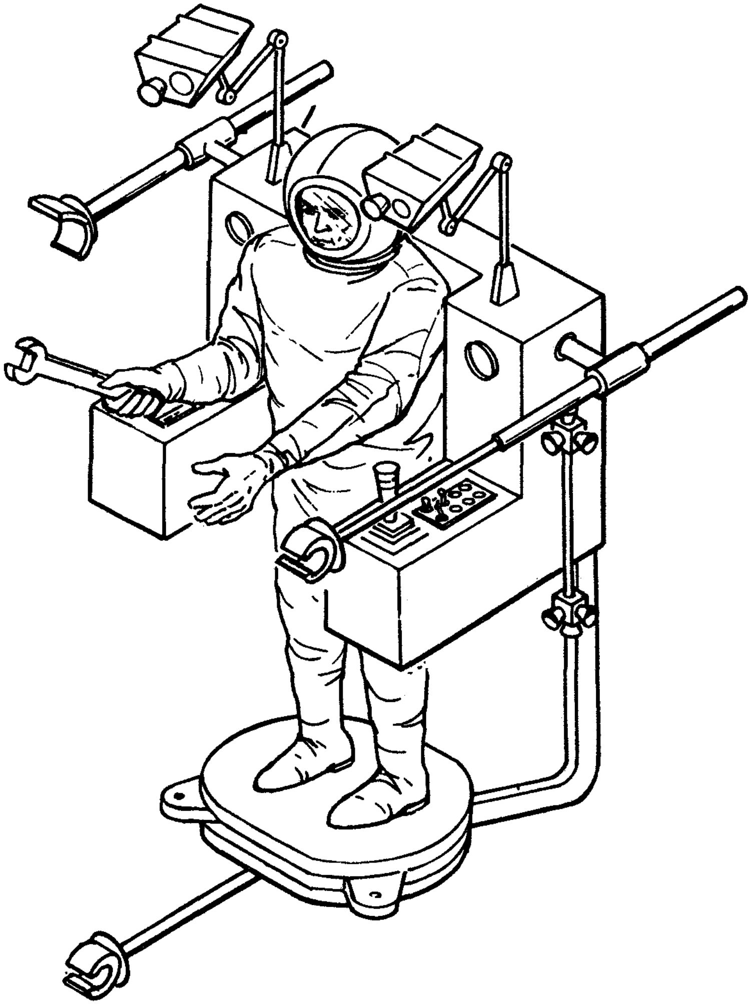
If the SRV is unable to dock with the DV, the transfer of the DV personnel and/or RC would have to take place by means of EVA. Present-day EVA space suits with their 3.5 psia pure oxygen atmosphere are not very well suited for such emergency transfers because of the required period (about 4 hours) of acclimatization to the 14.7 psia atmospheres for the SRV and the DV to avoid decompression sickness. This points to the need for development of a new suit with an N_2/O_2 atmosphere at a pressure of 7 psia or more, which would not require acclimatization time.

For the EVA transfer between the two vehicles, and also for providing a stabilized maneuverable platform with a variety of effort-saving devices (tools, manipulator arms, lights, etc.), platform-type astronaut maneuvering units (AMU's) (see Figure 7) may be highly desirable during certain EVA space rescue operations.

A manipulator unit (also shown in Figure 7), providing a shirtsleeve environment for the RC, is a logical extension of the platform-type AMU. This device requires all dextrous motions to be performed through manipulator arms.

A special transfer capsule is needed for the case of a DV crew member injured to the extent that he cannot be placed in a suit for EVA transfer to the SRV. A suggested design, Figure 8, consists of an inflatable shell with a docking port/hatch assembly at one end for attachment to a docking port of a DV. Once attached, it can be inflated by a pressurizing atmosphere supply and the injured crewman placed within on an inflatable personnel carrier (stretcher). The hatch is then closed, the transfer capsule undocked from the DV, and then transported (by EVA crewman or AMU) to the SRV, where the injured man can be removed in like fashion. This device could also be used as a quarantine isolation capsule.

- AMU (PLATFORM TYPE)
  - USED BY SRV CREW
  - WEIGHT = 500 LB
  - STOWED VOLUME = 30 FT^3



- MANIPULATOR (SHIRTSLEEVE ENVIRONMENT)
  - USED BY SRV CREW
  - WEIGHT = 2000 LB
  - STOWED VOLUME = 70 FT^3

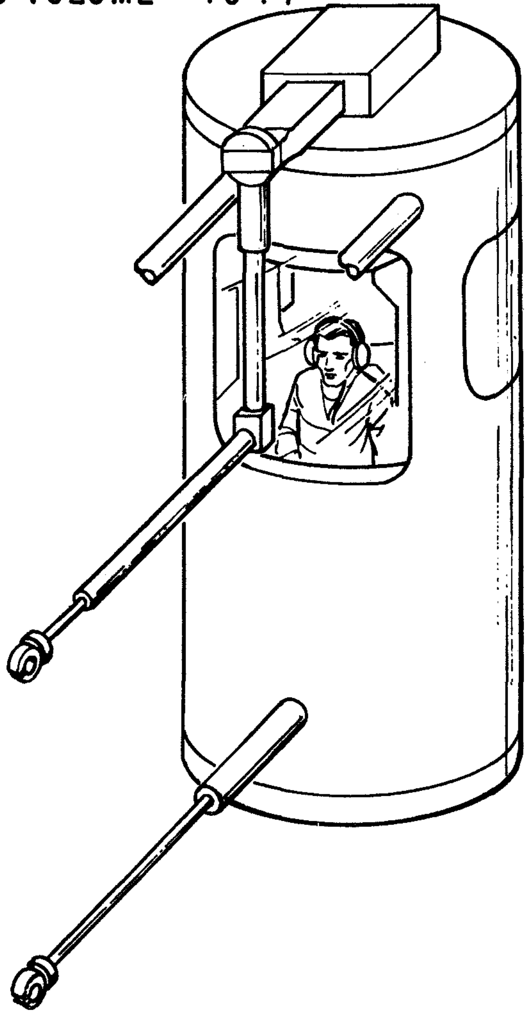


Figure 7. EVA/Transfer Equipment

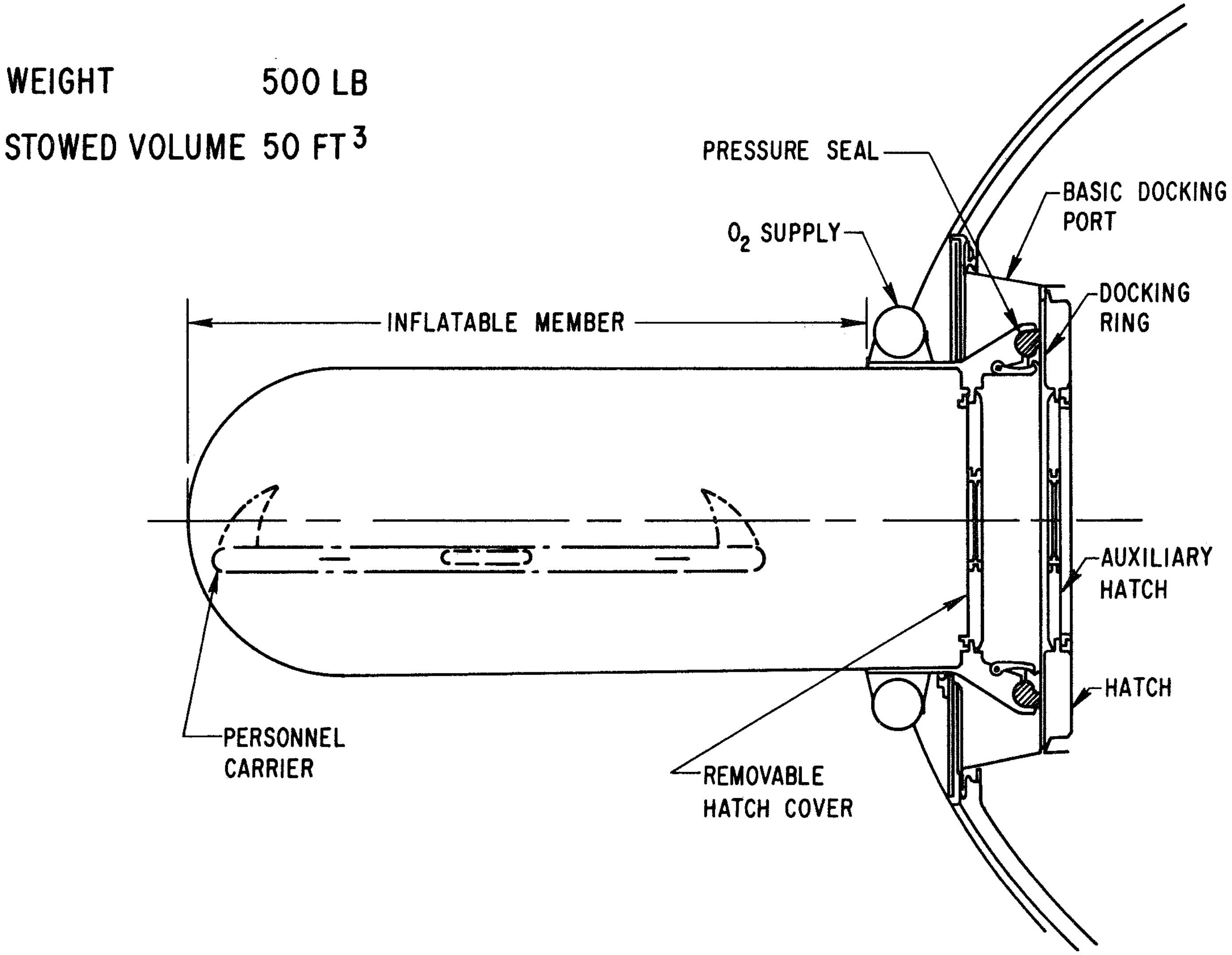


Figure 8. Transfer Capsule for DV Crew

5.3.3.3 EVA Not Feasible or Not Desired

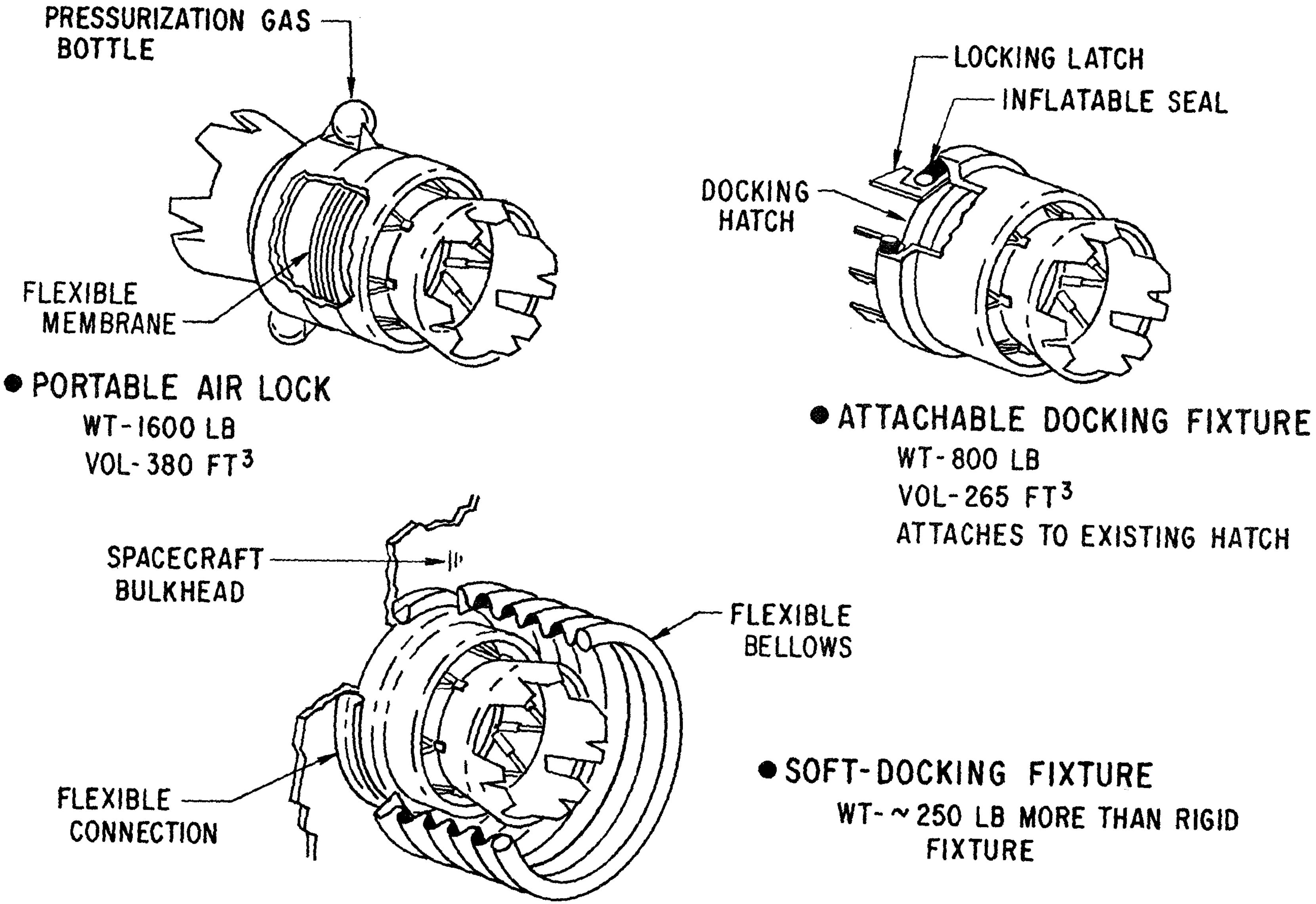
If, for any reason, the EVA transfer mode is either not feasible or is not desired under the existing conditions, other special transfer equipment could prove of value. Three such concepts, identified in this study, are depicted in Figure 9. They are a portable airlock, an attachable docking fixture, and a soft-docking fixture.

The first device, a portable airlock, consists of an inflatable shell with neuter docking/hatch assemblies at both ends. It is inflatable with a pressurizing gas supply, similar to the transfer capsule previously described. It could be stored on board a DV or the SRV.

The primary purpose of the portable airlock is to provide a means for EVA entry and exit in the event that a functioning airlock is not available. However, as defined herein, the portable airlock can also serve as a transfer device. With the addition of appropriate life support and stabilization equipment, it could also function as a Bail-Out-and-Wait device. Further, suitably equipped, it could provide a biological decontamination function.

Transfer of the portable airlock between the SRV and the DV is by EVA crewmen with AMU's, by a small reaction control system (RCS) built into the airlock, or by an automated unmanned maneuvering unit.

The second device, an attachable docking fixture, has application to those situations where the DV motion is sufficiently stable to permit docking, but the normal docking fixture of the DV is inoperable. It is a unit with a neuter docking interface at one end and locking latch/inflatable seal/docking hatch configuration on the other end. The intent is to attach the docking fixture to an existing hatch on the DV (e.g., the EVA airlock hatch) to permit a routine docking transfer operation to or from the DV. In this situation, the docking fixture locking latch mechanism would be inserted into the DV hatch opening and held in place with an inflatable seal, as illustrated. Attachment is accomplished by an EVA crew or by a remotely controlled automatic manipulator unit.



- PORTABLE AIR LOCK
  WT-1600 LB
  VOL-380 FT^3

- ATTACHABLE DOCKING FIXTURE
  WT-800 LB
  VOL-265 FT^3
  ATTACHES TO EXISTING HATCH

- SOFT-DOCKING FIXTURE
  WT-~250 LB MORE THAN RIGID FIXTURE

Figure 9. Special Transfer Equipment

The third device, a soft-docking fixture, has application in those instances where the DV is relatively stable but sufficient nutation (wobble) exists to prevent conventional hard-docking. If either the DV or SRV were equipped with a soft-docking fixture, the transfer operations could be performed by docking instead of EVA activity.

5.3.4 Rescue Delays

Aside from the difficulties involved in transfer of SRV and DV crews, as discussed above, large time delays may be encountered in rescuing the DV crew due to (1) damage on board the DV and (2) the need for immediate medical attention to injured crew members (see Appendix H).

5.3.4.1 Damage In The Distressed Vehicle

Damage in the distressed vehicle can cause rescue delays due to (1) loss of communications, (2) need for damage assessment by the RC, (3) need for damage control by the RC, and (4) emergency entry requirements.

5.3.4.1.1 Loss of Communications

The RC have many information needs during a rescue mission. If damage to the DV has deactivated the DV communications system, or if the DV crew are unable to perform, the RC may have to take time to acquire necessary information with their own communications or sensory systems before proceeding with the rescue operations.

Information required by the arriving SRV includes:

1. Hazards to the SRV (debris, radiation)
2. Extent of DV damage
3. Status of the crew
4. Location of the crew
5. Proper method for DV entry and/or DV crew transfer

Voice radio and telemetry links, of course, are the preferred techniques for communication between the SRV and DV. Visual communication (visual scanning, blinker signals) may be necessary in some situations. External readout provisions on the DV could provide another communication dimension for the RC.

To provide for communication contingencies, it is appropriate to consider implementation of the following types of communications features:

1. Located on DV
    - a. Redundant voice and telemetry transponder/ transmitter (with battery power supply)
    - b. Handsets in every compartment
    - c. Omnidirectional exterior antenna
    - d. Visual blinker system
    - e. Exterior readouts for telephones and damage sensors
2. Located on SRV
    - a. Visual blinker system
    - b. Portable plug-in damage sensor readout
    - c. Portable plug-in telephone system
    - d. Illuminator (for visual scanning)
    - e. Remotely controlled TV carrier

5.3.4.1.2 Damage Assessment

Additional equipment may be necessary for determining the extent of the DV damage and possible hazards to the SRV and crews. A portable sampling/ analysis kit would be especially useful to (1) determine compartment pressures and atmospheric composition, (2) test for contaminants, and (3) detect radiation. It would contain a gas analysis kit, a pressure gauge, and a radiation detector and would be plugged into exterior sampling ports built-into the DV. It could also be used for interior compartment surveys of the DV after entry. Preliminary estimates indicate a total weight of about 40 lb and a volume of approximately 1.25 ft^3 for a portable kit of this type.

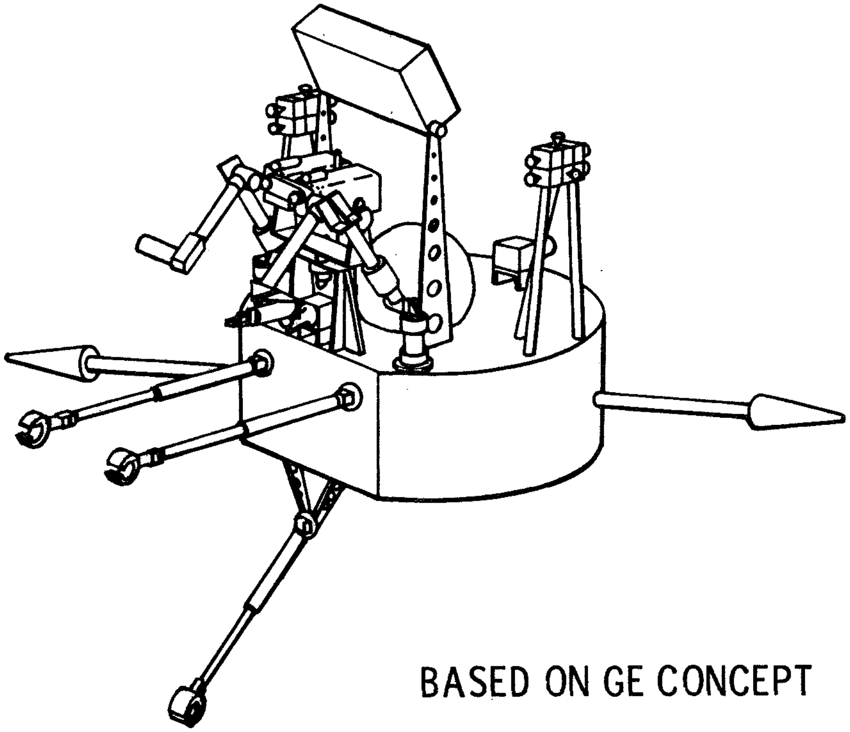
5.3.4.1.3 Damage Control

Possible damage control operations required of the RC include (1) fire fighting, (2) decontamination, and (3) clearing passageway obstruction.

The use of fire extinguishers and cabin depressurization are two recognized techniques for arresting fires. In order to implement depressurization, it may be necessary for the RC to use a drilling tool to make vent holes, if the DV does not have compartment vent valves in the particular area or if those vents are inoperable or inaccessible.

A decontamination operation may be required because of the presence of toxic gases, bacteria, or radiation sources. Depressurization could be used to vent the toxic gases, again with the possible need for a cutting or drilling tool to make a suitable vent. Chemicals may be required to suppress undesirable bacterial action. A device such as a portable radiation shield (carried by the RC) may be necessary to approach and retrieve the DV crew from radiation-contaminated areas or to acquire and dispose of nuclear radiation sources. A cutting or drilling tool would be a useful device also for the clearing of interior passages. In the event such damage control were to be accomplished exterior to the vehicle, the manned manipulator unit of Figure 7 would be applicable. Also applicable is a remote-controlled manipulator unit of the type illustrated in Figure 10.

There is also a potential requirement for decontamination of the RC and DV crew when reentering the SRV. If such decontamination steps cannot be effectively made while on board the DV, it may be necessary to provide decontamination facilities in an airlock of the SRV.



BASED ON GE CONCEPT

UNIT WEIGHT, LBS, ~ 1000 LBS
STOWED VOLUME, FT^3 ~ 40

Figure 10. Remote Controlled Manipulator

5.3.4.1.4 Emergency Entry

Regardless of whether transfer of the RC to the DV is accomplished by docking or by EVA, the RC is faced with the possibility that the DV crew may be entrapped within a specific portion of the DV, or injured to the extent that they cannot participate effectively in operations to permit RC entry through DV hatches.

In either case, it would be advantageous to provide means (1) to facilitate RC entry through DV hatches and (2) to enable the RC to enter DV compartments without hatches.

Entry through existing hatches can be augmented or facilitated in a number of ways. First, a double hatch design can be employed wherein a smaller-diameter inner hatch could be used for emergency entry in the event the larger-diameter hatch became inoperable. Second, explosively-actuated emergency hatch ejection mechanisms can be considered in the initial hatch design. Third, multiple entryways or hatches to any given compartment can provide alternate entry paths in the event of malfunction or damage of the primary entry path.

In those cases where the single entry (hatch, etc.) to a compartment is blocked or cannot be actuated, it may be necessary to attempt entry through a wall or bulkhead. Cutting through a bulkhead with tools is one approach, but it may be desirable to provide, in some spacecraft compartments, for a penetrable wall area or bulkhead design, which should be suitably marked as such. One approach is to incorporate built-in receptacles in a designated section of a wall or bulkhead to receive a flexible linear shaped charge that can be used to explosively cut an opening for emergency entry. It is estimated that this approach would require an added structural weight in the bulkhead of about 5 lb for a 3-ft diameter opening; the charge weight is approximately 0.05 lb/linear foot.

5.3.4.2 Medical Needs of Injured Crew

The potential need to provide medical aid to injured DV crew members implies that the RC should be trained in administering such aid and that the necessary supplies and provisions must be carried by the SRV. The need to provide medical aid on board the DV before transfer to the SRV further suggests that medical supplies be in easily transportable kit form.

Table 1 is a listing of various medical kits and their weights which are pertinent to emergency medical aid requirements. A more comprehensive discussion of potential injury or illness needs and their corresponding medical equipment requirements is presented in Appendix G.

5.4 OTHER OPERATIONAL REQUIREMENTS

A number of other operations may be necessary during a rescue mission. These include administering emergency life support, making repairs to the DV, carrying injured crewmen, and performing fly-around inspections of the DV. To meet these additional needs, other specific equipment and performance capabilities may also be required of the SRV. These are discussed in the following paragraphs.

5.4.1 Miscellaneous Equipment

A variety of miscellaneous equipment items were identified in the course of this study that were ancillary or needed in support of other discrete operational steps. These are briefly summarized in Table 2 together with estimated weight and volume characteristics. (See Appendix H for details.)

One item deserving special mention is a portable EC/LS unit to be carried from the SRV to the DV for sustenance of the DV crew while the rescue operation is in progress. As shown in Table 3, this unit would have an oxygen source, capacity for dehumidification, CO_2 removal, cooling, and a power supply. The estimated weight for a 14-man/48-hour capacity is about

Table 1. Medical Kit Requirements

Kit Type	Wt, lb
Drugs and Medication Kit	2.5
Intravenous Fluids Kit	15.0
Dressings, Packings, Bandages Kit	1.5
Suture Kits	1.0
Incision and Drainage Sets	1.0
Tracheotomy Kit	0.5
Inflatable Splints	0.5
Miscellaneous	3.0

Table 2. Miscellaneous Equipment Requirements

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

Table 3. Extended Survival Capability Requirements

Requirement	Solution
Emergency Supplies on DV	Provide for 48-hr Period Breathing oxygen Spare provisions
Emergency Supplies Brought by SRV	Provide for 48-hr Period Breathing oxygen Portable EC/LS Spare provisions

Equipment	Weight for 14 men/ 48 hr, lb	Stored Volume, ft^3
Sodium Chlorate Candles: Oxygen source	200	2.0
Portable EC/LS Unit: Oxygen source Dehumidification CO_2 Removal Cooling Power	520	12.0
Spare Provisions	96	1.5

520 lb at a volume of 12 ft^3. Emergency provisions (food, water) could be provided for the same period for approximately 96 lb and 1.5 ft^3.

As an emergency oxygen source stored aboard the DV, sodium chlorate candles could be carried at an estimated weight of 200 lb and volume of 2 ft^3 for the same 14-man/48-hour life support period.

5.4.2 Post-Rendezvous Performance

After arriving in the DV vicinity, the SRV requires a ΔV capability of about 200 fps under nominal conditions in order to perform terminal rendezvous, docking, and stationkeeping with the DV. If the SRV had to approach a rotating DV along its spin axis to dock, this ΔV requirement could approach 600 fps.

If a fly-around inspection of the DV were necessary prior to rendezvous and docking, the ΔV requirements would depend upon the fly-around technique to be used. If time permitted a slow fly-around, the ΔV could be as low as 5 to 10 fps in a single impulse burn, with an entire DV orbital period required for the fly-around. If a fast fly-around inspection were required, a ΔV of about 1900 fps applied over a 10-minute period at a thrust-to-weight ratio of 0.1 would be required at a fly-around radius of 5 n mi about the DV. If this radius were reduced to 100 ft, the ΔV requirement would be approximately 350 fps applied over a 30-minute period at a thrust-to-weight ratio of 0.006.

The foregoing results are summarized in Table 4. A more detailed discussion of the fly-around inspection problem is presented in Appendix I-3.

5.5 SUMMARY AND CONCLUSIONS

5.5.1 Distressed Vehicle Design Impact

Special design and equipment features must be considered early in the design of every spacecraft in order to facilitate rescue operations if they should ever be needed.

Table 4. SRV Terminal ΔV Requirements

Operation	ΔV, fps	Duration	Remarks
Terminal Rendezvous,	To 200		Nominal condition
Docking, and Stationkeeping	To 600		DV approached along spin axis
Fast DV Fly-around:			
5 n mi radius	1900	10 min	0.1 thrust/wt ratio
100 ft	350	30 min	0.006 thrust/wt ratio
Slow DV Fly-around	5 - 10	Orbital period	Single impulse

In the design area, the most important consideration is preplanning to facilitate entry of an RC into compartments of the DV. Double hatches, explosively actuated hatch mechanisms, multiple entryways and hatches, and penetrable bulkhead design are possible approaches.

Special equipment identified by this study includes (1) retro-reflectors for DV spin rate and nutation determination, (2) yo-yo or rocket de-spin systems, (3) spare EVA suits, (4) spare oxygen candles, and (5) various spare DV-SRV communications aids.

5.5.2 Space Rescue Vehicle Design Features

An SRV will require special rescue equipment, as well as equipment to deal with environmental hazards caused by a DV, in order to successfully perform diverse rescue operations.

Estimates indicate that under the most favorable rescue situation the time required from rendezvous to cast-off is approximately one hour. However, if communication is broken, the DV is critically damaged and/or tumbling, medical aid is required, and transfer to and from the SRV is by EVA, then the rescue timeline could exceed 24 hours.

Long RC work periods can be anticipated. Equipment carried aboard the SRV should, therefore, be designed not only for low weight, volume, and cost, but to emphasize low operations time as well. Steps are necessary to reduce EVA suit acclimating time and to lower the EVA activity demands on the RC. Consideration of higher pressure EVA suits, platform-type AMU's, and shirtsleeve work capsules appears highly desirable.

5.6 RECOMMENDED EQUIPMENT LIST

Based upon the assumption that all emergencies will occur with equal probability, a recommended list of useful equipment for a manned rescue mission is given in Table 5. Further equipment screening should be possible when the relative probability of occurrence is established for each emergency situation. For an unmanned SRV, a reduction of the items on board the SRV can be made.

Table 5. Recommended Equipment for Manned SRV

	Weight, lb
Communications and Survey Equipment	700
Despin Devices	250
Soft-Docking Fixture	250
Attachable Docking Fixture	800
Portable Airlock	1600
EVA Suits	70
AMU Backpack	150
Manipulator (Shirtsleeve)	2000
Transfer Capsule	500
Sampling and Analysis Kit	50
Damage Control Equipment	150
Remote Manipulator	1000
Medical Kit	60
Extended Survival Kit	500
Tethers (umbilicals)	45
Personnel Carriers	10
Miscellaneous	200

6. OPERATIONAL CONSIDERATIONS

6.1 GENERAL

There are numerous operational factors which have impact on the escape and rescue problem. The detailed operations involving a distressed vehicle (DV) and a Space Rescue Vehicle (SRV) in the period between rendezvous of the SRV at the DV and departure of the SRV were treated in Section 5. It was the purpose of this next phase of the study to examine some of the other important operational factors. They include:

a. Ground-based reaction time
b. Emergency ΔV requirements
c. Communications
d. Recovery site location

6.2 GROUND-BASED RESCUE REACTION TIME

6.2.1 Introduction

All transportation from earth to space in the Integrated Program is via the Earth Orbit Shuttle. Any ground-based rescue system will, therefore, involve the EOS and will be limited by its operational characteristics. Of paramount interest then are the EOS launch reaction time on the ground and the time required for ascent and rendezvous with a DV after launch. A comparison of this total reaction time characteristic to the estimated allowable reaction time would afford some measure of the potential effectiveness of the EOS as a ground-based rescue system.

In this regard, pertinent available material related to (1) allowable time delay, (2) ascent and rendezvous time, and (3) launch reaction time was reviewed to provide some insight into this complex problem area.

6.2.2 Allowable Time Delay

The time within which aid must be provided in order to prevent crew fatalities is, of course, dependent on the nature of the particular emergency situation on board the distressed vehicle. At one extreme, violent explosions could occur which result in 100-percent crew fatality immediately, with no need for rescue. At the other extreme, the foreseeable diminution of life support for a crew on an otherwise functioning spacecraft might afford as long as several weeks to respond to their need. Between these extremes, one could postulate a myriad of possible situations with widely varying time-response needs.

Determination of the most likely emergency situations and their attendant time-response characteristics was beyond the scope of this study. However, there are results from three previous study efforts which tend to shed some light on this problem area. Figure 11 summarizes the previous information pertaining to emergency time effects.

The figure depicts the change in crew fatalities as a function of time from the onset of the emergency. All studies assumed a non-catastrophic emergency situation, with initial crew fatalities in the 2-to-20 percent range. Any increase in crew fatalities beyond this initial figure then would be primarily caused by (1) lack of required medical aid, (2) continued exposure to the hazardous condition, and (3) diminution of required life support. The sharply rising crew fatality incidence beyond the five-day time period is indicative of ultimate loss of life support.

Also shown in the figure is one assessment of the effect of manned assistance, and one assessment of the effect of containment and escape. Containment in this case refers to spacecraft compartmentation to allow crewmen to retreat to a safe haven on board the DV. Escape refers to the ability to depart from the DV in a device affording shelter and life support while awaiting further aid.

The information in the figure is not presented to infer that a time-response characteristic for Integrated Program emergencies is well-defined, but merely to illustrate, based on available estimates, that crew fatalities tend to increase rather rapidly from approximately one day after the onset of a

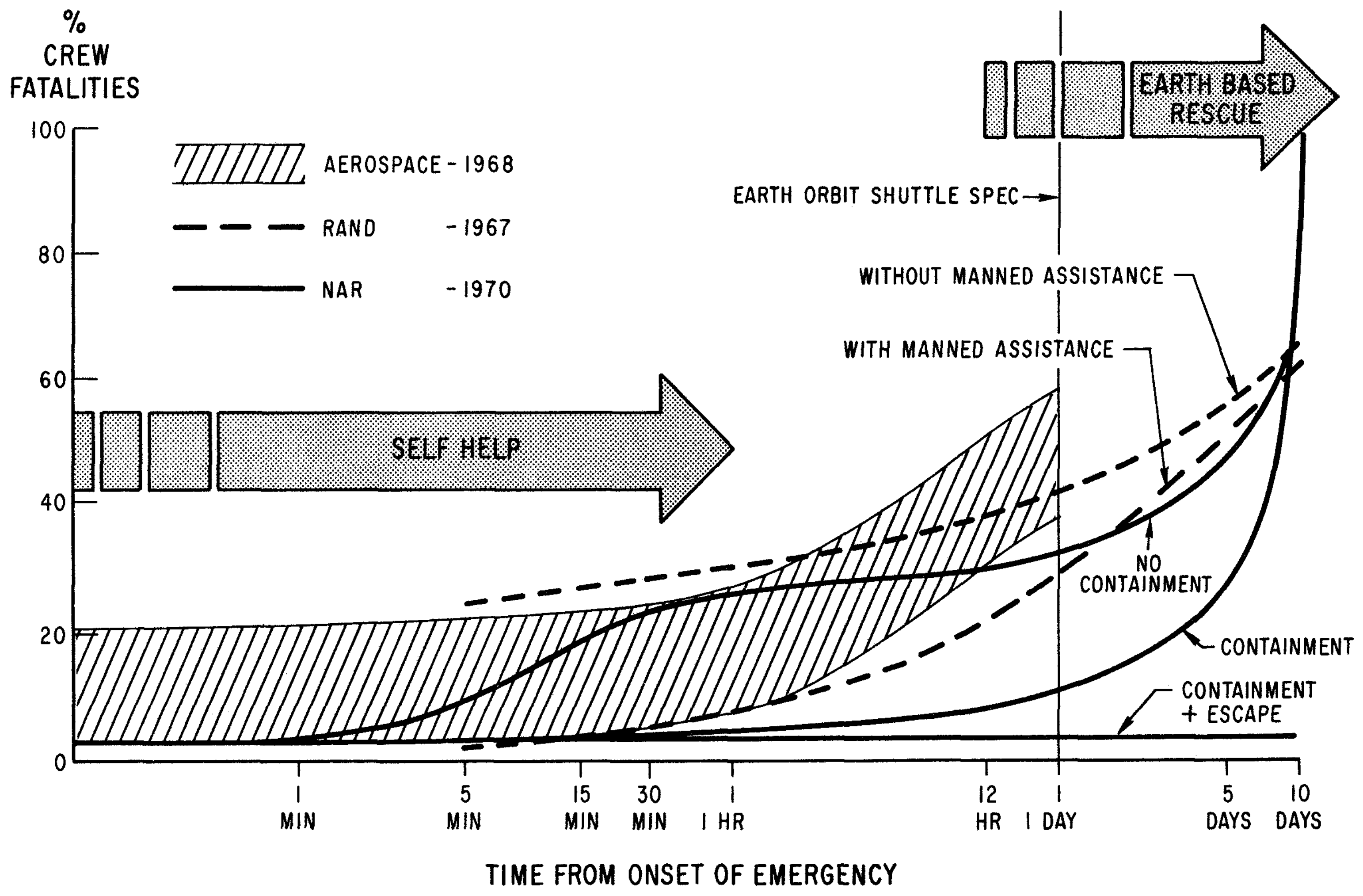


Figure 11. Emergency Time Effects Summary

non-catastrophic emergency, unless escape provisions are provided. It can be inferred that "self-help" remedial systems would be most effective in those periods immediately following the emergency, and that earth-based rescue systems most probably are faced with the conditions present in the one- to ten-day period following the onset of the emergency. The current EOS ascent and rendezvous response specification of 24 hours is indicated in the figure. However, as previously shown in Section 5, mere rendezvous with the DV is not the total answer. Additional time is required for the ensuing rescue operations.

6.2.3 Ascent and Rendezvous Time

An analysis was performed to determine the time required after launch from ETR for an EOS to ascend to and rendezvous with a target in a 270 n mi, 55° inclination earth orbit.

At one extreme, if the vehicle orbit is coplanar with ETR and optimally phased (no parking orbit phasing required), the ascent and rendezvous can be performed within approximately 1.5 hours after liftoff. At the other extreme is the worst combination of out-of-plane and phasing. These results are as shown in Figure 12. Here, the total time for ascent and rendezvous is a function of the Orbiter ΔV available in the 50 × 100 n mi parking orbit.

The singular point at approximately 38.5 hours represents the EOS Orbiter in-plane-ascent case, with a ΔV budget of 1100 ft/sec for ascent and rendezvous. If additional ΔV were available to perform plane changes and parking orbit phasing, the solid line extending downward from the circled point indicates that the time could be reduced to about 18.5 hours with 4000 ft/sec ΔV. Additional ΔV beyond that value involves direct ascent, which could further reduce the time to about 15 hours with 15,000 ft/sec ΔV, a value that is well beyond the EOS Orbiter capability.

The nominal Orbiter ΔV capability is approximately 1500 ft/sec although its propellant tanks are sized for ~2000 ft/sec. As can be seen, under the

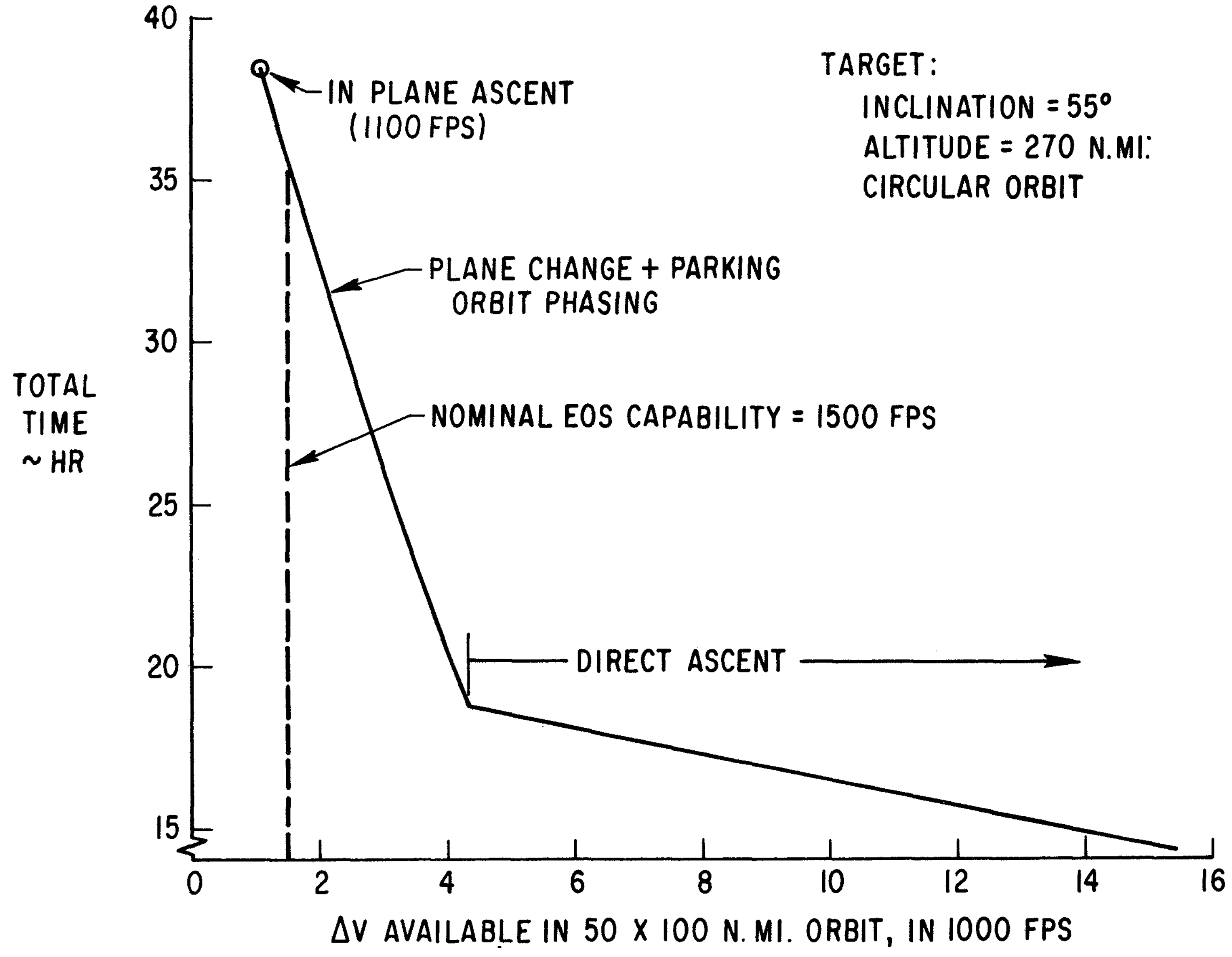


Figure 12. EOS Orbiter, Ascent and Rendezvous Time (Worst Case)

worst-case conditions assumed, the EOS would require about 35 hours to perform the ascent and rendezvous maneuver.

One other ascent and rendezvous situation was examined. This analysis was directed to the situation where the target vehicle orbit was "subsynchronous" (repeating ground track) and ideally phased, and a northerly coplanar ETR launch opportunity had just been missed. The answer sought was whether or not a southerly launch of the EOS would substantially reduce the 25.5 hour delay to rendezvous required by waiting for the next northerly launch opportunity.

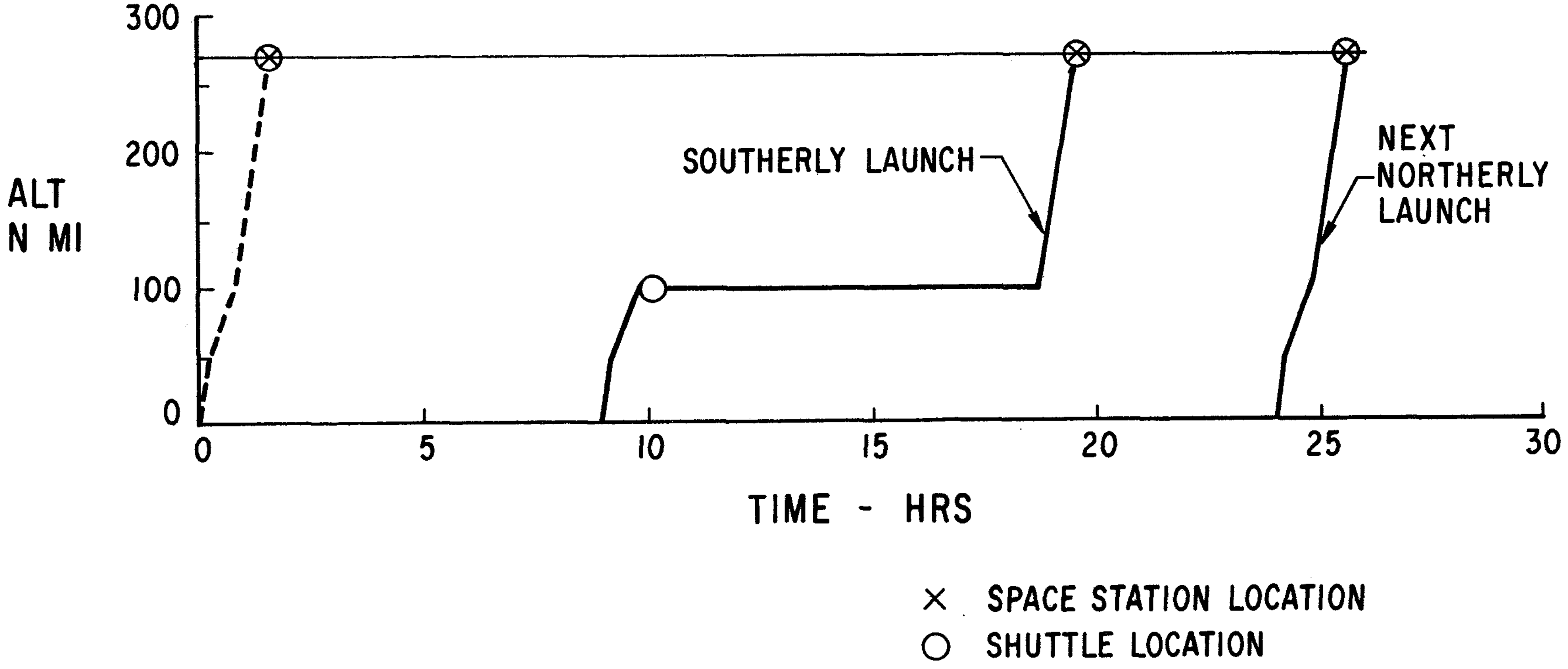
The problem scenario is depicted in Figure 13 and indicates that (1) an in-plane southerly launch can be made approximately 9 hours after the missed in-plane northerly launch opportunity, (2) the target vehicle is then approximately 150° ahead of the EOS in phase angle, (3) phasing of the EOS in the 100 n mi parking orbit for 8.8 hours would be required, and (4) the final rendezvous with the target vehicle could be made about 6 hours sooner than by waiting for the next northerly launch opportunity.

6.2.4 Launch Reaction Time

The ground delay in reacting to an emergency is a function of (1) the number of launch pads, (2) the boosters and orbiters procured, (3) the frequency and duration of missions, and (4) characteristics related to EOS refurbishment time, countdown requirements, payload installation time, and available work force.

Table 6 illustrates such launch reaction time results (on a maximum and minimum basis) for a considerable range of the above forcing variables. On the maximum side, it can be seen that from 1.5 to 6 days may be required for launch reaction.

The singular minimum reaction time of 12 hours results from the specific case where (1) an EOS has just been counted down to T-2 hours (where fueling is to commence) when the emergency is declared, (2) 10 hours are required to



- SPACE STATION IS ~150° AHEAD OF RENDEZVOUS VEHICLE
- PHASE IN 100 N MI ORBIT FOR ~8.8 HRS
- SOUTHERLY LAUNCH SAVES ~6 HRS

Figure 13. Launch Time Relationships, Subsynchronous Case

Table 6. Launch Reaction Time*

Mission Duration	Flights Per Year	No. of Pads	Boosters	Orbiters	Reaction Time	
					Max	Min
2 days	19	1	1	2	152 hr	12 hr
2	23	1	1	2	152	12
2	23	1	2	2	106	12
2	23	2	2	2	34	12
4	29	2	2	3	34	12
4	47	2	2	3	82	12

Assumptions: 3-day pad refurbishment period
24-hr shuttle countdown
10-hr P/L installation time
2-shift normal day
3-shift day upon emergency

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*Based on results from Aerospace Corporation Report No. ATR-71(7231)-11, Vol I, "Integrated Operations/Payloads/Fleet Analysis - Phase II Second Interim Report," 12 April 1971, Contract NASW 2129 remove the mission payload and insert a special rescue payload, and (3) the final two-hour fueling period begins immediately after the payload change, followed by immediate launch. Obviously, this would be an extremely unlikely situation.

6.2.5 Summary

The worst-case ascent to a 270 n mi, 55° inclination orbit is in-plane and to a randomly positioned target. Only phasing in a parking orbit at an intermediate altitude is required; no plane change maneuver is involved. Approximately 38 hours are required to reach the target from ETR with a ΔV expenditure of about 1100 fps from an initial 50 x 100 n mi orbit. This time may be reduced by combining parking orbit phasing with plane changing. Direct ascent, which involves extensive plane changes, provides an even greater time reduction. However, such procedures are at the expense of large ΔV expenditures. The present Orbiter ΔV capability provides only 1500 fps in the 50 x 100 n mi orbit. Even if this entire amount is expended in an optimal fashion for a combination of phasing and plane change, the total ascent and rendezvous time can only be reduced to 35 hours.

The subsynchronous (repeating ground track) case offers some improvement. The ascent and rendezvous delay following a "just-missed" launch opportunity is approximately 26 hours. If the EOS all-azimuth launch capability and a southerly launch opportunity are utilized, the time delay can be reduced to about 20 hours.

It is estimated that the maximum ground delay in reacting to an emergency can be between 1.5 and 6 days. The actual time will depend upon the number of launch pads, boosters, and orbiters available, and the frequency and duration of missions.

A reaction time of 24 hours or less is desirable in order to prevent further fatalities after the initial event. However, the EOS specification of a 24-hour reaction time appears unrealistic. The anticipated delays may require dedicated equipment in order to achieve an acceptable ground-based reaction time with the EOS.

6.3 EMERGENCY ΔV REQUIREMENTS

6.3.1 Introduction

When emergencies occur prior to mission completion, some ΔV usually remains available, unless the emergency is related to a propulsion system failure. This available ΔV, if sufficient, could be used to perform a mid-course abort or perhaps a fast return to an orbit containing a safe haven.

Externally provided rescue may be necessary for emergencies where any remaining ΔV is inadequate for abort or return, or where the available ΔV cannot be applied.

These considerations were examined with respect to (1) a distressed vehicle (DV) on geosynchronous and lunar missions, and (2) a space rescue vehicle (SRV) responding to distressed vehicles in low earth orbit, geosynchronous, and lunar missions. The results are summarized in the following sections, with the complete analysis and results presented in Appendix E.

6.3.2 Distressed Vehicle Requirements

6.3.2.1 Geosynchronous Mission

In the case of the geosynchronous mission, the specific situations examined were:

a. A DV in ascent from low earth orbit to geosynchronous orbit and having the requirement to perform a mid-course abort at approximately 2000 n mi altitude

b. A DV in geosynchronous orbit and desiring to perform a fast return to low earth orbit from geosynchronous orbit

In the first case, the analysis indicated that approximately 15,000 ft/sec ΔV would be required to perform the mid-course abort maneuver, with an elapsed time of about 1.5 hours (after Hohmann Transfer Ellipse insertion) to return to low earth orbit. For a vehicle nominally designed to ascend to geosynchronous orbit and return to low earth orbit, approximately 20,000 ft/sec ΔV would remain after initiating the Hohmann Transfer, indicating that this type of mid-course abort is indeed feasible.

In the second case, the nominal time to return to low earth orbit (LEO) from geosynchronous orbit (GEO) is 5.3 hours with a ΔV requirement of about 14,000 ft/sec for retrograde, mid-course corrections and LEO circularization. The analysis indicated that the utilization of an additional 2200 ft/sec could reduce the time to return to LEO from GEO to approximately 3.5 hours.

Table 7 summarizes these results for the GEO mission.

6.3.2.2 Lunar Mission

In the case of the lunar mission, the specific situations examined were:

a. A DV in earth-to-lunar transit and having the requirement to perform a mid-course abort after trans-lunar injection (TLI)

b. A DV in earth-to-lunar transit and desiring to perform a fast return to LEO without lunar orbit injection (LOI)

In the first case, it was assumed that the DV was a mission vehicle with the nominal ΔV capacity to travel to the moon and return to LEO, and was on a free-return trajectory to the moon. As such, the vehicle would have a ΔV of approximately 17,000 ft/sec remaining at the time of the requirement for abort, and could therefore successfully perform a mid-course abort and return to LEO with a total elapsed time of about 35 hours after TLI. If the vehicle had an additional ΔV of 8000 ft/sec (total ΔV ~ 25,000 ft/sec), the time to return to LEO would be reduced to about 20 hours.

In the second case, the same vehicle, having just decided not to perform the LOI maneuver, could use the 17,000 ft/sec ΔV to return to LEO in approximately 48 hours after trans-earth injection, (TEI). If this ΔV could be augmented by 2000 ft/sec, the return time to LEO could be reduced to about 36 hours. The above results are summarized in Table 8.

6.3.3 Space Rescue Vehicle Requirements

A number of potential bases for stationing the SRV were considered, including LEO, GEO, lunar orbit (LO), and the lunar surface base (LSB). The SRV ΔV needs calculated pertain only to the trajectory changes needed to go from

Table 7. Distressed Vehicle ΔV Needs for GEO Mission

	ΔV, fps		Time to LEO, hr
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)

Table 8. Distressed Vehicle ΔV Needs for Lunar Mission

	ΔV, fps		Time to LEO, hr
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

the SRV base to the DV and return to the base of origin of the SRV or to another designated safe haven. They do not include any ΔV associated with emplacing the SRV at its base or maintaining it at that position, or for rendezvous and docking operations.

The presentation below is organized to show which SRV basing concept is preferable in order to minimize SRV ΔV requirements. For this reason only the maximum and minimum ΔV requirements for each basing concept are shown in this report section. Appendix E discusses the ΔV requirements of emergency situations falling between these extremes.

6.3.3.1 Geosynchronous Mission

In the case of the geosynchronous mission, the specific situations representing the range of ΔV requirements were:

SRV based in GEO

A. DV is in transit from LEO to GEO and on an escape trajectory (unable to circularize at GEO).

B. DV is in GEO and unable to depart GEO.

SRV based in LEO

C. DV is in GEO and unable to depart GEO.

D. DV is in mid-course abort from ascent to GEO trajectory and has no LEO injection capability.

In all of the above situations, the SRV was assumed to return to LEO after performing the rescue.

In situation A, the ΔV required for the SRV was determined to be 14,000 + f(X) ft/sec, where X is the overspeed imparted to the DV at the Hohmann Transfer injection on the ascent leg of the DV trajectory to GEO. The "f(X)" ΔV is that required to rendezvous with the DV in its flyby trajectory. The 14,000 ft/sec is that portion associated with conventional return from GEO to LEO. A more detailed commentary on "f(X)" values is given in Appendix E.

In situation B, the SRV is in GEO; therefore it only needs the nominal ~14,000 ft/sec to return the DV crew to LEO.

In situation C, the LEO-based SRV needs the full ~28,000 ft/sec normally associated with transit to and from GEO.

In situation D, a minimum of ~16,000 ft/sec was determined for a LEO-based SRV to rendezvous with the DV in mid-course abort conditions and reenter LEO with the DV crew.

Table 9 summarizes the results for these situations which represent the maximum and minimum SRV ΔV requirements.

6.3.3.2 Lunar Mission

In the case of the lunar mission, the situations representing the extremes of the requirements spectrum were:

SRV based at LSB

A. DV is in transit from LEO and on an impact trajectory toward the moon.

B. DV is in transit from LEO to moon and has made an incomplete lunar orbit injection (LOI) maneuver.

SRV based in Lunar Orbit near Orbiting Lunar Station (OLS)

C. DV is in transit from LEO and on an impact trajectory toward the moon.

D. DV is in transit from LEO to moon and has made an incomplete LOI maneuver.

SRV based in LEO

E. DV is in LO and unable to depart LO.

F. DV is in trans-earth trajectory from moon and unable to perform LEO injection.

In situation A, the LSB was assumed as the safe haven. A maximum ΔV of ~39,000 ft/sec was determined to be required by the SRV to ascend from the LSB, rendezvous with the DV prior to impact, and return the DV crew to the LSB.

Table 9. Space Rescue Vehicle ΔV Needs for Geosynchronous Mission

SRV Starts from	ΔV Situation		SRV Returns to	Total SRV ΔV Requirement, fps
	Max ΔV Required	Min ΔV Required		
GEO	In escape trajectory		LEO	14,000 + f(X)*
		Unable to depart GEO		14,000
LEO	Unable to Depart GEO		LEO	28,000
		In midcourse abort without LEO injection capability		16,000

---

*"X" is overspeed imparted at Hohmann Transfer Injection

In situation B, the OLS was assumed as the safe haven. An SRV based at the LSB requires at least 11,000 ft/sec ΔV to ascend to the DV, rendezvous, and return the DV crew to the OLS.

In situation C, the haven was assumed to be in LEO. An SRV based at the OLS requires a maximum of 22,000 ft/sec ΔV to travel from the OLS to the incoming DV, rendezvous with the DV prior to impact, and continue with the DV crew to LEO.

In situation D, the haven was assumed to be the OLS. An SRV based at the OLS requires at least 4400 ft/sec ΔV to travel from the OLS to the DV in its elliptic lunar orbit, rendezvous, and return the DV crew to the OLS.

In situation E, the safe haven was assumed to be in LEO. An SRV based in LEO requires a maximum of 27,000 ft/sec ΔV to travel to LO from LEO, rendezvous with the DV in LO, and return the DV crew to LEO.

In situation F, the safe haven was again assumed to be in LEO. A LEO-based SRV requires at least 20,000 ft/sec to travel from LEO to meet the DV which was unable to perform LEO injection (upon return from lunar area) and return the DV crew to LEO.

In any of the above situations entailing transfer between the lunar surface and lunar orbit, at least one 90° plane change requirement was included in determining the SRV ΔV needs.

Table 10 summarizes these results which are of interest in deciding where to base an SRV to deal with lunar mission emergencies.

6.3.4 Summary

For emergencies which occur prior to mission completion, some ΔV usually remains available. Both a mid-course abort or a fast return to low earth orbit appear feasible from either geosynchronous or lunar mission trajectories with the remaining ΔV aboard the distressed vehicle.

Table 10. Space Rescue Vehicle ΔV Needs for Lunar Mission

SRV Starts From	ΔV Situation Requiring		SRV Returns to	Total SRV ΔV Requirement, fps
	Max ΔV	Min ΔV		
LSB	On impact trajectory with moon		LSB	39,000
		Incomplete lunar orbit injection	OLS	11,000
OLS	On impact trajectory with moon		LEO	22,000
		Incomplete lunar orbit injection	OLS	4,400
LEO	Trapped in lunar orbit		LEO	27,000
		Unable to perform LEOI		20,000

Externally provided rescue may be necessary for emergencies where the remaining ΔV is inadequate or cannot be applied. The ΔV needed by a Space Rescue Vehicle (SRV) depends upon the mission of the distressed vehicle and where the SRV is based. For lunar mission emergencies, basing the SRV in lunar orbit imposes the least ΔV requirement (~22,000 fps, max). For geosynchronous mission emergencies, synchronous earth orbit basing imposes the least ΔV requirement.

6.4 COMMUNICATION REQUIREMENTS

6.4.1 Introduction

Integrated Program communications requirements can be simplified by the orbits selected for the program. The nominal space station orbit (~270 n mi altitude, ~ 55° inclination) and the nominal translunar injection orbit (~260 n mi altitude, ~31.5° inclination) were considered to be "subsynchronous"; i.e., they give a repeating ground track, with the ground track cycle repeating every 15 orbits. Such orbits can simplify operational requirements and appear desirable from a safety standpoint because the communications, tracking, and reentry operations are no longer random processes.

6.4.2 Rescue Operations Needs

The various types of communications needed for a rescue mission were established by assuming (1) a rescue control center, RCC (2) a distressed vehicle, DV, and (3) a rescue vehicle, SRV, and then determining the various information needs for the entire rescue operation. The specific time periods of interest included:

a. prior to emergency
b. emergency declared
c. SRV enroute to DV
d. SRV-DV engagement
e. SRV return

6.4.2.1 Prior to Emergency/Emergency Declared

During the period just prior to the existence of an emergency and just after the emergency is declared, a number of communications links are necessary between the RCC and the DV to enable a successful rescue mission. Voice radio is desirable for status reports from the DV to the RCC, and for transmitting instructions from the RCC to the DV. Telemetry is required to transmit any caution and warning or diagnostics data from the DV to the RCC, as well as to permit guidance update data transmission or remote command activation from the RCC to the DV. Tracking beacons would be required for periodic tracking of the DV. The availability of television on the DV might provide useful supplemental information as to the nature and extent of the emergency on board. Figure 14 illustrates these DV-RCC communication links schematically.

It should be noted that the rescue control center need not be earth-based, but could be space-based as well.

6.4.2.2 SRV Enroute to DV

In the period commencing with notice to the SRV of the DV emergency and the command to respond, similar communication links are required between the RCC and the SRV as between the RCC and the DV. Caution, warning, and diagnostics data as well as tracking information (beacons), from the SRV should also be transmitted to the RCC. Voice radio links would provide instructions to the SRV and status reports from it. The communications links between the DV and the RCC are still necessary, as before.

Figure 15 illustrates the DV-RCC-SRV communications links during this period.

6.4.2.3 Rescue Operations (Rendezvous to Disengagement)

During the rescue operations period (from rendezvous of the SRV with the DV to the subsequent disengagement), the previous DV-RCC and SRV-RCC communications links are still required and need to be augmented by additional

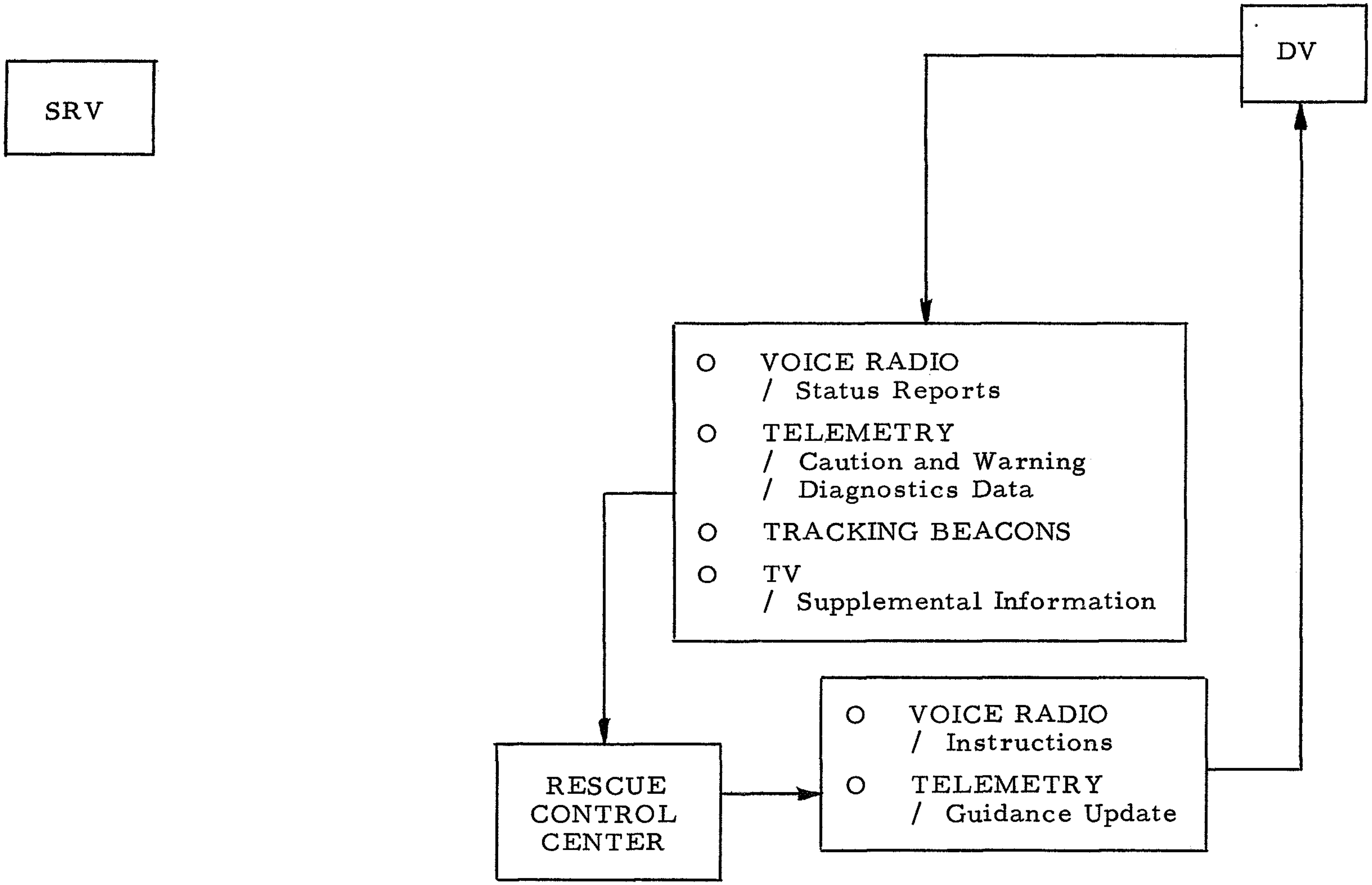


Figure 14. Communications Requirements, Prior to Emergency/Emergency Declared

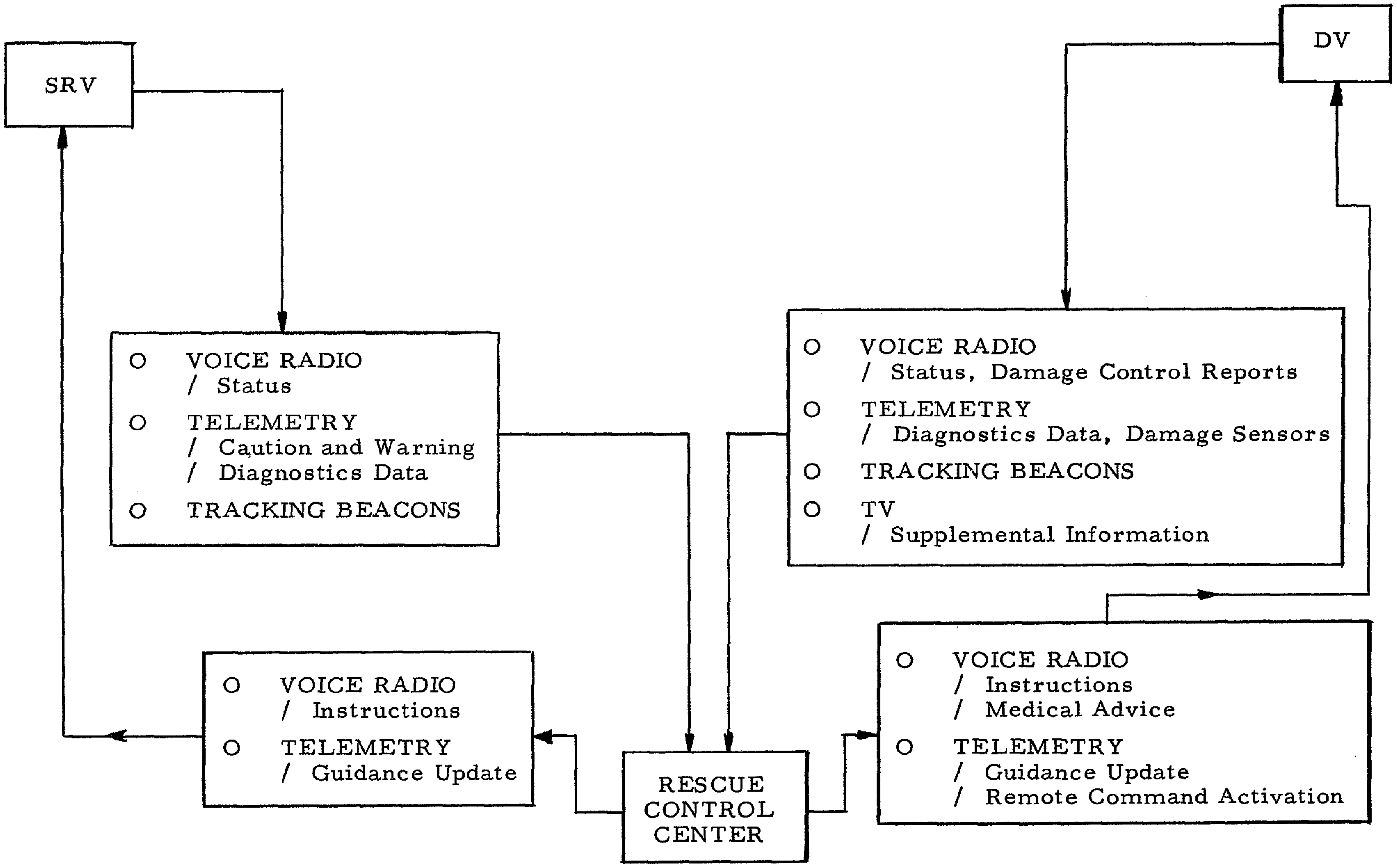


Figure 15. Communications Requirements, SRV Enroute to DV

links between the SRV and DV as follows. Voice radio communication between the SRV and DV is required to enable status or damage control reports from the DV to the SRV and to enable instructions or medical advice to be given by the SRV to the DV. In the absence of a radio link, visual means (blinkers, etc.) might be employed. Diagnostics or damage sensor data transmission from the DV to the SRV, as well as tracking information (from beacons), would also be useful to facilitate the rendezvous operation.

As a backup mode, the RCC could link the SRV to the DV during this period. Figure 16 illustrates the situation.

6.4.2.4 Disengagement to Landing

During the period following the in-space operations between the SRV and DV, the previously defined SRV-RCC communications links are still required. It is also desirable to maintain the telemetry and beacon links between the DV and RCC to facilitate continued tracking of the DV, guidance update transmission to the DV, having status information of the DV, and any later remote command activation functions.

Figure 17 represents the communications links during the period until the SRV is safely returned. The SRV links will not be required after it has completed its mission.

6.4.2.5 Summary

The foregoing serves to illustrate the basic communications requirements that may be necessary to fulfill the requirements of a rescue mission. As can be noted, voice radio, telemetry, and tracking beacons are the basic system needs, while TV may be useful to provide supplemental information.

It can also be seen that such communication links, from a safety standpoint, should be continuous and near realtime to permit the flow of vital information in a timely manner.

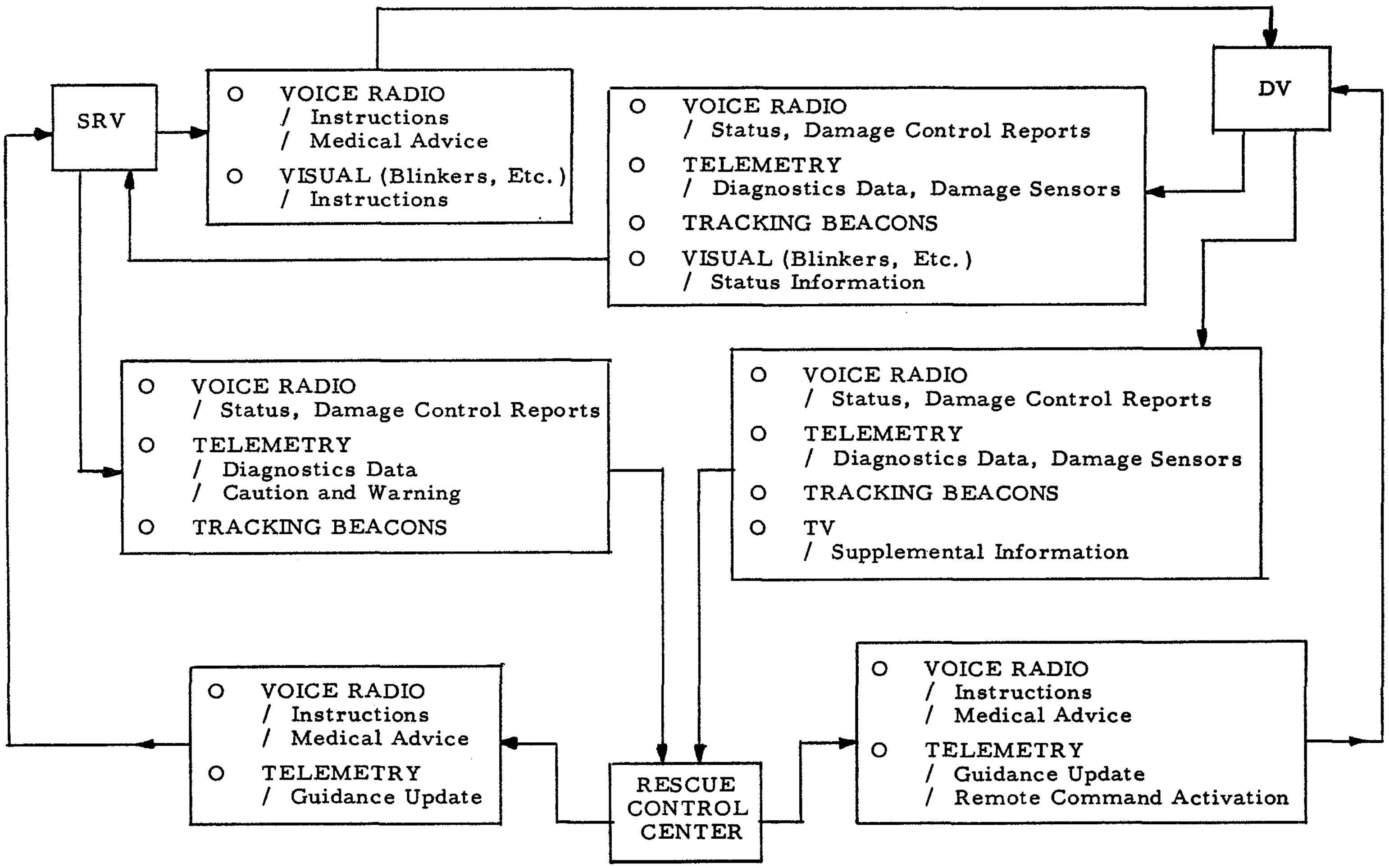


Figure 16. Communications Requirements, SRV Rendezvous to Disengagement

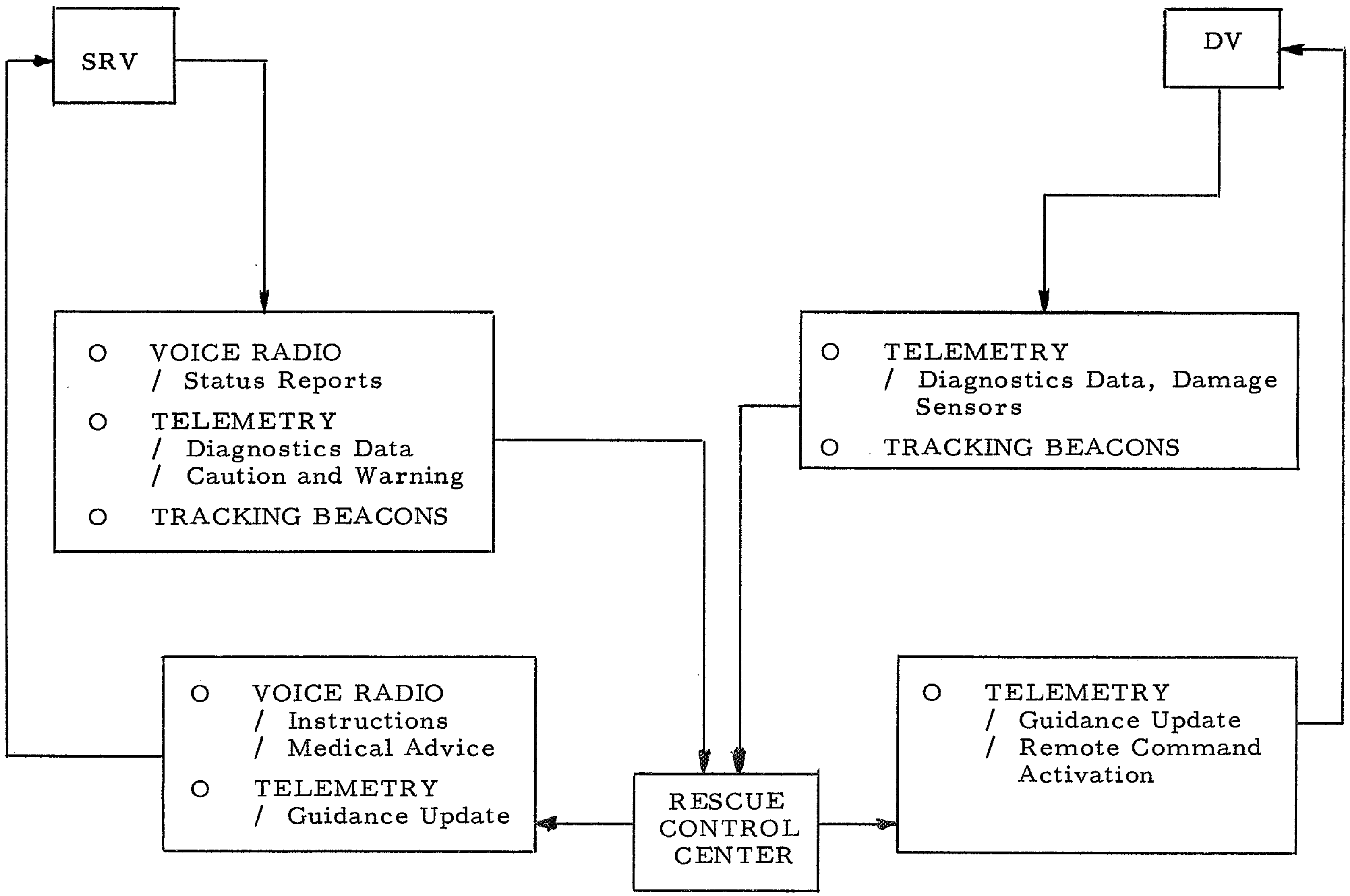


Figure 17. Communications Requirements, SRV Disengagement to Landing

6.4.3 Planned Facilities

Initial facilities planned for the communications/tracking functions of the Integrated Program include (1) the Manned Space Flight Network (MSFN) and (2) an Intelsat IV type of relay satellite in geosynchronous orbit.

Alone, the MSFN does not provide continuous tracking and communications coverage. For example, Figure 18 illustrates the case for the 270 n mi, 55° inclination "subsynchronous" (repeating ground track) orbit. Shown are the ground tracks resulting in both maximum and minimum communications interruptions (84 minutes and 17 minutes, respectively). Similarly, the lunar departure orbit (260 n mi, 31.5° inclination) has communications "blackouts" of 80 minutes maximum and 27 minutes minimum. Above 7000 n mi, however, there is no blackout period for either intransit lunar or geosynchronous vehicles. For the lunar orbit situation, blackout periods of up to 60 minutes can occur on the back side of the moon at the nominal 60 n mi altitude. Table 11 summarizes the MSFN capability as delineated above.

The addition of an Intelsat IV type of relay satellite in geosynchronous orbit eliminates these blackout periods, except for the lunar orbit blackout.

Additional Integrated Program facilities under consideration include advanced data relay satellites in both geosynchronous and lunar orbits and eliminate all blackout periods.

6.4.4 Summary and Conclusions

An examination of the basic communication and tracking needs for a rescue mission shows the need for voice radio, telemetry, and tracking beacons. It further indicates that such communications links, from a safety standpoint, should be continuous in nature to effect the flow of vital information in a timely manner.

The existing Manned Space Flight Network does not provide continuous tracking and communications coverage. For the low earth orbits of interest, blackout periods approaching 1.4 hours may be experienced. Above approximately

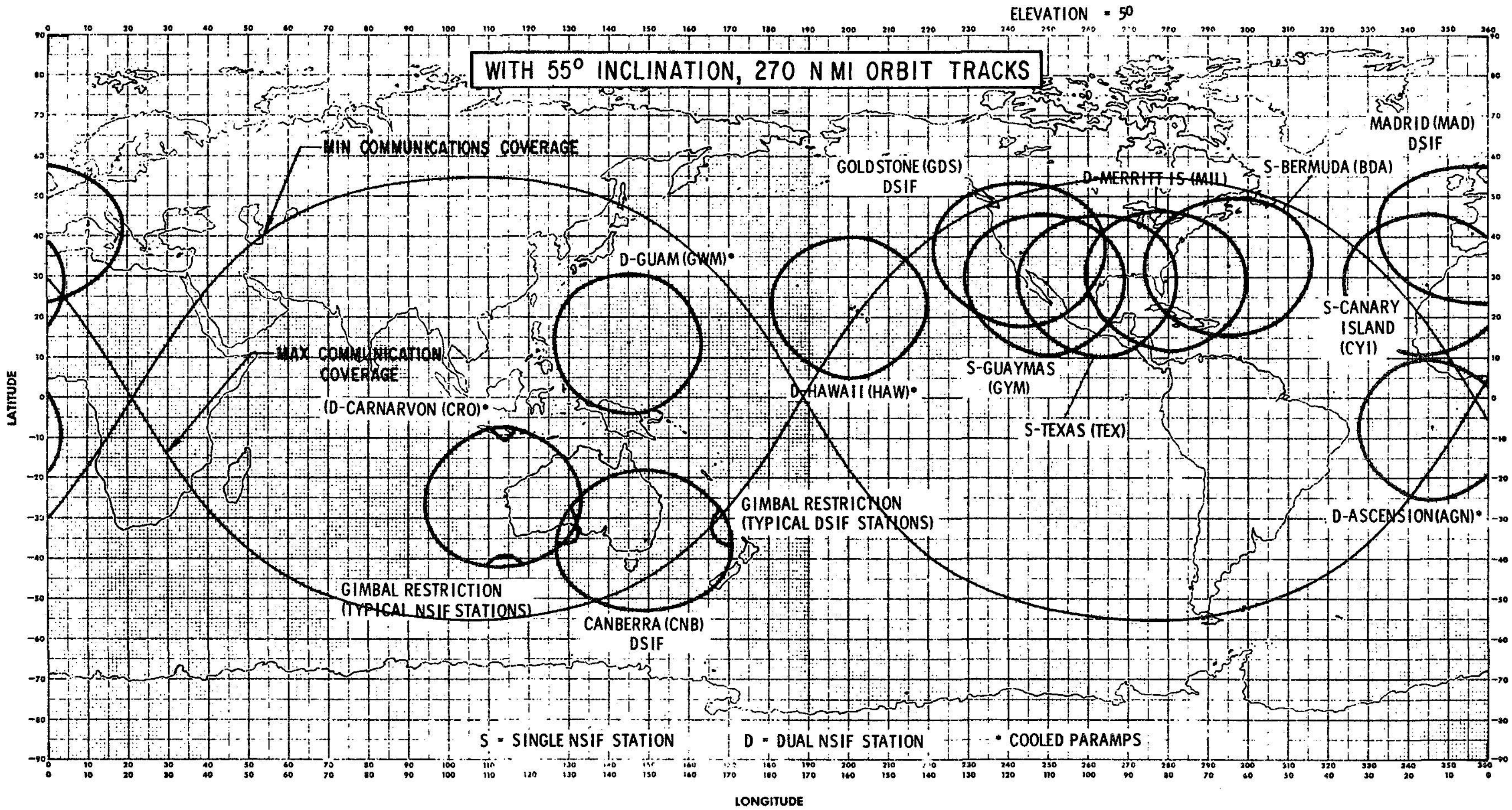


Figure 18. Manned Space Flight Network

Table 11. MSFN Capability

		Blackout	
		Max	Min
Shuttle Station	270 n mi 55°	84 min.	17 min.
Lunar departure Planetary departure	260 n mi 31.5°	80 min.	27 min.
Lunar, intransit GEO, intransit		None, above ~7000 n mi	
Lunar orbit		60 min.	

7000 n mi, continuous communication is feasible during the intransit phases of geosynchronous and lunar missions.

Initial facilities projected for the Integrated Program include augmenting the MSFN with an Intelsat IV type relay satellite to eliminate these blackout periods. However, lunar blackout for spacecraft behind the moon would continue. Plans are to ultimately eliminate the MSFN and to use advanced data relay satellites in both earth and lunar orbit, thus eliminating all blackouts.

From a safety viewpoint, facilities to skin track an "inactive" vehicle, i.e., a spacecraft unable to transmit or offer a communications target, are desirable. It is unclear, at present, whether the facilities planned to replace the MSFN will have this capability.

6.5 GROUND RECOVERY SITE ASSESSMENT

6.5.1 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. Immediate 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 of a launch site has, as yet, been made. One of the candidates is the Eastern Test Range (ETR). An analysis was made to assess the effect of Orbiter crossrange and the number and location of available alternate landing sites on the reentry waiting time, using ETR as the launch site.

6.5.2 Approach and Scope of Analysis

The return opportunities from two low earth orbits were examined in detail. One corresponds to the orbit of the Space Station, namely, 270 n mi altitude and 55° inclination. The other, 260 n mi altitude and 31.5° inclination, corresponds to the orbit of the Orbiting Propellant Depot which provides propellant storage for vehicles operating between earth orbit and lunar orbit. Both of these orbits are subsynchronized with the earth 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 16th 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 sites are:

- Edwards AFB
- Wendover AFB
- El Paso
- Hawaii
- Wake
- Guam
- Puerto Rico
- Bermuda

6.5.3 Discussion of Results

Complete results are presented in Appendix D, and several specific examples are treated in the next two sections.

6.5.3.1 270 n mi, 55° Inclination Orbit

The return opportunities at each of the nine landing sites considered are tabulated according to the orbit number in Table 12 for a crossrange of 1100 n mi. An "X" indicates the orbits from which the designated site can be reached for a landing. These data have been plotted in Figure 19 to show the effect of having more than one landing site available. Two curves are presented on the figure, one an optimum combination of sites, and the other a random selection with Edwards AFB as the second available site. Both curves 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 20. 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 eight-orbit (~ 13-hour) landing delay. The minimum delay for this crossrange is one orbit and requires five alternate landing sites in addition to ETR. They are: Edwards AFB, Hawaii, Wake, Guam, and Puerto Rico. With Edwards AFB as the only alternate, a seven-orbit reentry delay can be encountered.

6.5.3.2 260 n mi, 31.5° Inclination Orbit

Results for the OPD orbit are tabulated in Table 13 and plotted in Figure 21 for the 1100 n mi crossrange case. For this latter figure, 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 22. 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. 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.

Table 12. 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

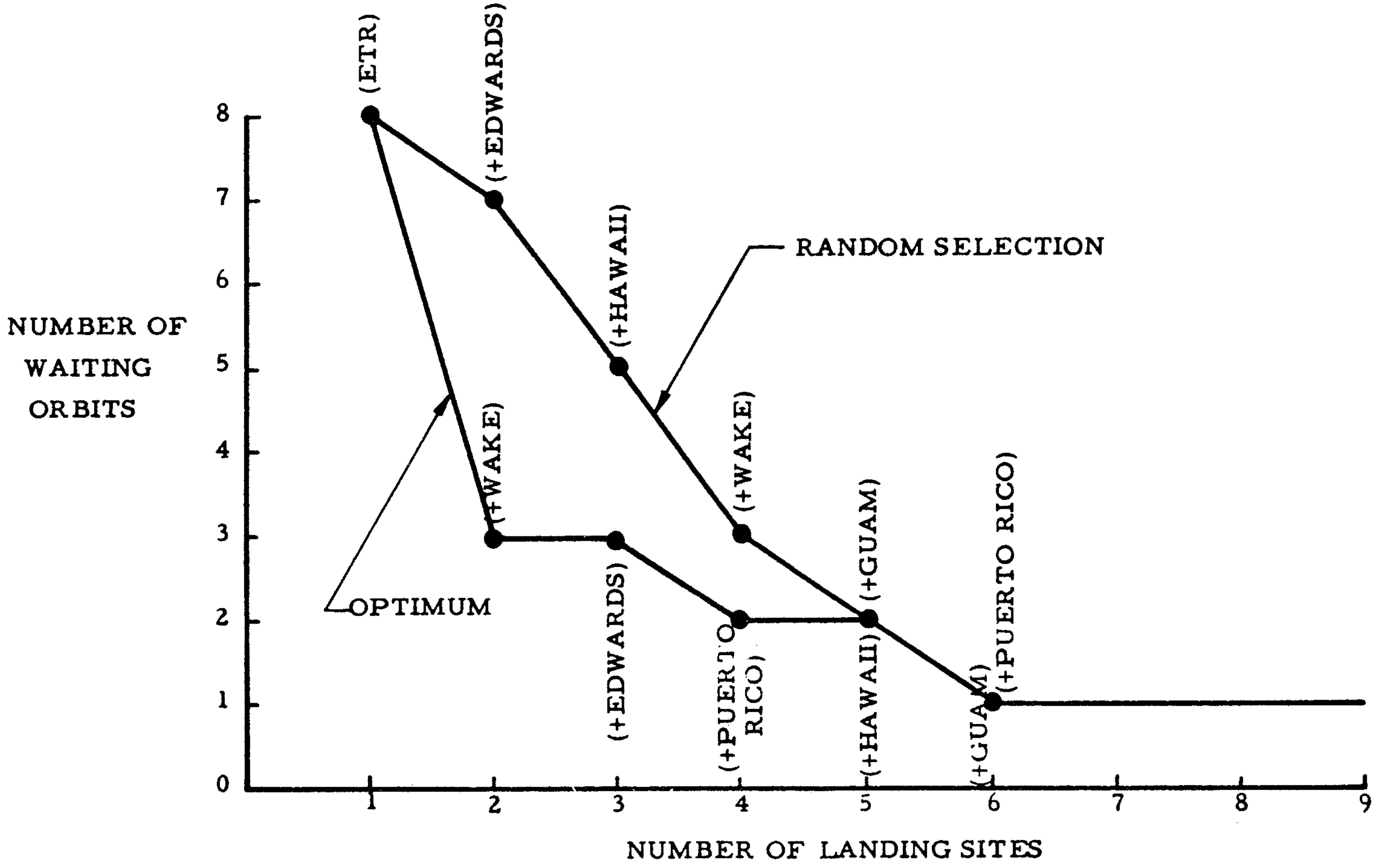


Figure 19. Return Opportunities from 270 n mi, 55-Degree Orbit -- 1100 n mi Crossrange (Worst Case Situation)

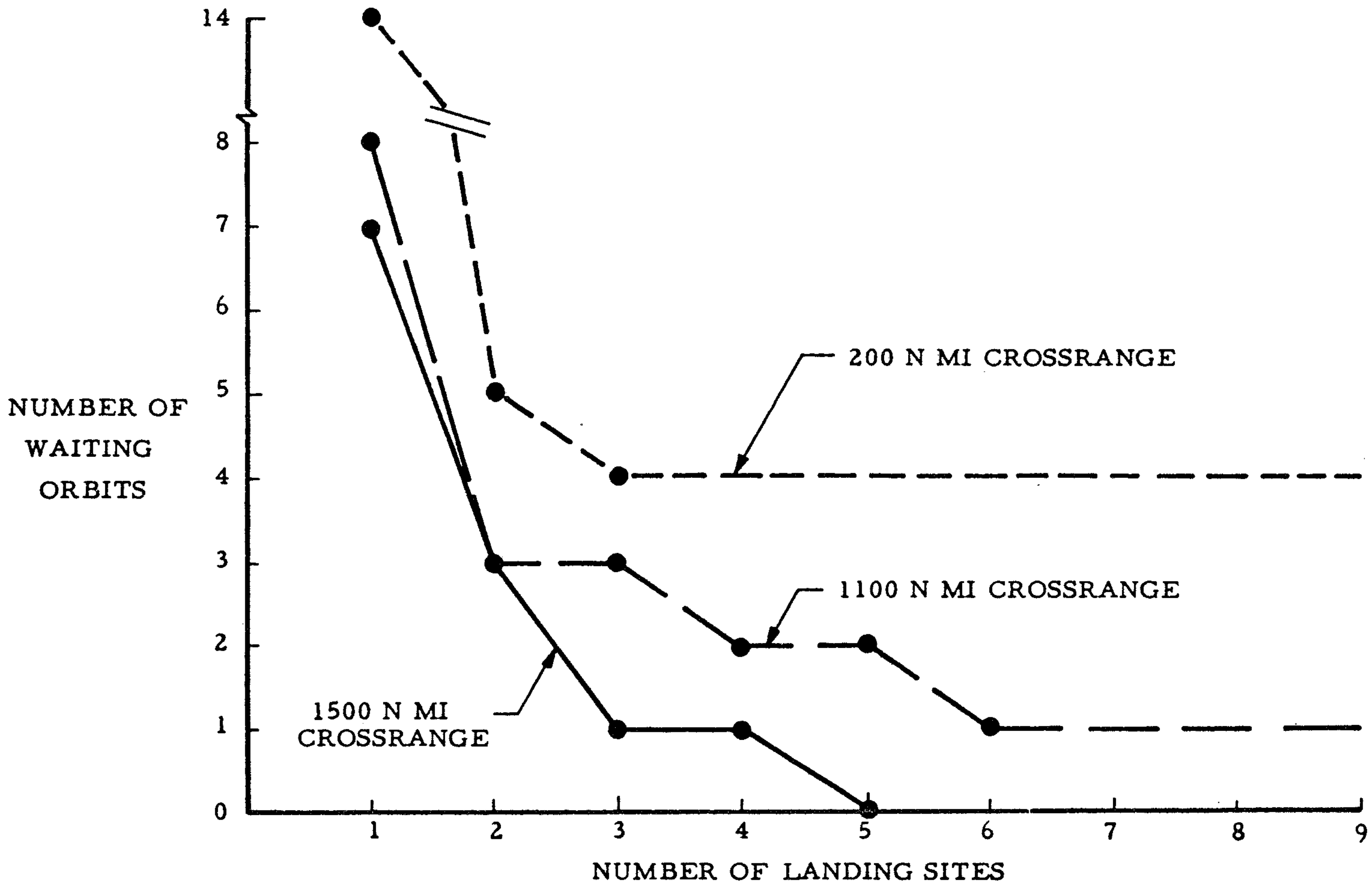


Figure 20. Maximum Return Delay from 270 n mi, 55-Degree Orbit with Optimum Site Selection (ETR -- Site No. 1)

Table 13. Return Opportunities from 260 n mi, 31.5-Degree 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

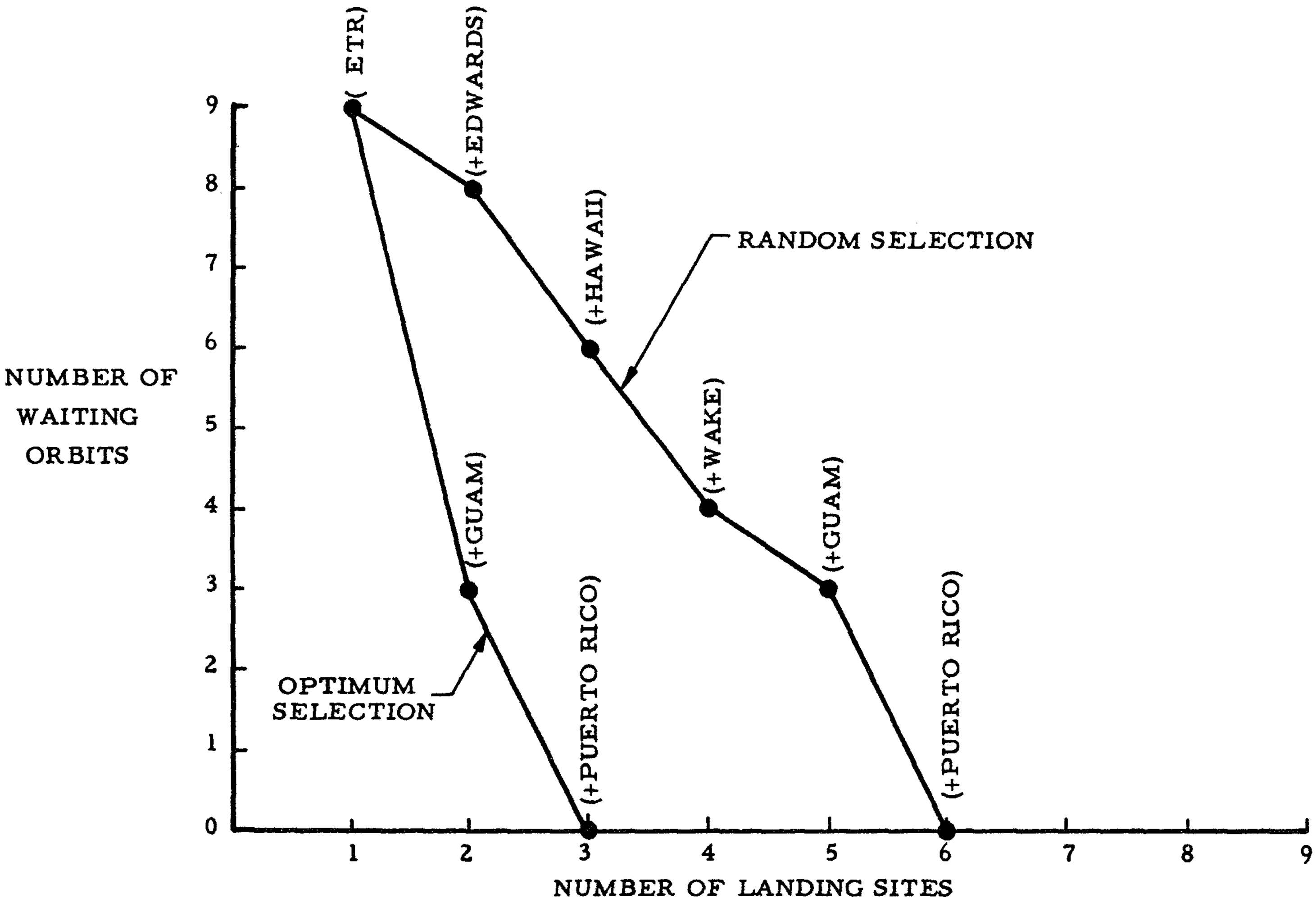


Figure 21. Return Opportunities from 260 n mi, 31.5-Degree Orbit -- 1100 n mi Crossrange (Worst Case Situation)

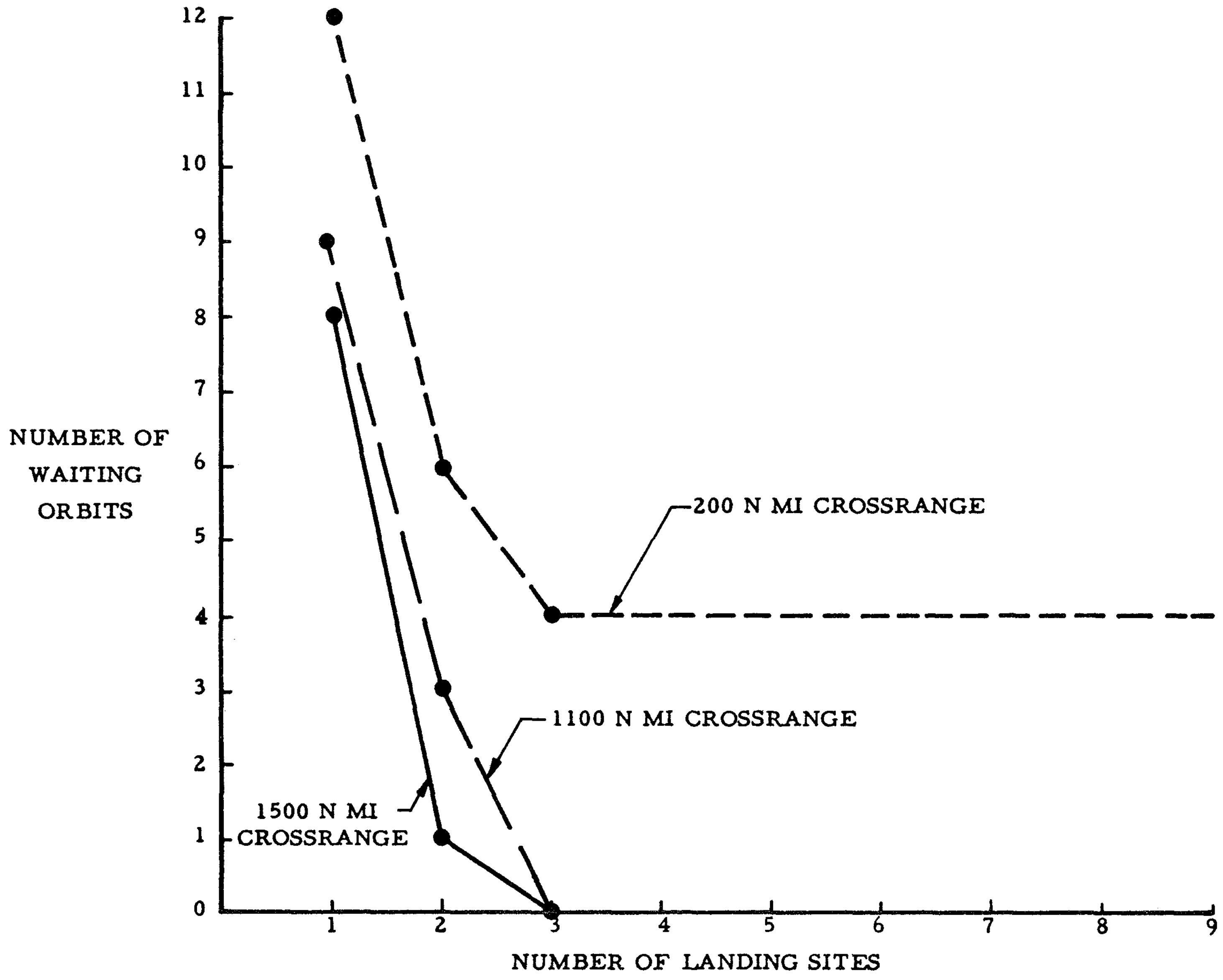


Figure 22. Maximum Return Delay from 260 n mi, 31.5-Degree Orbit with Optimum Site Selection (ETR -- Site No. 1)

6.5.4 Summary and Conclusions

The ultimate resolution of any emergency is the recovery of the crew of the distressed vehicle and their safe return to earth. The accuracy of planned reentry and the probability of landing the Orbiter stage of the EOS at a predetermined site is high, especially with its available crossrange. Reentry from low earth orbit following an emergency may, however, require a significant on-orbit loiter period. This reentry delay was examined as a function of crossrange, and number and location of recovery sites.

With ETR as the launch and landing site, an 1100 n mi crossrange orbiter can encounter up to an eight-orbit (~ 13-hour) reentry delay. No single Continental U.S. recovery site among those examined offers a shorter orbital reentry delay from a 270 n mi, 55° inclination orbit than ETR. Multiple CONUS recovery sites produce only a small improvement. With both Edwards and ETR as available recovery sites, the worst-case situation for an 1100 n mi crossrange capability requires a seven-orbit delay (~ 11 hours) before initiating reentry. In the case of a medical emergency, this type of delay may prove to be intolerable. Only by adding a mid-Pacific recovery site can this delay be significantly reduced.

7. REMEDIAL SYSTEM ANALYSIS

7.1 GENERAL

Concern for the safety of astronauts in the U.S. manned space program has resulted in the identification of a number of devices or approaches for providing either (1) crew escape from a distressed vehicle or (2) externally-supplied rescue. Configurational definition of such remedial systems has usually been made with reference to a specific space vehicle and mission, but none till now was ever formally implemented.

The first official U.S. commitment for implementation of a space remedial system was the NASA announcement in March 1971 that a ground-based rescue system capability would be provided for the Skylab Program. It is clear that any subsequent manned program, especially one of the scope of the Integrated Program, will also include plans for crew and passenger escape or rescue (Section 4).

The objective of the study effort discussed in this section was to assess candidate remedial systems for assuring crew and passenger survival on Integrated Program missions so that appropriate action can be implemented.

7.2 METHOD OF APPROACH

The general method of approach followed consisted of two basic steps:

a. identification of specific remedial systems potentially applicable to the Integrated Program problems

b. comparison of these various alternate remedial systems

The first step involved (1) review of potentially available devices and (2) conceptual identification of new devices. The results are presented in Section 7.3. The second step required development and use of a comparison and selection technique (described summarily in Section 7.4 and in detail in Appendix J).

7.3 ESCAPE/RESCUE CONCEPTS

Systems to support escape or rescue missions for the Integrated Program fall into three general categories:

(a) Direct use of planned program hardware
(b) Use of modified program hardware
(c) Other

In category (a), primary candidate vehicles of the Integrated Program which could be used as Space Rescue Vehicles (SRV's) include (listed in the order of their probable availability):

1. Earth Orbit Shuttle (EOS)
2. Crew/Cargo Module
3. Unmanned Space Tug
4. Manned Space Tug
5. Space Shuttle (SS)
6. Lunar Landing Tug

Each can be used independently for certain rescue missions. For other rescue missions two or more can be combined into Space Rescue Vehicle Systems. Vehicles like the EOS, the Space Shuttle, and possibly the Manned Space Tug, would be used essentially as transporters to add additional performance capability to the SRV actually performing the rescue operation.

To be used as SRV's, certain modifications for installing special equipment needed for space rescue operations may be required (see Appendix H). It is preferred that such equipment be carried in "palletized" form to the scene of the emergency. For the case where the EOS, Manned Space Tug, and Space Shuttle are used as transporters, a minimum of modifications would be required.

Table 14 shows an overview of Integrated Program hardware elements and combinations of these elements useful for rescue missions. The general area of application is also given.

Table 14. Potential Rescue Mission Application Areas for Integrated Program Elements

Element	LEO	GEO ↕ LEO	LO ↕ LEO	GEO	LO	LS ↕ LO	LS
Earth Orbit Shuttle (EOS)	X						
EOS & Unmanned Tug	X	X					
EOS & Crew/Cargo Module	X						
Space Shuttle (SS)		X	X	X	X		
SS & Unmanned Tug		X	X	X	X		
SS & Crew/Cargo Module		X	X	X	X		
SS & Manned Tug		X	X	X	X		
SS & Lunar Landing Tug			X		X	X	X
Manned Tug	X	X		X	X		
Unmanned Tug	X	X		X	X		
Crew/Cargo Module	X			X	X		
Lunar Landing Tug					X	X	X

In category (b) are included (1) modified Space Tug Crew Modules (TCM) to serve either as Bail-Out-and-Wait (BOW) devices or as the habitable portion of a Bail-Out-and-Return (BOR) to safe haven device, and (2) modified EOS Crew/Cargo Modules (CCM) to serve as the basis of a rescue vehicle.

In category (c) are included the general concepts of (1) emergency life support systems, (2) Bail-Out-and-Wait devices, and (3) Bail-Out-and-Return devices.

For convenience of presentation, the descriptions, content, and (where appropriate) weight characteristics of the various remedial systems are discussed by concept, rather than category.

7.3.1 Earth Orbit Shuttle as a SRV

The Orbiter stage of the EOS is the element of principal interest, since the Booster stage does not achieve orbit. Although the Orbiter is still in the process of detailed definition, some of its characteristics relevant to rescue capability are sufficiently well known for purposes of this study.

Figure 23 illustrates some of the more significant configurational features of a typical Orbiter. As can be seen, the Orbiter itself has no docking provisions. The present approach is to transfer crew and passengers from the Orbiter via a cargo or Crew/Cargo Module (CCM) carried in the 15-ft × 60-ft payload bay. The CCM contains a docking port at one end for the docking interface with the receiving vehicle, e.g., space station. Under one approach (shown in the figure), the CCM hard-docks at one end while supported by an erecting and transporter mechanism extending from the Orbiter cargo bay. Under another approach, the Orbiter can stand off from the station. The CCM is then transferred by either a Space Tug or CCM-integral propulsion from the Orbiter to the station and docked.

Two Orbiter hatches are shown in Figure 23. One exits the crew compartment area to permit EVA (EVA not planned as normal operational procedure), and the other separates the cargo bay from a tunnel leading to the crew compartment

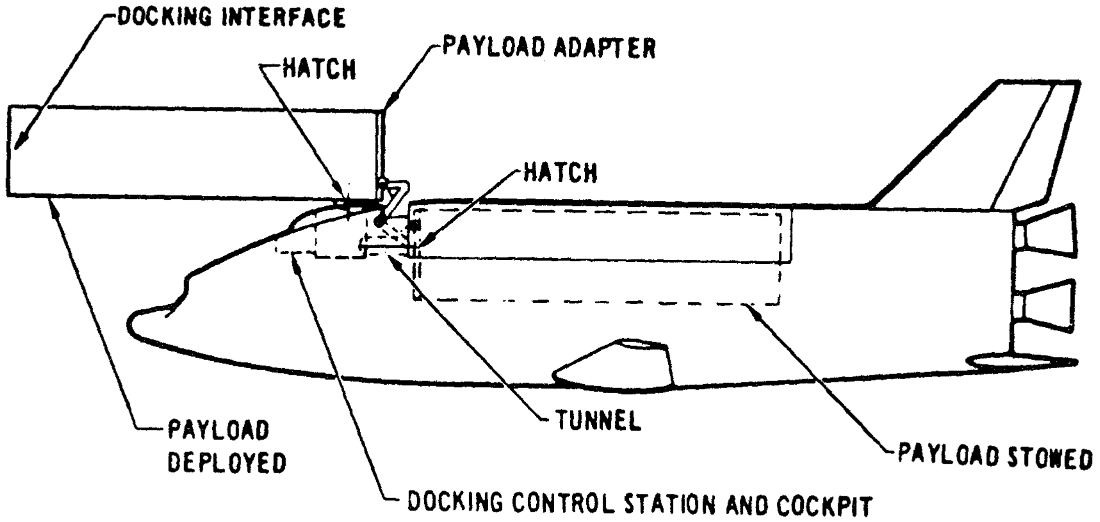


Figure 23. Earth Orbit Shuttle (Orbiter Stage)

area. Current specifications require an airlock only at the former hatch location; however, it is anticipated that similar airlock features may be provided for the EVA hatch.

The actual positioning of passengers in the Orbiter is as yet not resolved. One approach locates the passengers immediately behind the crew until the time for transfer, whereupon they enter the CCM. Another approach locates the passengers below the crew until transfer time. A third approach locates the passengers in the CCM for the entire mission.

The orbital maneuvering ΔV capability of the Orbiter is very limited. Current specifications require 1500 fps ΔV available in the 50×100 n mi transfer orbit. This allows $\sim$300-400 fps after rendezvous at the reference 270 n mi, 55° inclination orbit, or $\sim$1000 fps if the Orbiter were circularized at a 100 n mi orbit.

The true ground-based reaction time (launch reaction time plus ascent and rendezvous time) is not well defined. Based on the analyses presented in Section 6.2, however, it appears that the current EOS specification requirement of 24 hours to rendezvous (after receipt of notice of emergency at space station) plus completion of all rescue aid in an additional 24 hours appears unrealistic.

The Orbiter, designed as a mission vehicle, currently contains no special rescue equipment and aids as identified in Section 5 (debris detection and collision avoidance systems, special radiation protection, EVA retrieval capability, tumbling arrest, etc.). As currently defined, its available ΔV is small, EVA is not planned, and it has no direct docking facilities. Docking must be accomplished via a cargo module. However, the Orbiter can deliver rescue equipment to low earth orbit as cargo.

7.3.2 Space Tug as a SRV

Within the framework of Integrated Program planning, it is proposed that a Tug crew module (TCM) will be utilized with the Space Tug Propulsion Module in 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 the pre-phase A design activities.

The space tug system weight breakdown is given in Appendix K as:

Propulsion module	
- gross weight (including propellants)	71,000 lb
- propellants (O_2/H_2)	60,000
Crew Module	10,000
Guidance & control module	5,000
Total (incl. propellants)	86,000 lb

Pre-phase A definition studies conducted by Boeing and North American Rockwell provide a limited insight into potential crew module configurational arrangement and subsystem features.

Figure 24 illustrates a representative crew module (TCM) concept and, as shown, incorporates a docking port, side hatch and airlock, and manipulator arm kit, in addition to providing a habitable haven for crew and passengers. The basic size (volume) tentatively selected is for a 3-4 man crew performing a reasonably-long-duration space mission (~28 days). Contractor estimates indicate that the TCM could accommodate larger numbers (to 15 men) for short-duration missions, particularly in an emergency situation.

Based on the space tug weight breakdown shown above, extensive orbital maneuvering capability (17,000-18,000 fps) is available. However, as in the case of the EOS, the tug incorporates no special rescue equipment or aids.

The Space Tug appears to have considerable versatility as a remedial system for both earth and lunar emergencies. The Tug can be based in space for rapid response or can be delivered upon demand by the EOS or the Space Shuttle.

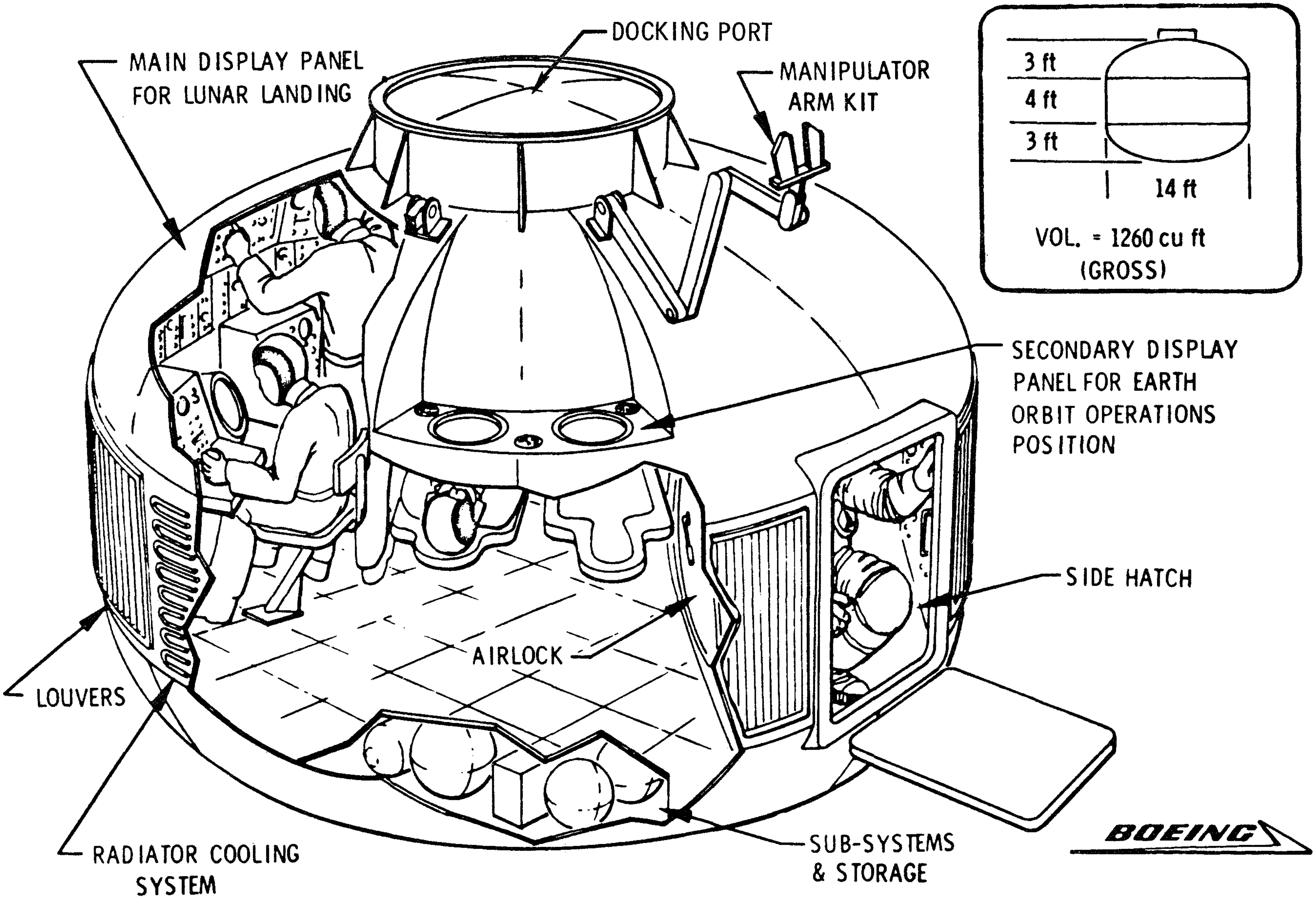


Figure 24. Representative Space Tug Crew Module (TCM) Concept

Tug propulsion modules could be staged to provide a greater ΔV capability or to propel special rescue vehicles weighing more than the standard tug crew module (TCM).

7.3.3 Crew/Cargo Module as a SRV

Although the EOS Orbiter Crew/Cargo Module (CCM) is as yet undefined, its anticipated design includes having a crew module section plus a cargo module section and suggests that it could be modified into a useful SRV (Figure 25).

The modifications assumed were (1) a center section incorporating 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 refitted to accommodate crew and passengers from a distressed vehicle (including incapacitated members transported by personnel carriers (stretchers)) and to enable medical aid to be provided, and (3) the structure modified to accommodate a variety of special rescue equipment that may be appropriate for a rescue mission. Such equipment may include portable airlocks, special transfer capsules, manipulator arms, etc.

Thus, one type of SRV could be simply a specially refitted CCM. Its delivery and recovery are performed by the Earth-Orbit and Space Shuttles. Additional maneuverability could be obtained by adding a propulsive stage to the module. Such an SRV would be useful for earth orbit and lunar mission emergencies. Both manned and unmanned versions are possible. The latter depends upon self-help, whereas the former is the equivalent of a space emergency vehicle/ambulance outfitted with special equipment designed for the rescue mission and a specially trained rescue crew.

7.3.4 Onboard Devices

A number of remedial concepts have application if they are either stored on board, attached to, or in the immediate vicinity of a distressed vehicle (DV) at the time of an emergency. Emergency life support systems and a variety of bail-out devices fall into this category.

CONCEPT

- MANNED SPACECRAFT
- DESIGNED FOR RESCUE MISSION
  - DOCKING FIXTURE
  - AIR LOCK
  - MANIPULATORS
  - SPECIAL RESCUE EQUIPMENT
- CREW TRAINED FOR RESCUE MISSION
- PROPULSION
  - SELF-CONTAINED RCS
  - PROPULSIVE STAGE FOR LARGE ΔV's
- NOT CAPABLE OF REENTRY
- BASED ON MODIFIED CREW/CARGO MODULE
- BASING
  - SPACE
  - EARTH--DELIVERY AIDED BY SHUTTLE

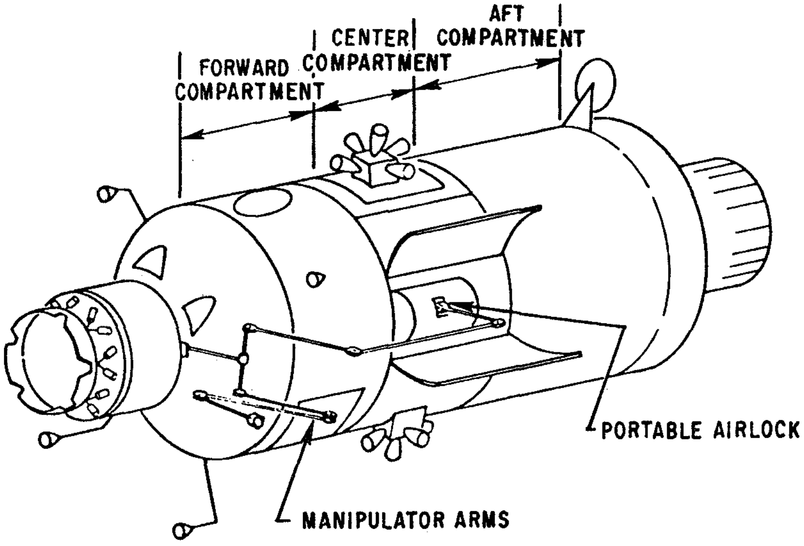


Figure 25. Manned Rescue Vehicle

Detailed descriptions are presented in Appendix K. Only the salient features are briefly summarized in the following sections.

7.3.4.1 Emergency Life Support

The simplest onboard solution is a selected assortment of life support subsystems in a packaged container. The container contents are prepared for long-term storability aboard spacecraft and are used "only in case of emergency." This concept is applicable to all spacecraft and missions but is limited to extending crew survival until an ultimate solution is provided.

Although termed "onboard" 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.

Figure 26 illustrates the weight characteristics of such devices for 14- and 28-day survival periods as a function of the number of crewmen being sustained.

An EC/LS unit utilizing sodium chlorate candles for oxygen is employed. Initial pressurization is provided by high-pressure (~2000 psi) bottled gaseous breathing atmosphere. 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 is dried; water is stored in tanks.

- **CONCEPT**
  - —SELECTED ASSORTMENT OF EC/LS SUBSYSTEMS IN PACKAGED CONTAINER
    - LONG-TERM STORABILITY
    - STORED ON-BOARD DISTRESSED VEHICLE
- **CONTENTS**
  - —ATMOSPHERE SUPPLY AND CONTROL
    - GASEOUS O_2 (INITIAL PRESSURIZATION)
    - SODIUM CHLORATE CANDLES (O_2)
    - MOLECULAR SIEVE (CO_2 CONTROL)
  - —WASTE MANAGEMENT
    - GEMINI-TYPE
  - —THERMAL CONTROL
    - RADIATORS, ETC
  - —POWER SUPPLY
    - SOLAR ARRAY, BATTERIES
  - —FOOD AND WATER

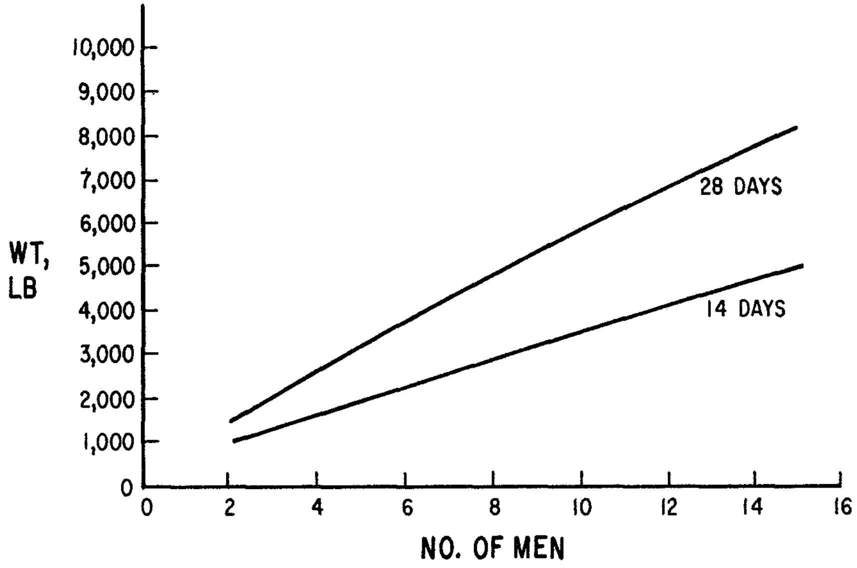


Figure 26. Emergency Life Support

7. 3. 4. 2 Bail-Out-And-Wait Devices

The Bail-Out-and-Wait device (BOW) or "lifeboat" is frequently suggested to permit a crew to disembark (escape) from an uninhabitable spacecraft and await rescue. In concept, the BOW device merely provides a habitable structure with 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) a space vehicle for emergency use in case it becomes a distressed vehicle (DV). Long-term storability is desired and a lightweight structure with minimum storage volume is especially important.

The subsystems related to environmental control and life support were selected as the same type previously described for Emergency Life Support Systems, since long-term storability is again required. 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 (XBOW) and rigid (RBOW) structure versions were considered. Figure 27 illustrates typical weight characteristics for BOW devices with 2- and 28-day survival periods as a function of the number of crewmen being sustained. The rigid RBOW weights shown reflect the use of the Space Tug Crew Module (TCM) outer shell for basic structure. Benefits resulting from this selection are the docking port, airlock, and side hatch, which were assumed inherent features of the TCM and are, therefore, "built in" to the RBOW.

7. 3. 4. 3 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.

- **CONCEPT**
  - — HABITABLE STRUCTURE WITH SUBSYSTEMS FOR SURVIVAL, STABILIZATION AND COMMUNICATIONS
    - LONG TERM STORABILITY
    - CARRIED ABOARD DISTRESSED VEHICLE
    - LIGHT WEIGHT STRUCTURE
  - — ULTIMATELY REQUIRES RESCUE VEHICLE AID
  - — VOLUME TO 1300 FT^3

- **CONTENTS**
  - — ATMOSPHERE SUPPLY AND CONTROL
    - GASEOUS O_2 (INITIAL PRESSURIZATION)
    - SODIUM CHLORATE CANDLES (O_2)
    - MOLECULAR SIEVE (CO_2 CONTROL)
  - — WASTE MANAGEMENT
    - GEMINI-TYPE
  - — THERMAL CONTROL
    - RADIATORS, ETC
  - — POWER SUPPLY
    - SOLAR ARRAY, BATTERIES
  - — FOOD AND WATER
  - — ATTITUDE CONTROL SYSTEM
  - — COMMUNICATIONS SYSTEM

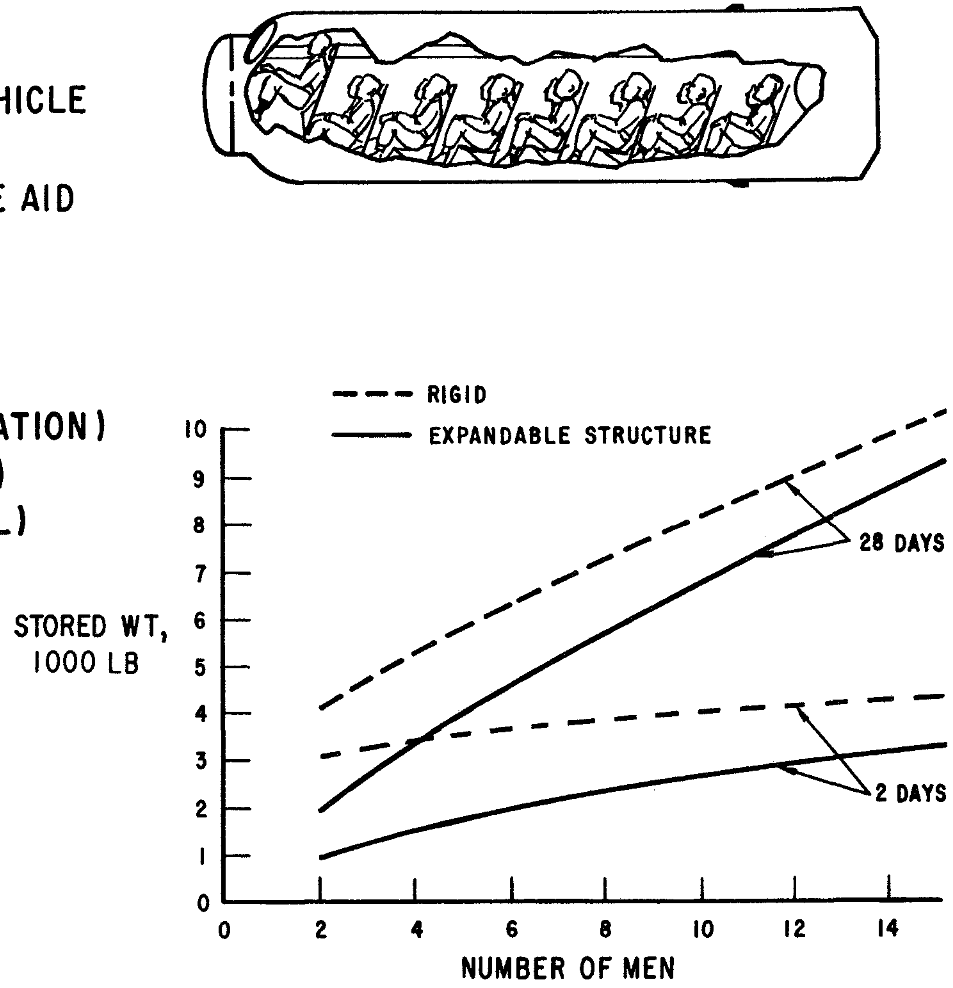


Figure 27. Bail-Out-and-Wait Device (Lifeboat)

7.3.4.3.1 Return-to-Earth BOR Devices

Much effort has been expended in the past in defining the capabilities and characteristics of devices with which one or more astronauts could escape from a distressed vehicle (DV) and reenter the earth's atmosphere for an earth landing.

One relevant study was primarily concerned with small (2-3 men) devices (rigid and expandable) for reentry from low earth orbit. Another study 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 study reported herein summarized this existing data base and extended it to include a broader scope. The extensions included (1) extrapolating data to include BOR devices with up to 15-man capacity, and (2) calculating propulsion system weights to enable geosynchronous deorbit.

Figure 28 illustrates typical expandable and rigid BOR configurations. Also shown are estimated BOR weights for reentry from LEO and GEO.

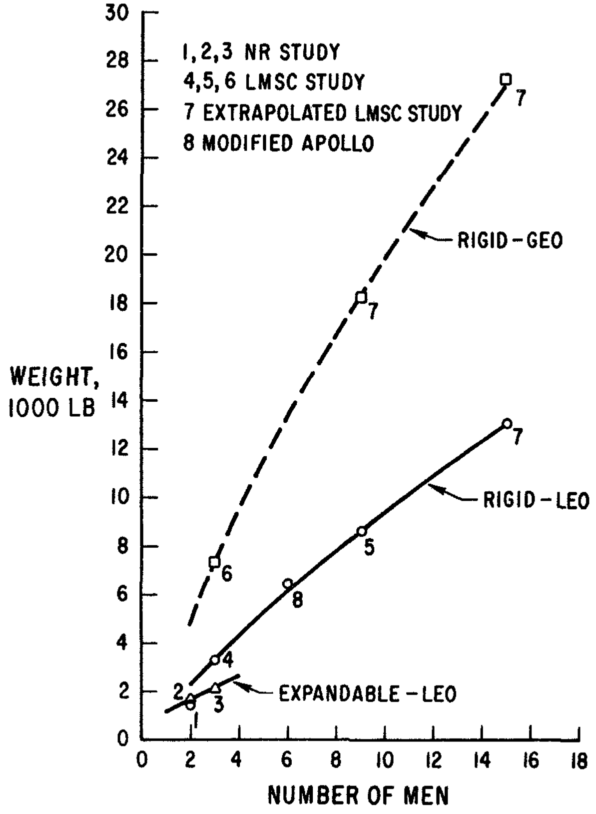
7.3.4.3.2 Return-to-Space Haven BOR Devices

In the return-to-space haven concept, the BOR device is not faced with earth reentry and is, in its simplest form, a BOW device plus a propulsion module (PM) sized to provide the necessary ΔV for return to a space haven from the region of distress. One special requirement is the guidance and navigation equipment (and associated instrumentation, etc.) necessary to perform the ΔV maneuver and the subsequent rendezvous and docking operations.

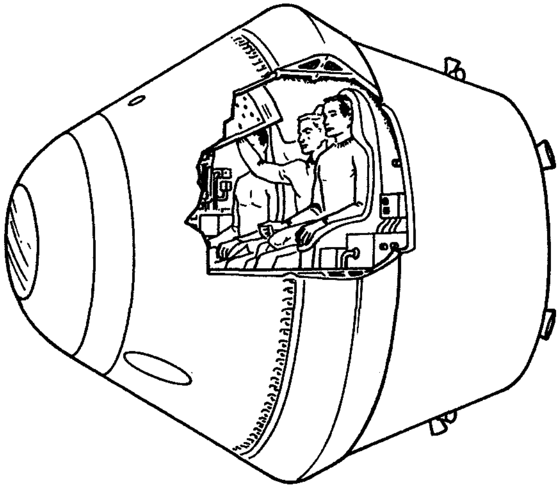
Both rigid and expandable structures were again considered in this application, and both storable and cryogenic propulsion modules were examined. Figure 29 illustrates typical rigid and expandable BOR (space haven) configurations. Also shown are estimated weights for the crew module portions only of the BOR as a function of capacity (number of men, mission duration). In the rigid

CONCEPT

- HABITABLE STRUCTURE
- CARRIED ABOARD DV
  - LONG TERM STORABILITY
- RE-ENTRY CAPABILITY
  - LEO
  - GEO
- LIGHT-WEIGHT STRUCTURE
  - EXPANDABLE STRUCTURE
  - RIGID



RIGID DESIGN
LMSC NASA STUDY



EXPANDABLE DESIGN
NR SAMSO STUDY

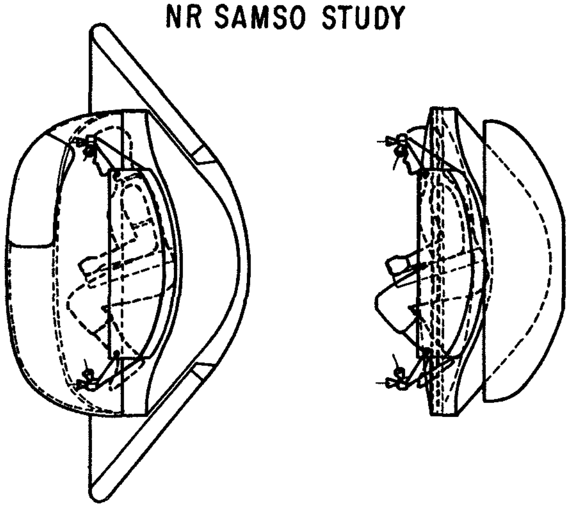


Figure 28. Bail-Out-and-Return Device (Return to Earth)

structure case, 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 again 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.

For the expandable structure case, all subsystems were identical to the rigid case described above, except for the structural shell. Here, the crew module (TCM) shell was replaced by an expandable structure.

Both cryogenic (O_2/H_2) and storable propellants were considered. 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. The overall weight of any desired return-to-space haven BOR device is then the sum of the crew module weight given in Figure 29 plus the weight of a propulsion module.

7.4 CONCEPTS COMPARISON

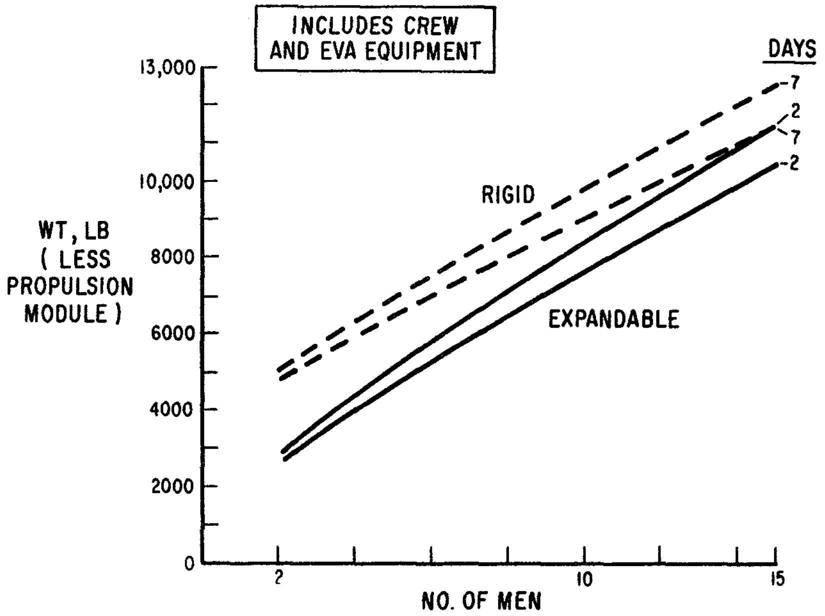
7.4.1 Approach

The objective of this portion of the study effort was to compare the relative effectiveness and utility of the various candidate remedial concepts identified above, and to select a preliminary set of remedial systems appropriate to meet the potential emergencies of the Integrated Program.

Eleven general mission categories (see Figure 37) were selected to represent the Integrated Program. Ten emergency situation categories were previously identified (Figure 3). This results in 110 combinations of mission categories and emergency situation categories for examination. The probability of occurrence of any given emergency was not available (and beyond the scope of

CONCEPT

- HABITABLE STRUCTURE
- CARRIED ABOARD DV
  - LONG TERM STORABILITY
- LIGHT-WEIGHT STRUCTURE
  - EXPANDABLE STRUCTURE
  - RIGID
- REQUIRES PROPULSION MODULE
- PREFERABLY INCLUDES DOCKING FIXTURE



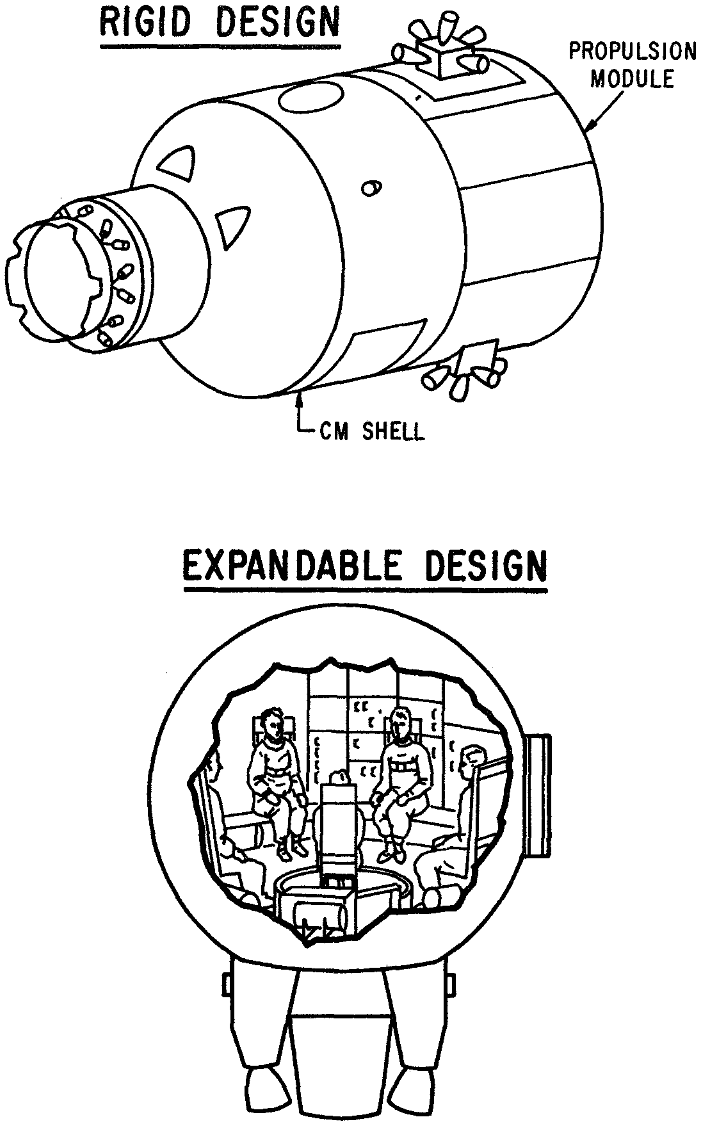


Figure 29. Bail-Out-and-Return Device (Return to Space Haven)

this study). Therefore a qualitative comparison and selection technique was utilized to analyze this very large matrix. The analysis technique is described below and discussed in detail in Appendix J.

7.4.1.1 Definitions and Ground Rules

The analysis technique employed required that a distinction be made between "remedial means" and "remedial systems," defined as:

a. Remedial Means -- a functional or operational concept which provides the desired relief (or remedy) for a given specific emergency situation

b. Remedial System -- a hardware system which implements the functional or operational concept

In this context nine remedial means were identified within the general categories of self-help, unmanned assistance, and manned assistance. In the self-help category the specific remedial means included:

a. On-board supplies and equipment
b. Bail-Out-and-Wait (BOW) devices
c. Bail-Out-and-Return to safe haven (BOR) devices
d. Prepositioned Aid Packages (PAP)
e. Mission abort operations (to safe haven)

The unmanned assistance category included:

a. Shipped supplies and equipment
b. Unmanned rescue vehicle (URM) with return to safe haven capability

The manned assistance category included:

a. Space Rescue Vehicle (SRV) with return to safe haven capability
b. Buddy system

These remedial means are summarized in Table 15 and assigned a number (circled) which is used throughout the comparison and selection process to identify it. It should be noted that the "Buddy system," as utilized herein, does not require the use of identical twin systems, but does require two systems

Table 15. Remedial Means Categories

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.

each with the capability to complete the mission or return to a haven of safety. (Attached buddy vehicles are not included under this definition.)

7.4.1.2 Selection Process

The selection process involved two general steps:

a. remedial means concept definition and selection
b. remedial system definition and selection

Within the first general step a number of discrete qualitative and subjective operations are required. First, for a single mission category (e.g., space station in low earth orbit, LEOSS) and a single emergency situation (e.g., stranded/entrapped crew), the most critical aspect of the emergency was specified (e.g., stranded in EVA). Then the particular "remedial means" most effective in resolving the critical aspect of the emergency was selected from the nine available alternatives listed in Table 15.

The above operations were then repeated for the same mission category for all of the ten emergency situation categories, and the minimum number of "remedial means" required to be effective over the entire emergency spectrum determined. This sequence was repeated for each of the eleven mission categories to determine the minimum number of "remedial means" required to effectively deal with the entire emergency and entire mission spectrum.

In the second step of the selection process, the critical requirements (performance capability, crew capacity, etc.) were identified for each of the necessary remedial means concepts included in the minimum set. Then, candidate "remedial systems" were configured to implement the remedial means concepts. These "remedial systems" were then screened by comparison with selection criteria to reduce the set of candidate "remedial systems" to those most effective or utilitarian.

Finally, a second screening process was utilized to further reduce the candidate set by combining functions, i. e., configuring one broad-capability remedial system to satisfy the requirements of two or more single-capability remedial systems. The remedial systems surviving the foregoing selection and comparison process were those then considered most applicable for implementation in the Integrated Program.

A logical additional (and final) step to the above process would be a further screening to identify a least-cost set of remedial systems. This would require a precise definition of total Integrated Program mission schedules, hardware element costs, etc., none of which is currently available, and therefore this selection process step was beyond the scope of the study.

Figure 30 summarizes the foregoing selection process procedures in step-wise fashion. (See Appendix J for a detailed treatment.)

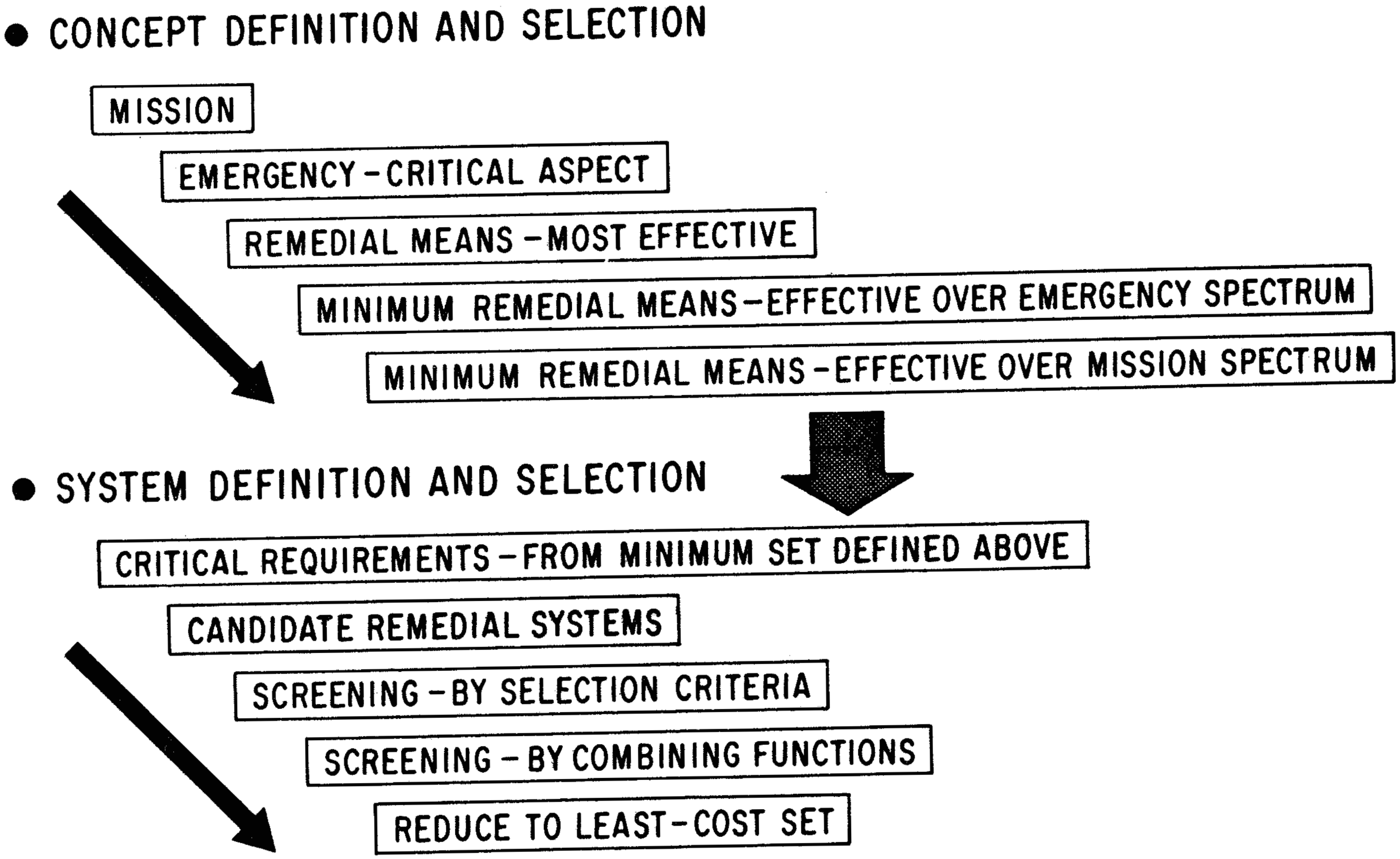
7.4.2 Remedial Means Selection

The nine remedial means evaluated were previously listed in Subsection 7.4.1.1. In considering their applicability to any given emergency situation, the general guidelines employed were that the rescue means should maximize:

a. the speed of response
b. the speed of return to a safe haven
c. the aid required for a specific emergency

In furtherance of these guidelines, the following application principles were followed:

a. Self-help capability is preferred, if adequate.
b. Any selected remedial means must respond to the critical aspect (worst case) of a given emergency situation.
c. The emergency situation may require backup remedial means selection. (This follows from the fact that crew disability may limit the capability of an otherwise totally-effective remedial means, and that practical limitations may be imposed by IP missions and hardware.)



- CONCEPT DEFINITION AND SELECTION

MISSION

EMERGENCY - CRITICAL ASPECT

REMEDIAL MEANS - MOST EFFECTIVE

MINIMUM REMEDIAL MEANS - EFFECTIVE OVER EMERGENCY SPECTRUM

MINIMUM REMEDIAL MEANS - EFFECTIVE OVER MISSION SPECTRUM

- SYSTEM DEFINITION AND SELECTION

CRITICAL REQUIREMENTS - FROM MINIMUM SET DEFINED ABOVE

CANDIDATE REMEDIAL SYSTEMS

SCREENING - BY SELECTION CRITERIA

SCREENING - BY COMBINING FUNCTIONS

REDUCE TO LEAST-COST SET

Figure 30. Selection Process

In view of the foregoing guidelines and application principles, it was possible to identify a preferred specific remedial means for various specific emergency situations. For example:

a. A BOR device is always preferred for its direct return-to-haven capability.

b. A BOW device is preferred in the situation only where spacecraft abandonment is required.

c. An unmanned rescue vehicle (URM) is preferred for aid and retrieval of crew (including return to haven) if manned assistance is not specifically required.

d. A manned rescue vehicle (SRV) is required where the DV crew is incapacitated or unable to utilize self-help.

Figure 31 illustrates one step in the remedial means selection process, wherein the single emergency situation "stranded or entrapped crew" is applied to each mission class. For each mission class the most critical condition of the emergency situation is identified, and those remedial means most suitable for the critical condition selected.

For example, in the case of the low earth orbit space station (LEOSS), a crew member stranded in EVA was considered as the most critical condition under the general "stranded/entrapped" category. Note that this condition is singular in nature, i.e., the crew member is stranded only, not injured or ill, and therefore could help himself if means were available. For this condition, a self-help remedial means (a prepositioned aid package, PAP) was the preferred solution. The PAP could be such as to provide either a BOW or BOR function. If it were a BOR-type PAP, it could totally remedy the situation by enabling a return to a safe haven; if a BOW-type PAP, a paired solution means would be additionally required. In the latter case the URM is designated as the paired remedial means. Detail on treatment of other cases is presented in Appendix J.

The entire spectrum of emergency situation categories and mission categories was examined in a similar fashion. Figure 32 indicates the remedial means selected as appropriate for each combination of emergency situation and mission category. There are three columns in each matrix box consistent

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 31. Example of Remedial Means Application (Stranded or Entrapped Crew)

with the categories of self-help, unmanned assistance, and manned assistance as displayed in Table 15, and the identifying remedial means numbers are also consistent with the numbers presented in Table 15. The preferred remedial means in each instance is designated by a triangle. In many instances alternate approaches are feasible.

The significant results of the information in Figure 32 is summarized in Table 16, where the number of applications of any given type of remedial means, either as the desired or back-up means, is delineated.

Onboard emergency supplies and equipment, ①, were not shown in Figure 32 because they were assumed to be on board in all cases, to the extent permitted by vehicle payload considerations. Mission abort, ⑤, is a procedural or operational capability and therefore was not considered for remedial system configurational examination. Shipped supplies and equipment, ⑥, was dropped at this point because of lack of application. Generic prepositioned aid packages (PAP), ④, were converted at this point to their more specific functions as BOW's, ②, and BOR's, ③, for further configurational examination.

Therefore, remedial means concepts ②, ③, ⑦, ⑧, and ⑨ were determined to be those remedial means of sufficient application potential to warrant their further investigation in the next step of the analysis.

7.4.3 Remedial System Selection

As previously indicated, the first step in the remedial system selection process was to establish the configuration, size, capacity, and weight of candidate remedial systems to provide the desired functional capabilities.

In this regard, certain critical remedial system requirements were identified (see Figure 33) to aid in remedial system sizing. Figure 34 is an abbreviated example of one such determination for BOR devices.

	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	△3 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	△3 ② ⑦	△5 ③ ② ⑦	⑦ △9	

△ = PREFERRED MEANS

Figure 32. Remedial Means Summary Matrix

Table 16. 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	-

CRITICAL REMEDIAL SYSTEM (RS) REQUIREMENTS TO BE DETERMINED:

- CREW AND PASSENGER CAPACITY
- RESPONSE TIME LIMITS
- MISSION DURATION TO SIZE EC / LS
- REQUIRED ΔV (WHERE APPLICABLE)
- STRUCTURAL (SHIELDINGS, ETC.)
- DOCKING SYSTEMS (WHERE APPLICABLE)

Figure 33. Remedial System Requirements

MISSION CLASS.	SAFE HAVEN	ΔV FPS	ECLS LIFE HR	STRUCTURAL	CREW AND PASSENGERS
LEOSS	EARTH	300	36	WATER LANDING EARTH REENTRY	12
GEOSS	EARTH	5,000	36	WATER LANDING EARTH REENTRY	12
	LEO	14,200	10	SPACE DOCK	12
TUG IN LUNAR ORBIT	OLS	2,000	48	SPACE DOCK	3 - 15
	LEO	14,000	100	SPACE DOCK	3 - 15
	EARTH	4,000	90	WATER LANDING EARTH REENTRY	3 - 15

Figure 34. Example of Critical Remedial System Requirements: BOR

Following critical requirement determination, remedial systems were synthesized (configuration, size, capacity, weight, etc., determined) to the level necessary to support a comparison and selection process. In this effort the remedial system weight data presented in Section 7.3 and Appendix K were utilized wherever possible. In some instances, modifications to this data were necessary to meet specific remedial system requirements.

Tables 17, 18, and 19 illustrate the resulting definition of candidate BOR, BOW, URM, and SRV remedial systems. As can be noted, the resulting candidate remedial system set contains 5 BOW's, 8 BOR's and 10 URM/SRV systems. In addition to these special remedial systems, the Earth Orbit Shuttle (EOS), Space Tug, and Space Shuttle were available for consideration both as "rescue" vehicles and as "transportation" vehicles for other remedial systems. The "buddy system" design was retained for comparison purposes.

To aid in further comparison and selection operations, a number of selection criteria were applied to the candidate remedial systems (see Figure 35). An illustrative example of applying the first criteria (degree of aid) to the candidate remedial systems is given in Figure 36, where a higher number indicates a a greater degree of aid. The term "aid," as used herein, encompasses the total spectrum of response to a need; from direct physical assistance to transportation. As can be noted, the ability to provide an immediate return to a final haven of safety was assigned the greatest value.

Table 20 is an example of applying the ranking procedure to the remedial systems appropriate for the low earth orbit space station (LEOSS), and Table 21 is a summary of the ranking factors for all remedial systems surviving the screening process (including estimated ROM costs). Such comparison and ranking factors provide useful insight into the status and utility of a given remedial system. In general, the higher the ranking level the greater the preference as a remedial system.

Table 17. 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 18. Candidate Bail-Out-and-Wait Systems

	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 19. 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
ΔV, 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

- DEGREE OF AID
- REACTION TIME
- DV CREW PARTICIPATION (COMPLEXITY FACTOR)
- DEVELOPMENT STATUS
- STATE OF ART
- FEASIBILITY OF MULTIPLE USE
- PRACTICALITY OF USE

Figure 35. Remedial System Selection Criteria

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 36. Ranking by Degree of Aid

Table 20. Ranking Procedure Applied to LEOSS Mission

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 21. Remedial Systems Selection Summary

	MULTIPLE USE FACTOR	DEVELOPMENT STATUS	COMPLEXITY FACTOR	SOA	DEGREE OF AID	COSTS IN $ MILLION	
						R &D	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

The remedial systems considered to be most appropriate for the Integrated Program are summarized in Figure 37 in terms of the particular missions to which they apply. They are discussed in detail in Appendix J and briefly delineated below.

7.4.3.1 New Equipment

In the new equipment category is the XM, a small (3-man) expandable structure Bail-Out-and-Return to earth device, and the MTCM-I/PM, a storable propellant Bail-Out-and-Return to space haven device which utilizes a modified Tug Crew Module (MTCM) as the habitable portion. Only the PM would constitute new equipment. The XM has application to the LEOSS, a manned Tug in LEO, and the EOS Orbiter in LEO. The MTCM-I/PM has application to a manned Tug in GEO and LO.

7.4.3.2 Modified Integrated Program Elements

In the modified Integrated Program hardware element category are three rigid bail-out-and-wait (RBOW) devices, and the EOS Crew/Cargo Module modified to serve as a Space Rescue Vehicle. The MCCM could be delivered by the EOS, a space tug propulsion module, or staged tug propulsion modules.

All RBOW's are based on modifying Space Tug Crew Modules (TCM) to perform the bail-out-and-wait function. RBOW I (15-man, 2 days) has application to the LEOSS, GEOSS, and the Space Shuttle in LEO, GEO, or in transit to and from LEO/GEO. RBOW II (15-man, 28 days) has application to either the LSB or the OLS. RBOW III (3-man, 28 days) has application to the Space Shuttle in LO or in transit to and from LO.

The MCCM and EOS combination (EOS/MCCM) is applicable to LEO situations (LEOSS, Tug in LEO, EOS in LEO, and Space Shuttle in LEO).

The MCCM and tug propulsion module combination (Space Tug/MCCM) has application to the same LEO situations and also to geosynchronous (GEOSS, Tug in GEO, Space Shuttle in GEO or transit) and some lunar situations (Tug

		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 37. Remedial System Application Matrix

in LO, Space Shuttle in LO or transit). The MCCM and staged tug propulsion module combination (staged tug/MCCM) has application to the lunar situations of Tug on LS, and to LSB or OLS problems.

7.4.3.3 Planned Integrated Program Elements

Basic unmodified planned Integrated Program elements also have remedial system application. As previously mentioned, the EOS and Space Tug (with TCM) have been proposed to act as rescue vehicles in the Integrated Program; however, their capacity to do so is limited by the fact that they do not (as presently defined) incorporate special rescue equipment which may be required. Aside from the aforementioned constraints, the unmodified EOS is applicable as a rescue vehicle to LEO situations while the Space Tug/TCM has application as either a BOW, BOR, or rescue vehicle across the entire mission spectrum. The Space Shuttle (held in standby in LEO) has application to go to the geosynchronous and lunar orbit areas to render aid. It has the further capacity to be "paired with" (or deliver) a Space Tug/MCCM rescue vehicle combination for application to the GEOSS, Tug on LS, or LSB/OLS situations.

Finally, the buddy system category is mentioned to reflect the conclusion that buddy system design should be considered for those transportation elements of the Integrated Program (EOS, Space Tug/TCM, Space Shuttle) where immediate manned assistance or immediate self-help facilities may be required for emergencies developing during the in-transit portions of their missions.

7.5 SUMMARY OF RESULTS

For the equally high occurrence probability of emergencies assumed herein, a balanced mix of remedial systems is required to provide escape and rescue capability for the Integrated Program. This balanced system mix includes:

a. New developments (XM, MTCM-I/PM)

b. Modified Integrated Program elements (RBOW's based on modified TCM's, space rescue modules based on CCM's)

c. Planned Integrated Program elements (EOS, Space Tug/TCM, Space Shuttle)

If actual emergency event probabilities are determined, they may permit the number of required remedial systems to be reduced.

An expandable BOR or BOW device appears attractive for EOS Orbiter application due to its packaging flexibility.

An SRV, manned or unmanned, seems desirable to meet the diverse emergency situation needs identified; the modified EOS Crew/Cargo Module (MCCM) appears attractive for this purpose.

The Space Tug/TCM has many potential retrieval and/or BOR applications; the TCM itself has further application potential as a BOW device.

As the EOS Orbiter is the primary mode for return to earth in all cases, the Orbiter should have the capability to return an MCCM or its equivalent as a space rescue module.

7.6 RECOMMENDATIONS

In view of the sensitivity of remedial systems selection to emergency event probabilities, it is recommended that:

a. The input data needed for a quantitative assessment of remedial systems be developed. This would include not only emergency occurrence probability determination but also the definition of an explicit mission model and improved cost estimates of associated hardware elements.

b. Additional tradeoff studies be performed to further reduce the number of desired remedial systems.

8. CONCLUSIONS

In the foregoing sections, many of the diverse requirements and needs attendant to potential Integrated Program escape and rescue missions were addressed. Each specific area of investigation was shown to have unique equipment and/or operational requirements and varying degrees of impact on the overall problem of space rescue. This section provides a summary overview of the more significant study conclusions presented in more detail throughout the report.

8.1 HAZARDS ANALYSIS

The space hazards pertinent to the Integrated Program are much the same as for earlier programs and missions. Ten general emergency situations resulting from the occurrence of space hazards were identified. However, when the numerous missions and hardware elements of the Integrated Program are combined with these ten general emergency situation categories, the resulting potential emergency situation matrix is very large.

8.2 CONTINGENCY PLANNING

An overall safety contingency plan is needed for the Integrated Program.

This conclusion is based on a review of NASA and contractor documents for safety guidelines and contingency planning which indicates that:

a. There is only a "de facto" safety plan, elements of which are scattered throughout many documents.

b. There is little coordinated planning between interfacing program elements.

c. Equipment capabilities and safety operations were assumed without determining their technical feasibility.

d. Availability, when needed, of specialized escape and rescue equipment is assumed. Planning for its acquisition has not been initiated.

e. There are no escape or rescue provisions specified, as yet, for either the Earth Orbit Shuttle or the manned Space Tug (nor for the Space Shuttle).

8.3 OPERATIONAL CONSIDERATIONS

a. Subsynchronous earth orbits (repeating ground tracks) offer a potential safety advantage in that communications and reentry functions are no longer random processes.

b. Initial and projected Integrated Program communications and tracking facilities (MSFN, data relay satellites) offer continuous coverage. It is not clear whether these facilities will include the capability to skintrack mute vehicles. Both of these capabilities are desirable from a safety viewpoint.

c. CONUS-only landing sites can impose a reentry delay of 7 or 8 orbits or 11-13 hours (based on ETR as launch site). Multiple CONUS sites offer little benefit over a single site. No single CONUS site offers a shorter reentry delay than ETR.

d. Available information indicates that remedial action need be taken in from 1 to 5 days for non-catastrophic emergency situations, in order to prevent additional crew fatality among the surviving crew members. With regard to ground-based reaction time, the current EOS reaction time specification of 24 hours appears unrealistic; launch reaction times can approach 150 hours and ascent and rendezvous times can approach 26 hours. In addition, space rescue operations at the scene of the emergency may take a day or more. Dedicated or standby rescue equipment may be required to provide an acceptable ground-based response.

e. Midcourse abort and fast return to LEO with still-available onboard ΔV appear feasible for in-transit vehicles on geosynchronous and lunar missions.

f. Space rescue vehicle ΔV needs can be very high. For the lunar mission, the ΔV requirement is least (~22,000 fps) when the SRV is based in lunar orbit. For the geosynchronous mission, the ΔV is least (14,000 fps and up) when the SRV is based in GEO.

8.4 SPACE RESCUE VEHICLE REQUIREMENTS

Potential operations and equipment needs to perform a rescue mission are extensive. Hazards to the SRV itself may be present, requiring specific equipment and operational capability for that reason alone. Techniques for personnel and equipment transfer to and from the distressed vehicle must be provided. This results in extensive special rescue equipment needs for the case where no docking is possible. Such support hardware should be developed in parallel with the basic Integrated Program hardware element to which it is intended to interface.

8.5 REMEDIAL SYSTEM ANALYSIS

Integrated Program rescue vehicles (EOS, Space Tug) lack the capability to cope with all emergency situations. They have only a limited capacity for incorporating "special rescue equipment," and generally have inadequate ΔV. Because the EOS and the Tug have limited capability, additional capability for rescue operations may be required. This may be in the form of a separate special SRV, a BOW device, or a BOR device. A mix of desired rescue and escape equipment was identified which contains new devices, basic Integrated Program hardware, and modifications of basic hardware. These selections were based on the current mission and hardware element status; this number may be reduced when emergency event probabilities are determined.

9. RECOMMENDATIONS

In view of the foregoing conclusions, a number of specific recommendations are appropriate.

9.1 GENERAL RECOMMENDATIONS

9.1.1 Means for Enhancing Integrated Program Safety

In this general area, it is recommended that:

1. Mission definition and operational procedures be adjusted to provide for a standby Space Rescue Vehicle (SRV) in a given theater of operation, and to provide for a standby Space Shuttle whenever such a vehicle is making a trip to or from GEO or LO.
2. Special emergency equipment (docking fixtures, airlocks, transfer capsules, kits, high-pressure EVA suit, etc.) be considered to facilitate a rescue mission.
3. Planned Integrated Program hardware elements (CCM, TCM) be adapted to perform special purpose remedial functions (BOW, BOR, rescue modules).
4. The small (2 to 3-man) expandable BOR device be given consideration for LEO applications.
5. Mission hardware be designed to permit (1) escape using bail-out devices and (2) docking under emergency conditions.

9.1.2 EOS Studies

It is recommended that continuing and future EOS studies give specific consideration to (1) the EOS as a "distressed vehicle" and (2) as part of a rescue system.

9.1.3 Analytic Studies

It is recommended that analyses be conducted to (1) determine emergency event probabilities and (2) further study the techniques for increasing the rescue and escape utility of Integrated Program hardware elements.

9.2 SPECIFIC RECOMMENDATIONS

More specific detailed recommendations, in the same areas as delineated above, are summarized in Figures 38 through 40.

9.3 IMPLEMENTATION PLAN

In consonance with the foregoing, a plan for implementation is presented in Figures 41 and 42.

Figure 41 lists those remedial system hardware developments appropriate as either special rescue equipment or specific remedial devices (BOR, BOW, SRV). Also shown are projected ROM development costs, assuming parallel development of any device based on modification of an existing or planned Integrated Program element (RBOW, MTCM-I, MCCM).

Figure 42 presents a schedule for implementing some of the hardware developments and analytical studies previously mentioned. It should be noted that the schedule, as shown, is keyed to the EOS operational date (assumed to be mid-CY 1979) and the LEOSS operational date (assumed to be late CY 1981). With regard to this schedule, the following observations are pertinent.

a. An advanced technology effort is required only for the expandable Bail-Out-and-Return-to-earth device.

b. The minimum cost Bail-Out-and-Wait device (RBOW I) development would require the availability of the Space Tug Crew Module (TCM) in 1981.

c. Space rescue module (MCCM) development requires availability of the EOS crew/ module (CCM) by 1981.

d. Acquisition schedules for remedial systems intended for LO, LS, and GEO application were not determinable due to lack of a firm mission plan.

e. Hardware implementation decisions are required by mid-1976 to make the plan timely and effective.

- ADJUST MISSION DEFINITION AND OPERATIONAL PROCEDURES
  - STANDBY SRV IN ALL PERMANENT ORBITAL AREAS (LEO, GEO, LO)
  - STANDBY SPACE SHUTTLE DURING TRANSIT MISSION TO/ FROM LEO AND LO, TO/ FROM GEO AND LEO
- ACQUIRE SPECIAL EMERGENCY EQUIPMENT
  - HIGH PRESSURE EVA SUIT
  - AMU'S AND MANIPULATORS
  - EMERGENCY DOCKING FIXTURES (ATTACHABLE, SOFT, ETC.)
  - PORTABLE AIRLOCKS
  - INFLATABLE TRANSFER CAPSULES
  - MEDICAL KITS
  - DESPIN DEVICES/TECHNIQUES
  - DAMAGE CONTROL EQUIPMENT
  - BOR'S (EXPANDABLE, 2-3 MAN CAPACITY, RETURN FROM LEO)
  - CCM FOR USE AS SRV
  - TCM FOR USE AS BOW
  - ST/TCM FOR USE AS BOR

Figure 38. Detailed Recommendations, Means to Enhance IP Safety

- MISSION HARDWARE REQUIREMENTS
  - CONCURRENT IP ELEMENT DESIGN SHOULD AIM TOWARD
    - ABILITY TO ESCAPE IN BOD
      - GREATLY SIMPLIFIES RESCUE OPERATION
    - ABILITY TO ALWAYS DOCK
      - AVOIDS EXCESSIVE RESCUE EQUIPMENT NEEDS
      - REDUCES OPERATIONS TIME
    - ABILITY TO CYCLE CABIN ATMOSPHERE
      - REDUCES RESCUE EQUIPMENT REQUIREMENTS
      - SPEEDS TRANSFER
    - ABILITY TO DETERMINE DAMAGE/ CREW STATUS FROM DV EXTERIOR
      - REDUCES RESCUE TIME
      - REDUCES RESCUE CREW HAZARDS

Figure 38. (Continued)

- MISSION HARDWARE REQUIREMENTS (CONTINUED)
  - EARLY DESIGN PHASE CONSIDERATIONS SHOULD INCLUDE:
    - MULTIPLE ACCESS MEANS
      - INTO DV FROM EXTERIOR
      - BETWEEN CREW COMPARTMENTS
    - BULKHEAD CUTTING REQUIREMENTS
    - DESPINNING REQUIREMENTS
    - EXPLOSIVE DEBRIS AVOIDANCE
    - USE OF LASER RENDEZVOUS AND DOCKING GUIDANCE FOR
      - DEBRIS DETECTION
      - SPIN CHARACTERIZATION

Figure 38. (Continued)

- CONSIDER EOS AS A DV
  - — ACCESS/ EGRESS WITHIN EOS
    - MULTIPLE ROUTES FOR CREW AND PASSENGERS
  - — SHELTER FOR CREW
  - — CREW ESCAPE
    - LOCATION OF DOCKING PORT ON MAJOR AXIS OF ROTATION
    - INCORPORATION OF EMERGENCY DESPIN DEVICES
    - INCORPORATION OF EVA EQUIPMENT/ FACILITIES
  - — STOWAGE OF EMERGENCY EQUIPMENT
    - EVA SUITS
    - AMU'S
    - TRANSFER CAPSULES
  - — DAMAGE SENSOR EQUIPMENT AND READOUTS

Figure 39. Detailed Recommendations, Earth Orbit Shuttle Studies

- CONSIDER EOS AS PART OF RESCUE SYSTEM
  - CARRIER OF SPECIAL RESCUE VEHICLE (SRV)
    - EOS RELIEVED OF MOST SPECIAL EQUIPMENT REQUIREMENTS
      - STILL NEEDS DEBRIS AND RADIATION DETECTION EQUIPMENT
      - SERVES AS COMMUNICATIONS CENTER
    - SRV WITH SPECIAL RESCUE NEEDS
      - DOCKS TO DV
      - CONTAINS SPECIAL EQUIPMENT
      - SERVES AS CREW HAVEN
    - RETURNS SRV OR BOD, ETC. TO EARTH

Figure 39. (Continued)

- DETERMINE EVENT PROBABILITIES OF EMERGENCY SITUATIONS
  - MAY ALLOW REDUCTION OF REMEDIAL SYSTEMS AND RESCUE EQUIPMENT NEEDS
- CONTINUE EXPLORATION OF TECHNIQUES INCREASING RESCUE / ESCAPE UTILITY OF IP ELEMENTS
  - EOS PERFORMANCE IMPROVEMENTS WITHIN PLANNED CONFIGURATION
  - ADAPTATION OF TCM, CCM TO PROVIDE GREATER REMEDIAL CAPABILITY
- RELATE MEDICAL EMERGENCIES TO RESCUE OPERATIONAL FACTORS
  - ACCESS TIME LIMITS
  - SPECIAL EQUIPMENT
  - MEDICAL SKILL NEEDS
- OPTIMIZE CREW TRANSFER METHODS FOR VARIOUS EMERGENCY CONDITIONS

Figure 40. Detailed Recommendations, Analytical Studies

- ESTIMATE DEBRIS DETECTION SYSTEM REQUIREMENTS
  - ENCOUNTER PROBABILITY
  - DEBRIS CHARACTERISTICS
- OPTIMIZE DV DISPOSAL TECHNIQUES
  - CONVENTIONAL SPACECRAFT
  - NUCLEAR SYSTEMS
- OPTIMIZE SET OF REMEDIAL SYSTEMS BASED ON
  - MISSION MODEL
  - COST TRADES

Figure 40. (Continued)

DEVELOPMENT ITEM	ESTIMATED DEVELOPMENT COST - $\$10^6$
AMU'S[*]	
PLATFORM	50
ENCLOSED (SHIRTSLEEVE ENVIRONMENT)	175
REMOTE CONTROL TYPE	120
PORTABLE EC / LS SYSTEM	24
TRANSFER EQUIPMENT	
TRANSFER CAPSULE (INFLATABLE)	5
PORTABLE AIRLOCK	13
PORTABLE DOCKING FIXTURE	7
SOFT DOCKING FIXTURE	7.5
MISCELLANEOUS RESCUE EQUIPMENT	20.0
BOW'S[**]	
RBOW I	25
RBOW II	200
RBOW III	80
BOR'S	
XM II	75
MTCM-I/PM	190
SRV (MCCM ONLY)	175

[*] SAME TYPE AS POSTULATED FOR IP IN-SPACE BUILDUP, MAINTENANCE, REPAIR FUNCTIONS

[**] PREDICATED ON USAGE OF CREW MODULE (CM) OUTER SHELL, INCLUDING DOCKING/ AIRLOCK PROVISIONS

Figure 41. Implementation Plan

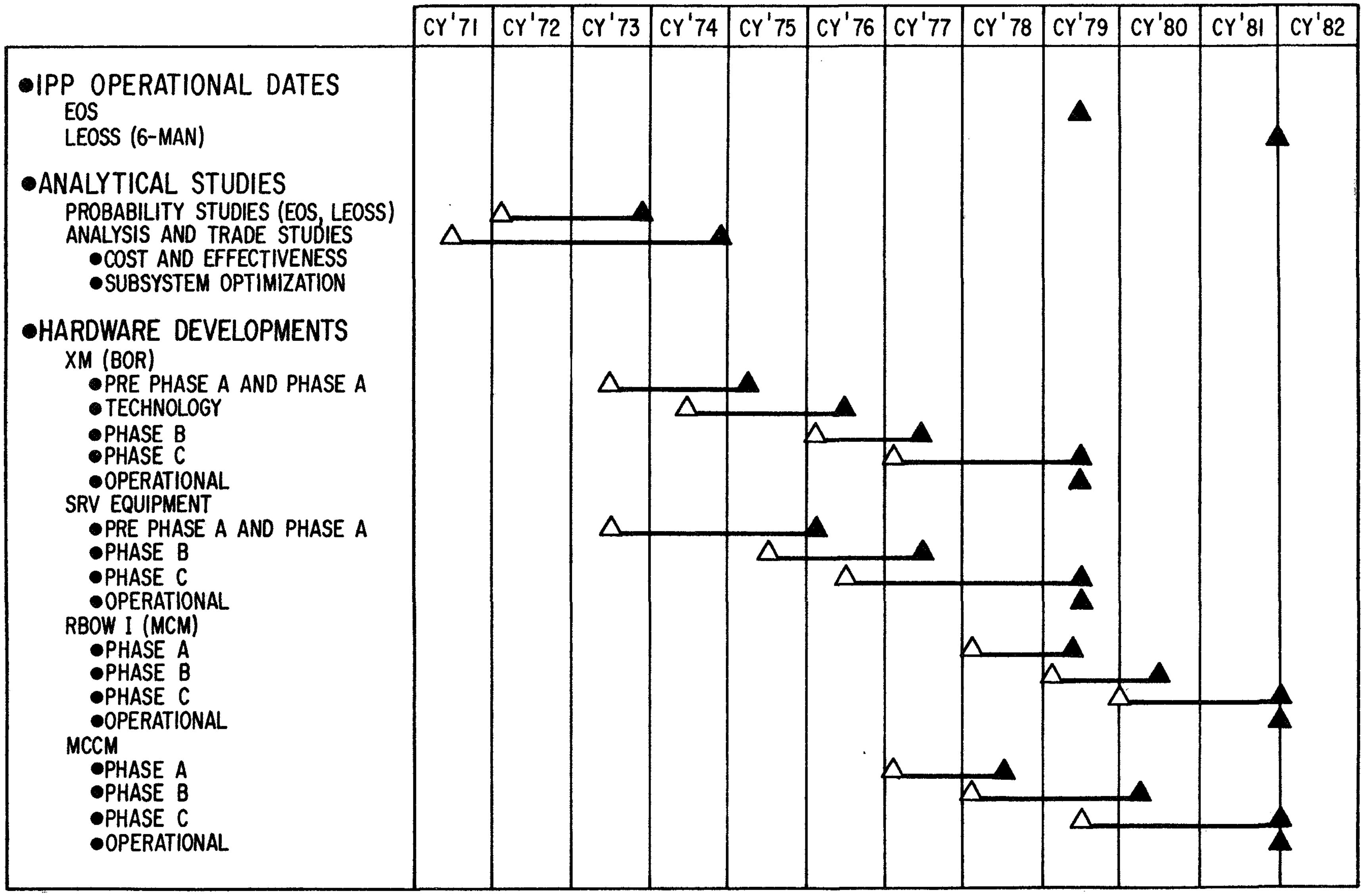


Figure 42. Implementation Schedule for Remedial System Acquisition

10. 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)