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Space Rescue Operations

Volume I: Management Summary Report

Prepared by SYSTEMS PLANNING DIVISION

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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Volume I: Management Summary Report

Submitted by

E. Perchonok

E. Perchonok, Study Manager

Approved

Samuel M. Tennant

S. M. Tennant
Assistant General Manager
Systems Planning Division

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.

CONTENTS

TABLES

FIGURES

1. INTRODUCTION

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 who have not been 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 therefore clearly appropriate.

2. STUDY OBJECTIVE

The objective of this study was to provide a technical perspective from which desirable safety-oriented actions could be identified.

3. RELATION TO OTHER NASA EFFORTS

The results of this study provide useful safety-related inputs to the Integrated Program planning process. Issues that need immediate attention have been identified. Factors involving hardware design and development decisions, operational procedures, and safety, escape, and rescue interfaces between major hardware elements and remedial equipment need to be considered.

From a safety-oriented point of view, the following items require attention at present:

a. Preparation of a formal safety contingency plan

b. Planning and acquisition of specialized escape and rescue equipment

c. Coordination of planning between interfacing Integrated Program elements and safety-related special equipment

d. Accelerated planning for a Manned Tug

e. Escape and rescue provisions for the crews of the Orbiter stage and the Manned Tug

f. Assessment of the EOS as a ground-based rescue vehicle

g. The long acclimatizing time required for current EVA suits

4. METHOD OF APPROACH

The general plan followed in this study was to:

a. Identify potential emergency situations requiring remedial action

b. Screen possible methods for providing solutions to these situations

c. Determine special equipment needs for Space Rescue Operations

d. Assess the feasibility of adapting Integrated Program hardware for escape and rescue

5. RESULTS

5.1 GENERAL

The Integrated Program is conceptually summarized in Figure 1. Since only the manned phases are of interest, whether or not Saturn (Int. 21) is used has no effect on the study results. Also, although a nuclear space shuttle is illustrated, a chemical system is equally applicable.

5.2 EMERGENCIES

The missions and the planned hardware were analyzed in order to predict possible emergency situations. Potential Integrated Program emergencies are summarized in Table 1. The list covers all mission phases and hardware elements, but individual items do not necessarily apply to all missions.

Based on these anticipated emergencies, it was concluded that any device used for rescue should provide the following:

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 disabled 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 was also concluded that a Space Rescue Vehicle (SRV) coming to the aid of a distressed vehicle (DV) may need the following capabilities:

a. Collision avoidance with debris generated by the DV
b. Protection from DV radiation 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

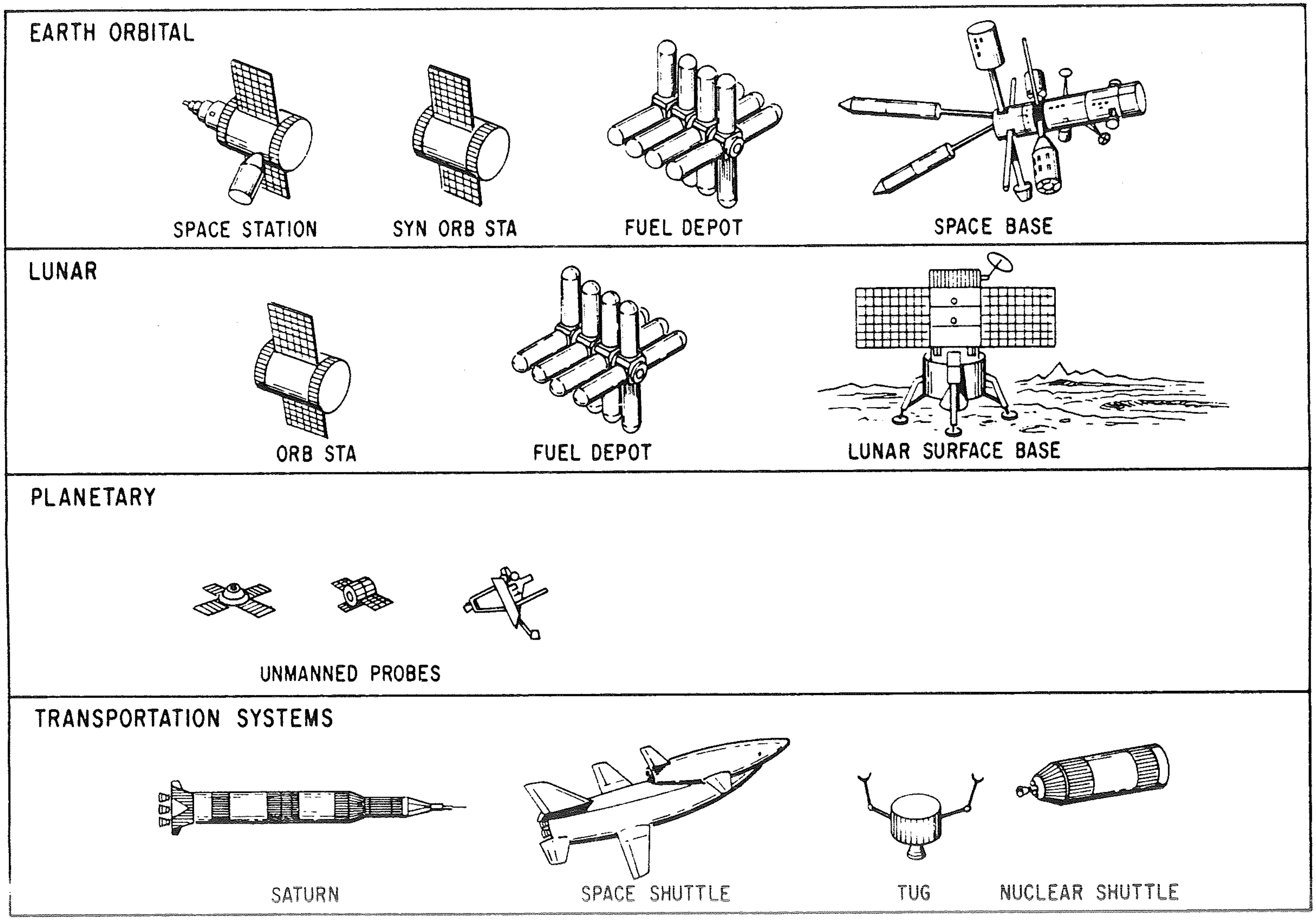

Figure 1. Integrated Program

Table 1. Emergency Situations

- Ill or Injured Crew (physical, chemical, disease, mental)
- Metabolic Deprivation
- Stranded or Entrapped Crew
  - during EVA
  - in vehicle
- Inability to Communicate
- Out-of-Control Spacecraft
  - tumbling in safe orbit
  - in decaying orbit
  - on unsafe trajectory
- Debris in Vicinity
- Radiation in Vicinity
- Non-Habitable Spacecraft Environment
  - lack of environmental control (pressure, temperature, humidity extremes)
  - contamination (experiments, animals, insects, bacteria)
  - Radiation (internal source)
- Abandonment (crew in EVA after bail-out)
- Inability to Reenter Earth's Atmosphere

5.3 CONTINGENCY PLANNING

There is, as yet, no separately documented, overall safety plan for the manned phases of the Integrated Program. However, extensive examination of available NASA and contractor documents revealed numerous guidelines and references to crew and passenger safety. When these individual items were assembled, an incomplete "de facto" plan emerged.

Three categories of safety planning are treated in this plan:

(1) Operational - based on mission provisions and hardware capability

(2) Preventive - based on hardware detail design philosophy

(3) Remedial - based on maximizing effectiveness of reaction to an emergency

The intent is to be able to deal with any contingency. An escape and rescue capability is proposed for both earth orbit and lunar missions. It should be noted, however, that:

a. There is little indication of coordinated safety planning between interfacing program elements.

b. Equipment capabilities and safety operations are assumed without considering their technical feasibility.

c. Availability when needed of specialized escape and rescue equipment is assumed.

d. There are no escape or rescue provisions specified as yet for the Earth Orbit Shuttle, the Manned Tug, or the Space Shuttle.

5.4 OPERATIONAL CONSIDERATIONS

There are numerous operational issues which have an impact on the escape and rescue problem. Four of these issues were examined in this study, and are summarized in the following paragraphs.

5.4.1 Ground-based Reaction Time

Ground based rescue will utilize the Earth Orbit Shuttle and will therefore be limited by its operational characteristics. To prevent additional fatalities after the initial event, a reaction time of about 1 day appears acceptable.

Coincidentally, the current EOS specification calls for a 24-hour reaction capability.

It was concluded, however, that the EOS specification of a 24-hour reaction is unrealistic because:

(a) Ground delays can approach 150 hours

(b) Ascent and rendezvous with a "subsynchronous*" target can require up to about 26 hours

(c) Ascent and rendezvous with a random target can take up to 38 hours

It was further concluded that a dedicated pad and a dedicated vehicle may be required for emergency use only.

5.4.2 Emergency ΔV Requirements

Some ΔV usually remains unused and available for emergencies occurring aboard in-transit vehicles. This remaining ΔV is generally sufficient for midcourse abort from in-transit trajectories to both geosynchronous and lunar orbits.

5.4.3 Communications

Continuous communication (voice preferred) is desirable between the rescue control center, the distressed vehicle, and the rescue vehicle. Facilities to skin-track a mute spacecraft are also desirable. Subsynchronous orbits which give repeating ground tracks simplify both of these objectives.

With respect to this requirement, it should be noted that:

(a) The present manned spaceflight network does not provide continuous coverage.

(b) Projected Integrated Program communication facilities (data relay satellites) should eliminate the existing blackout periods.

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*A combination of orbit altitude and inclination which is synchronized with the earth's rotation to assure at least one in-plane, in-phase launch opportunity per day. The resulting ground track is thus repeated every day.

(c) There is no evidence that the projected facilities will include skin-tracking capability.

5.4.4 Recovery Site Location

In spite of its large crossrange, emergency Orbiter reentry may require a significant on-orbit loiter period, if the landing sites are restricted to the continental United States (CONUS).

For an Orbiter launched from the Eastern Test Range (ETR) and in a 270 n mi, 55° inclination orbit, analysis indicates that:

(a) No single CONUS landing site offers a shorter reentry delay than ETR.

(b) For a single CONUS landing site, an 1100 n mi crossrange Orbiter can encounter up to an 8-orbit reentry delay (~13 hr).

(c) Multiple CONUS sites (for example, ETR and Edwards AFB) only reduce this maximum delay to 7 orbits.

(d) A mid-Pacific landing site is required to significantly reduce this maximum delay.

5.5 RESCUE VEHICLE REQUIREMENTS

The operational capability and rescue equipment requirements for a Space Rescue Vehicle (SRV) are extensive. Because of the present lack of information on the expected frequency of occurrence, it was necessary to assume that all emergencies will occur with equal probability.

Consideration was given to the following factors in determining rescue vehicle requirements:

(a) Hazards to the SRV (such as debris or radiation) caused by the distressed vehicle

(b) Problems of personnel and equipment transfer to and from the distressed vehicle under docked and undocked conditions; specialized equipment needs include:

- a transfer capsule
- a portable airlock

- an attachable docking fixture
- a soft-docking fixture
- an anti-tumbling device

(c) Means for establishing communication with a mute spacecraft after rendezvous

(d) Procedures for gaining emergency access to the interior of a disabled vehicle

(e) Equipment for assessing and controlling damage to the disabled vehicle

(f) Medical aid for the rescued crew

(g) Portable equipment and supplies to provide extended survival on an emergency basis for the crew of the disabled vehicle

(h) ΔV needs of the SRV for rendezvous and an external inspection of the disabled vehicle

The SRV equipment requirements are summarized in Table 2. This list represents the needs of a manned SRV and may be reduced if the SRV is unmanned. Additional reductions may be feasible by selecting, prior to displatching the SRV, only those items needed for the specific emergency.

The following considerations are important in SRV planning:

1. The equipment items and individual kits should be separately packaged for easy handling.
2. Since long rescue crew work periods are likely, rescue equipment design should emphasize ease of use as well as low weight, volume, and cost.
3. The interface requirements between a distressed vehicle and a Space Rescue Vehicle must be considered early in the design of all planned Integrated Program hardware.

5.6 REMEDIAL SYSTEMS

Three categories of equipment for use in escape and rescue were examined: (1) planned Integrated Program hardware, (2) modified program hardware, and (3) other applicable solutions. These are discussed in the following paragraphs.

Table 2. Space Rescue Vehicle Requirements*

	Unit Weight, lb
Communications and Survey Equipment	700
Despin Devices	250
Soft Docking Fixture	250
Attachable Docking Fixture	800
Portable Airlock	1,600
EVA Suits	70
AMU Backpack	150
Manipulator (Shirtsleeve)	2,000
Transfer Capsule	500
Sampling and Analysis Kit	50
Damage Control Equipment	150
Remote Manipulator	1,000
Medical Kit	60
Extended Survival Kit	500
Tethers (Umbilicals)	45
Personnel Carriers	10
Miscellaneous and Spares	200

*The development of some of these items is anticipated for other than Space Rescue Vehicle requirements.

5.6.1 Planned Program Hardware

Direct use for rescue operations of the several transportation systems planned for development appears feasible. However, it should not be assumed that the current payload and operational capabilities of these systems meet escape and rescue needs and objectives.

Table 3 summarizes the arenas where the various Integrated Program hardware elements have potential rescue mission application. In some cases, independent use of the individual elements is sufficient. In other cases, a combination of elements is required.

1. Earth Orbit Shuttle - As a remedial system, the EOS has limited application to low earth orbit emergencies because:

   (a) It has limited on-orbit ΔV capability (300-400 fps).

   (b) EVA capability at present is uncertain.

   (c) It is unable to dock directly.

   Although not normally equipped for a rescue mission, the Orbiter can carry rescue equipment as cargo and is capable of returning a rescued crew to earth.

2. Space Shuttle - The Space Shuttle represents the only means of transportation between low earth orbit and geosynchronous or lunar orbits. It will have a large payload capability, and could deliver and return an SRV. Specific evaluation awaits a more detailed Space Shuttle design definition.

   It should be noted that either chemical or nuclear propulsion is acceptable for this vehicle.

3. Space Tug - The Space Tug, as currently conceived, is especially useful for both earth orbit and lunar emergencies. The manned version of the space tug is particularly versatile. Its features include:

   (a) Potentially large ΔV (depending upon the size of the propulsion module)

   (b) EVA capability (hatch, airlock)

   (c) Docking port

   (d) Remotely controlled manipulator arms

Table 3. 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

(e) Space basing for rapid response

(f) Delivery upon demand by the EOS and the Space Shuttle

Current plans do not include a manned tug in the early phases of the Integrated Program. Also, the tug, whether manned or unmanned, would normally not carry special rescue equipment.

5.6.2 Modified Program Hardware

Modifications to the current design for the Tug Crew Module (TCM) and the EOS Crew/Cargo Module (CCM) will produce useful escape and rescue devices. The changes appear feasible, involve only interior modifications, and are estimated to add only a small increment to their original development cost.

1. Tug Crew Module - The Tug Crew Module can be used as an onboard, self-help bail-out device for earth orbit and lunar mission spacecraft. Two versions appear feasible:

   (a) Bail-Out-and-Wait for rescue

   (b) Bail-Out-and-Return to a space haven (includes a propulsion module)

   The required modifications to a standard TCM include:

   (a) Stripping down to eliminate extraneous equipment and reduce stored weight

   (b) Adding short-term life support and facilities for up to 15 men

   Note that such bail-out devices are to be stored aboard mission vehicles for use only in case of emergency. Also, these devices must operate in concert with, and thus enhance the utility of, the rescue vehicles.

   It should be re-emphasized that current plans do not include a Tug Crew Module in the early phases of the Integrated Program.

2. EOS Crew/Cargo Module - The crew/cargo module (CCM) can be converted into a Space Rescue Vehicle for both earth orbit and lunar mission applications. Delivery via the EOS, Space Tug, or Space Shuttle is required. Two versions of the CCM appear feasible:

   (a) Unmanned SRV - depends on self-help by the crew of the disabled vehicle

(b) Manned SRV - the equivalent of a space emergency vehicle / ambulance with special equipment designed for the rescue mission and a specially trained rescue crew.

Required modifications to a standard CCM include:

(a) Refit for the rescue mission (stretchers, medical facilities, etc.)

(b) Add attitude control for independent docking

(c) Add propulsion module for limited space maneuvering (optional)

(d) Provide for extensive EVA

The modified CCM can be based in space. However, basing on earth allows selection of equipment and services according to the needs of the emergency. In either case, intact return to earth of the CCM via the Orbiter is possible.

5.6.3 Other Useful Concepts

Remedial solutions based only on Integrated Program hardware do not meet all requirements. Two additional schemes should therefore be considered: Emergency Life Support and Bail-Out-and-Reenter capsules.

1. Emergency Life Support - A primary source of potential crew or passenger fatality is the unexpected loss of life support. A simple onboard solution to this problem is a selected assortment of life support subsystems in a packaged container. Features include:

   (a) Prepackaging for long-term, unattended storage

   (b) Use only in case of emergency

   It should be noted that this solution represents only an interim step to extend survival until an ultimate solution can be provided.

2. Bail-Out and Reenter Device - A Bail-Out and Reenter (BOR) device provides an independent, onboard means for escape from a distressed vehicle in earth-orbit. It is especially applicable to escape from the Orbiter or the manned tug when the crew is capable of self-help. Design features include:

   (a) Lightweight structure (rigid or expandable)

   (b) Reentry capability

   (c) Capacity of 2 - 3 men (14 -15 for later missions)

   (d) Long-term, unattended storage

This approach represents the most immediate remedy for a functioning crew, and has been the subject of numerous contractor studies.

It should be emphasized that neither the Orbiter nor the Tug have provision, as yet, for crew escape.

6. STUDY LIMITATIONS

The results of this study are based on the current status of mission definition and hardware design concepts. Additional insight on space rescue operations should be possible:

(a) After assessment of the probabilities of occurrence of the identified emergencies

(b) After further mission and hardware definitions

7. IMPLICATIONS

Extensive use of EOS and Tug hardware appears feasible and effective for space rescue operations. Some additional equipment not now included in the Integrated Program is also needed. It is concluded that from a safety operations viewpoint:

(a) Manned tugs are needed sooner than planned.

(b) A Space Rescue Vehicle is needed early in the program. (A design based on EOS crew/cargo module is recommended for consideration.)

(c) The Orbiter should have the capability for returning the SRV to earth.

(d) Means for escape or rescue of both the Orbiter and the Manned Tug crews should be provided.

(e) Integrated Program hardware should be designed for compatability with the selected escape and rescue equipment.

(f) Planning and design of escape and rescue equipment should be concurrent with basic Integrated Program hardware planning and design.

(g) A procurement decision for specific escape and rescue hardware will be required by 1975 - 1976, and appropriate planning and design definition studies must precede this decision.

8. SUGGESTED ADDITIONAL EFFORT

Many safety-oriented issues need attention. Near-term effort should realistically be directed toward the Earth Orbit Shuttle, the Tug, and the Space Station. It is suggested that activity be initiated in the following areas:

Analytic Studies

(a) Probability assessment of the occurrence of identified emergencies

(b) Performance and operations concepts for increasing the rescue and escape utility of the Earth Orbit Shuttle and the Tug (off-loading, staging, orbital refueling, etc.)

New-Design Studies

(a) A Bail-Out and Reenter device for the Orbiter crew

(b) A Bail-Out and Wait device for the Tug crew (also has Orbiter and Space Station application)

(c) Design concepts for specialized emergency equipment:

- Portable air lock
- Portable docking fixture
- Manned transfer capsule
- EVA aids
- Kits (medical, tool, etc.)
- Anti-tumbling device

Expansion of Studies on Integrated Program Hardware

(a) Operations and equipment for dealing with the EOS as a distressed vehicle requiring crew and passenger escape or rescue

(b) Operations and equipment for dealing with the manned Tug as a distressed vehicle

(c) Procedures for using the EOS as part of a Rescue System (includes identification of design preferences based on Rescue System use)

(d) Methods for adapting planned hardware components to rescue missions:

(1) Tug Crew Module as a Bail-Out-and-Wait device

(2) Orbiter Crew/Cargo Module as a Space Rescue Vehicle