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# SAFETY IN RECOVERY OPERATIONS

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SAFETY IN RECOVERY OPERATIONS

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## Abstract

Concepts applicable to past, present, and possible future manned-space-flight programs to provide an optimum balance between personnel safety and efficiency in recovery operations are discussed in this paper. The use of a new spacecraft design necessitates the conducting of operational testing in various likely postlanding environments to validate the performance of the spacecraft and establish the reliability of its postlanding systems. Some of the major elements of this testing related to the safety of flightcrews and recovery personnel are discussed. The paper also includes a discussion of the flightcrew safety aspects of the recovery support planned for Apollo missions. Safety considerations in the development of procedures and in the recovery-support equipment to be used for retrieval of Apollo flightcrews and spacecraft are also presented. In addition, the training conducted to familiarize flightcrews and recovery personnel with the retrieval procedures and equipment under simulated and actual operational conditions is described.

## Introduction

The operational activities which constitute the recovery function in a manned-space-flight mission consist of locating the spacecraft, providing on-scene assistance to the flightcrew, and retrieving the spacecraft and crew. Prior to the execution of the mission, the areas of recovery activity consist primarily of the development and testing of recovery and postlanding-associated systems and of the formulation of plans and procedures required during the recovery period.

From the very beginning of manned space flight, two basic philosophies have been followed in preparing for recovery. The first, in the area of postlanding-systems development and testing, is that all systems and procedures shall be validated in an operational test environment prior to flight whenever possible. These systems include both those inherent in the spacecraft and those utilized by recovery support forces. The second basic philosophy, pertaining to recovery operations, is that a positive course of action shall be preplanned for all possible landing situations, with the level of recovery support deployed into a given recovery area commensurate with the probability of a spacecraft landing in that particular area. As a result, recovery forces are in position and are prepared to support many different landing situations during a mission. Together, these two philosophies provide the foundation on which the factor of safety for the spacecraft crew and the recovery personnel depends. The purpose of this paper is to describe this emphasis on safety as it applies to all aspects of the recovery phase.

## Spacecraft Operational Testing

In conducting operational and environmental tests of spacecraft recovery and postlanding-associated systems, considerable knowledge and experience has been gained from past programs. This knowledge and experience will contribute to the safe and reliable function of like systems employed in present and future spacecraft. In keeping with the basic philosophy expressed previously, extensive operational testing is carried out under controlled test conditions. In some cases, this testing requires the use of special facilities; in other cases, particular emphasis is placed on testing under conditions very closely representing those which will be encountered in actual mission landing and recovery situations. The basic types of operational tests conducted on the spacecraft are as follows:

1. Water stability (static and dynamic)
2. Structural integrity in the postlanding environment
3. Postlanding environmental-control-system operation
4. Postlanding electrical-power-system operation
5. Spacecraft electronic communications and location-aid operation
6. Spacecraft postlanding habitability
7. Operation of miscellaneous postlanding equipment, visual location aids, et cetera

Since the spacecraft being readied for Apollo flights are designed for water landings, the greater part of the postlanding testing must be conducted in a water environment. Preliminary information is gained from tests conducted in a test-tank facility (Fig. 1). This specially built tank permits testing with simultaneous control of the following simulated environmental conditions:

1. Air temperature
2. Humidity
3. Water temperature
4. Surface wind
5. Solar-heat loading
6. Wave-induced spacecraft motion (by mechanical linkage)
7. Spacecraft cabin reentry-heat pulse

Follow-on tests are conducted in the Gulf of Mexico (Fig. 2) utilizing specially designed and built spacecraft with systems that are actual flight hardware or very closely simulate this hardware. Here again, the tests are conducted under environmental conditions that closely approximate those expected in recovery areas. However, in those situations where specific sea and wind conditions can have considerable effect on test results, it becomes desirable to conduct tests in broad ocean areas. Consequently, testing is also conducted in the Atlantic and Pacific Oceans.

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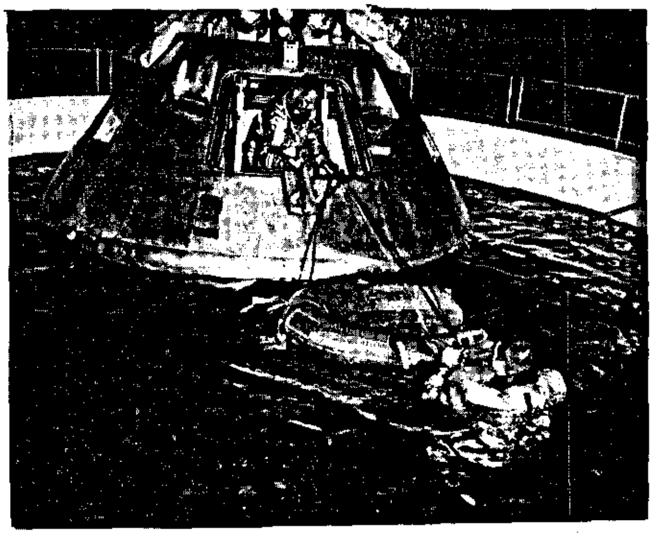

FIGURE 1. SPACECRAFT TESTING IN CONTROLLED ENVIRONMENT

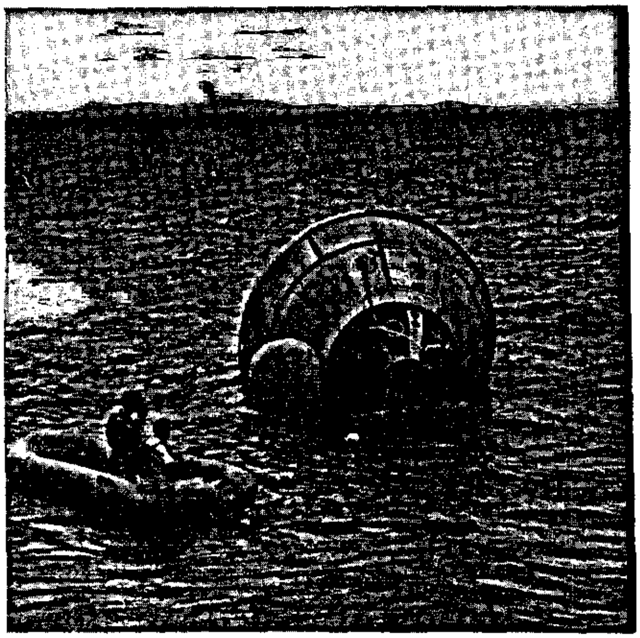

FIGURE 2. SPACECRAFT TESTING IN THE GULF OF MEXICO

Solutions to a number of the problems encountered during the Gemini Program, which were directly associated with crew safety, were obtained through operational testing. One problem in particular was the potential danger that the spacecraft would flood and sink during egress of the flightcrew because of its flotation attitude and the low freeboard at the hatch hinge line, especially under dynamic conditions. The solution to this problem included the addition of a sea curtain that extended across the low-freeboard part of the hatch opening and the addition of buoyant material in the spacecraft to improve its flotation attitude. Associated with this water-stability problem was the development and definition of safe crew-egress procedures for various sea conditions.

Another potential problem in the Gemini Program was that possible postlanding problems might result from the electrical- and electronic-systems packages being located outside the Gemini spacecraft pressure vessel. Because systems and the attendant cabling would be in flooded compartments after a water landing, it was recognized that failures caused by electrical shorting, as well as by the corrosive qualities of salt water, could adversely affect the safety of the flightcrew and the safety of those involved in the recovery operation. Therefore, an extensive operational evaluation was conducted to provide data that could be used to assure safe operational conditions and reliable performance of such systems. Modifications to the spacecraft snorkel system and to the high-frequency antenna were also made as a result of deficiencies that were revealed during the at-sea tests. Subsequent to the correction of these deficiencies, manned at-sea tests were conducted with the complete monitoring of spacecraft systems and with the recording of biomedical data.

At the present time, engineers are engaged in a continuing program of testing the Apollo spacecraft systems in a manner similar to that in which the Gemini spacecraft was tested. A problem directly related to crew safety that was encountered during the spacecraft water-stability testing involved the two possible flotation attitudes of the spacecraft (apex-up or apex-down). If the spacecraft assumed the apex-down position (Fig. 3) during or after landing, perhaps because of rough seas, the postlanding ventilation system would become inoperative and the communications capability would be almost totally eliminated because part of the antennas would be under water. This attitude of the spacecraft would also leave the crewmembers suspended in their harnesses in uncomfortable and undesirable positions. As a result of these tests, an uprighting system consisting of three large bags and an inflation system, packaged in the spacecraft recovery compartment, was developed (Fig. 4). Inflation of the bags after landing would right the spacecraft if it should be in the apex-down attitude and would also assure that the spacecraft remained upright if it should be in the apex-up attitude. Extensive testing of the system, both in the test-tank facility and in the open sea, has been conducted to validate its performance.

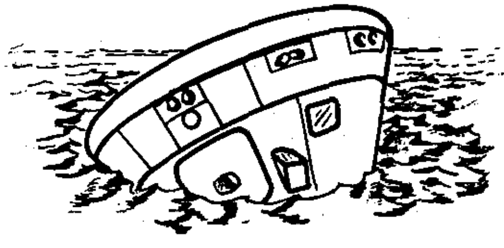

FIGURE 3. APEX-DOWN FLOTATION ATTITUDE

The first of the Apollo manned at-sea tests was conducted during a 48-hour period in which the spacecraft drifted on rough seas while various system-performance checks were made. Included were checks of the uprighting sequence, voice-communications systems, postlanding-ventilation system, erection of the high-frequency (hf) antenna,

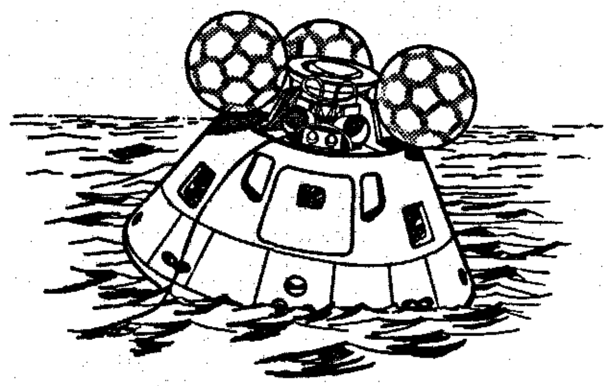

FIGURE 4. APEX-UP ATTITUDE AFTER INFLATION OF UPRIGHTING BAGS

and general habitability of the spacecraft. Included for evaluation during other separate test periods were the range capabilities of recovery-location beacons and antennas, the visibility and endurance of the sea dye emitted from the spacecraft under several sea-state conditions, and the visibility of the flashing light at different ranges as the flash rate versus intensity was varied.

Procedures for egress from the Apollo spacecraft were also defined during operational evaluations conducted in the Gulf of Mexico; however, because of the recent side-hatch design changes, new procedures will be developed and practiced by designated flightcrews.

Not to be overlooked in any discussion of the safety aspects of operational testing are the safety practices followed by the test personnel themselves during all of the discussed tests. These practices include a method of documentary control and approval that clearly defines the responsibilities of each individual involved in the test and provides for reviews by an organized safety review board. In addition to the chairman, the board includes representatives of all organizations associated with the test. This board functions in much the same way as does the Air Force Flight Safety Review Board prior to committing a vehicle to flight.

## Recovery Support Equipment and Retrieval Procedures

The majority of the special recovery-support equipment furnished for Project Apollo is very similar to or, in some cases, the same as that which was utilized during the Gemini Program, with only a few exceptions. Because of the successful operation and dependability of this equipment in the Gemini Program, a high confidence level, considering safety, has been established for its use in Project Apollo. The major items consist of davit cranes installed aboard destroyers designated to provide recovery support, auxiliary flotation collars issued to recovery ships and aircraft, and special electronic location equipment installed in recovery aircraft. Some additional items of equipment developed to provide the safest possible recovery operation include special line-handling devices, "man-rated" recovery hooks and lines, shipboard spacecraft cradles and dollies, and training hardware.

Early in the manned-space-flight program it was recognized that a destroyer-type ship provided the best overall recovery support for those landing areas, exclusive of the primary landing area, where the highest level of support is desired. Because of their high speed, destroyers are capable of covering comparatively large areas; their communication and radar capabilities enable them to work well with search aircraft; and, they are more apt to be available to support space-flight programs than other types of ships which could be used for this purpose. With a davit crane installed, a destroyer is capable of retrieving spacecraft with a relatively high degree of safety. The fully power-operated crane (Fig. 5) incorporates both lifting and rotation capabilities and is mounted on the side of the fantail. The design also incorporates a power-operated hold-off arm which protectively encircles the spacecraft so that pendulous motions of the spacecraft caused by rough seas are reduced while the spacecraft is being lifted onto the deck. Destroyers have been modified with quickly detachable deck sockets in sufficient numbers to allow the Navy flexibility in scheduling in both the Pacific and Atlantic fleets. The davit crane was subjected to thorough operational testing prior to and during the Gemini Program. Techniques and procedures were developed which permitted a safe operation, regardless of the difficulties normally encountered in retrieving objects from the ocean. Modifications to the equipment and procedures have been incorporated for the retrieval of Apollo spacecraft, along with refined operating procedures and proper training of shipboard personnel. Considerable experience has already been gained in this area during two deployments for unmanned Apollo missions during which training and practice were conducted. Also, special training exercises have been conducted recently on destroyers to gain additional overall experience in retrieval operations.

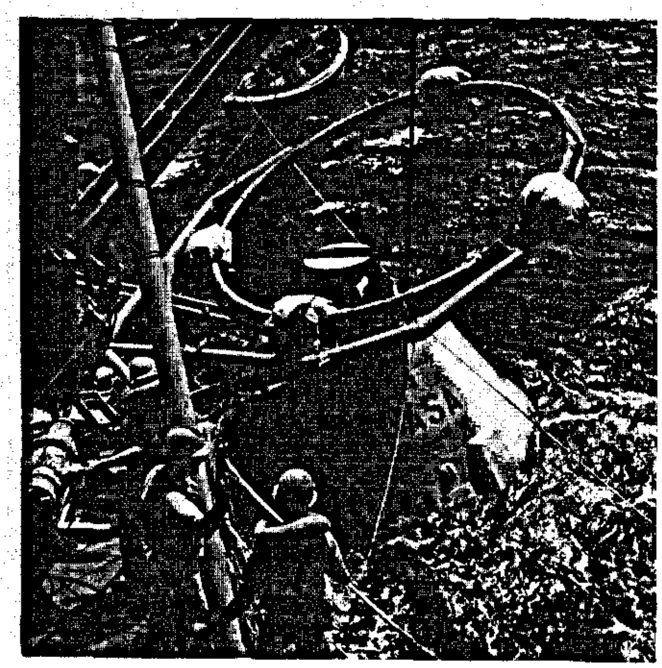

FIGURE 5. SPACECRAFT RETRIEVAL USING DESTROYER EQUIPPED WITH DAVIT CRANE

Another item of special recovery-support equipment which greatly enhances the safety of a recovery operation is the auxiliary flotation collar (Fig. 6) which is attached to the spacecraft as soon after landing as feasible. Those who have watched the Gemini recoveries on television have observed helicopter-deployed swimmers attaching the flotation collar. If a landing occurs in a secondary or contingency area, pararescue personnel, prepared to install the flotation collar, are deployed from fixed-wing aircraft. This maneuver was performed following the Gemini VIII landing in the Western Pacific. Basically, the flotation device provides the following:

1. Support to the spacecraft to prevent its loss from sinking if leaks resulting from structural damage should be present
2. A relatively stable work platform so that recovery personnel can assist the flightcrew, if required, while they are awaiting retrieval

The collar is designed to fit the form of the spacecraft when the collar is inflated; thus, little or no relative motion exists between the spacecraft and the collar. This formfit provides a damping of spacecraft wave-induced dynamic motions without creating difficult load-point or fatigue problems. For added safety, the design incorporates a redundant tube installed within the external tube and a second inflation system. Flotation collars have been used on several Mercury missions, every Gemini mission, and on the unmanned Apollo missions in which spacecraft recovery was required. Throughout this entire period, including use during much of the spacecraft-system testing, the collar has proved to be a reliable and a most useful piece of equipment.

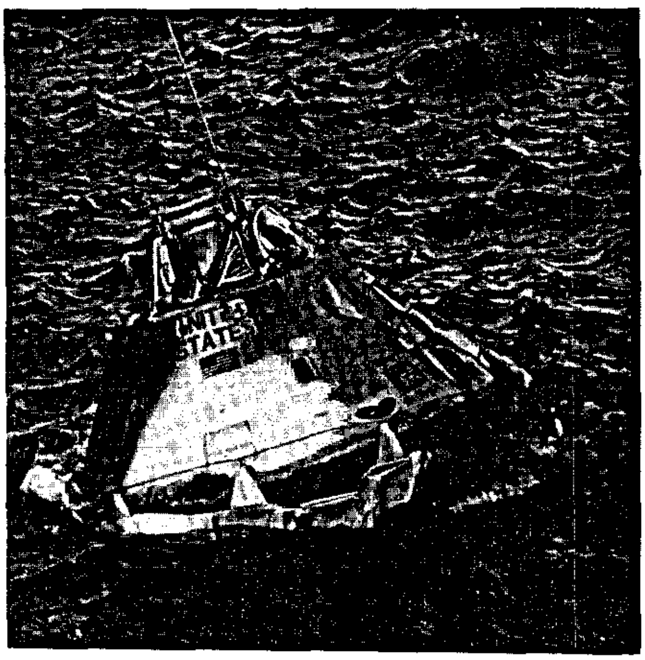


FIGURE 6. FLOTATION COLLAR BEING INSTALLED ON SPACECRAFT

Specially developed and utilized locating equipment installed in recovery aircraft — both fixed-wing and helicopters — has been invaluable in the rapid, efficient, and safe recovery of spacecraft and crews following every mission. The HC-130 recovery-support aircraft, now provided by the Department of Defense (DOD), are all equipped with spacecraft-locating equipment (AN/ARD-17 Direction-Finder Set) funded and developed under a joint NASA-DOD program. This locating equipment, installed as shown in Fig. 7, is compatible with frequencies of the Apollo spacecraft unified S-Band transmitter, the very-high-frequency (vhf) voice transmitter, the vhf recovery beacon, and the vhf survival radio. Also, the equipping of helicopters in the primary landing area with Search and Rescue and Homing (SARAH) beacon systems has significantly decreased locating time by enabling the helicopters to obtain a bearing on the spacecraft and "home" on its recovery beacon. Previously, the helicopters were directed to the spacecraft by fixed-wing aircraft.

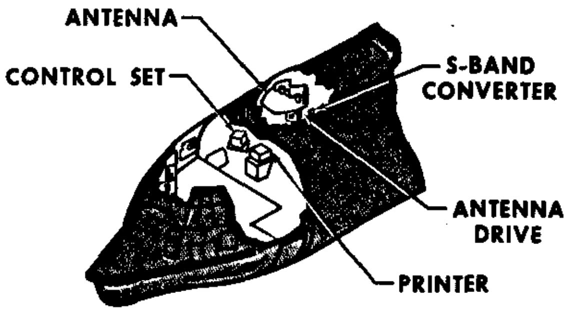


FIGURE 7. DIRECTION-FINDER SET INSTALLATION IN HC-130 AIRCRAFT

Another area of activity directly associated with recovery-personnel safety has been the development of rather sophisticated equipment and procedures which are used by a "safing team" to deactivate the spacecraft after its retrieval. Prior to the actual spacecraft deactivation, several hours are required to prepare the deactivation equipment and to inspect the spacecraft externally. The inspection consists of an evaluation of all pyrotechnics and of the reaction control system thrusters. Any of the pyrotechnic devices which did not operate during the landing sequence are safed, and the thrusters of the reaction control system are checked for leaking propellants. Since the propellants carried on board the Apollo spacecraft are extremely toxic, any leaking propellant from a thruster would present a hazard. Therefore, a problem such as this is carefully evaluated prior to the connection of the support equipment to the spacecraft.

During deactivation of the reaction control system, all unused propellants are expelled from the propellant tanks of the spacecraft, and system plumbing checks and component leak checks are made to determine the extent of system degradation. Following these steps, the reaction control system is purged initially with dry nitrogen to remove as much of the raw propellant as possible. Immediately following the nitrogen purge, the oxidizer system is flushed with a fluid known as Freon-TF, and the fuel system is flushed with isopropyl alcohol. Once the flushing process has been completed, a nitrogen purge is used to remove the flush fluids from the systems. A vacuum is then drawn on the system to dry it further. Following the flush and purge operations, gas samples are taken to determine if the spacecraft propellants have been removed to a level that would allow the spacecraft to be transported safely to the location where postflight evaluation would be carried out.

To utilize all of the recovery-support equipment in the prescribed manner, documented procedures developed under systematic test programs are followed. Where practical, the equipment is tested under laboratory conditions to determine preliminary procedures. This is followed by further refinement of procedures and equipment by simulated operational situations. Following a mission, personnel involved in the recovery operations are debriefed, and a thorough analysis is made of all available data associated with the operations and hardware. Then, equipment and procedures are changed, or further test work is carried out if necessary.

## Planning Apollo Recovery Support

As stated in the Introduction, the factor of safety is inherent in the basic philosophy governing recovery planning. To develop a plan for every conceivable landing situation, a detailed analysis of the mission plan is required, as well as a thorough understanding of the effects that various flight events might have on recovery activities.

The detailed recovery planning for a specific mission is evolved in working sessions with the mission planners as the mission plan is defined. Well-defined coordination channels with mission planners and flight controllers are in existence and are exercised repeatedly so that all elements of a mission plan are reviewed thoroughly to determine the recovery support needed to assure the safe retrieval and return of the flightcrew and spacecraft under both probable and contingency landing situations. After recovery-support requirements have been documented, they are submitted to the DOD for review. Subsequently, operation plans and operation orders are issued by the DOD for the direction of the recovery forces which are designated to support the mission.

Among the most important requisites to be considered in analyzing a mission plan to establish requirements for the deployment of recovery forces are the following:

1. Launch-vehicle and spacecraft malfunction modes, including their probability and time of occurrence
2. The desirability of daylight landings and the amount of daylight time available to conduct search and recovery operations
3. Spacecraft on-water endurance, including the electrical power available during the postlanding phase of the mission
4. Probable weather conditions
5. Availability of desired staging areas for ships and aircraft
6. Availability of communications

As suggested by the preceding list, in planning for recovery support, account must be taken not only of the recovery forces needed for a nominal flight, but also of those needed for various abort situations. Before proceeding with the discussion of these considerations, however, it may be of value first to define the major recovery operational tasks.

### Recovery Tasks

The recovery tasks can be divided into three general categories — the locating of spacecraft, on-scene assistance, and retrieval. Spacecraft locating may be performed by one, or by a combination of, the following methods:

1. Prior to the spacecraft landing, or after it has landed, the Manned Space Flight Network, using tracking information, computes a landing point or a general landing area.
2. Also available during reentry and after landing are spacecraft computer readouts giving approximate landing coordinates which can be transmitted to recovery forces.
3. During past missions, and also planned for the next several Apollo missions, hf signals transmitted by a spacecraft beacon and received by alerted, ground-based, worldwide direction-finding stations can be used to determine the spacecraft position in the event of a landing in a remote area.
4. The spacecraft is equipped with the previously mentioned vhf electronic-recovery beacon as well as crew-survival radios which operate on the international distress frequency of 243.0 megahertz.

All landing areas are supported by aircraft having the special receiving equipment which is compatible with the spacecraft recovery beacon, and electronic homing by aircraft is considered to be the primary means of spacecraft locating. Consequently, considerable attention has been given to the providing of the necessary equipment and to the training required for this task. After electronic homing by aircraft has been accomplished, visual locating of the spacecraft in the daytime is assisted by the sea-dye marker which is emitted from the spacecraft after landing; at night, visual locating is assisted by the flashing light on the spacecraft.

Because of certain factors, such as the location of the tracking stations, the information available at these stations, worldwide deployment of aircraft at staging bases, and a knowledge of the location of the spacecraft ground track, it has been demonstrated that the primary means of spacecraft locating — electronic homing on the recovery beacon — can be performed well within the planned lifetime of the postlanding systems.

After the spacecraft has been located, the second task begins — that of providing on-scene assistance. This on-scene assistance is supplied by swimmers or pararescuemen deployed either by helicopter or by fixed-wing aircraft. Each group deployed is equipped with a flotation collar which can be rigged on the spacecraft, as previously described.

The final recovery task is the retrieval of the flightcrew and the return of the crew and spacecraft to a designated port. In the primary landing area, this task is accomplished by using the inherent capability of an aircraft carrier to lift the spacecraft from the water. The crew may remain in the spacecraft for transfer to the recovery ship, or they may elect to be transferred to the ship by helicopter prior to spacecraft retrieval. Other ships regularly used in the recovery forces, such as oilers and fleet tugs, are also inherently capable of retrieving the spacecraft. Destroyers, as discussed earlier, are fitted with NASA-supplied retrieval cranes.

The Project Mercury MA-4 mission, flown on September 13, 1961, was the first successful orbital mission for which worldwide tracking facilities and recovery support were provided. In this and all subsequent missions in which recovery support has been required, the time needed to locate and retrieve the flightcrew and/or spacecraft has been well within the allowed time. Pertinent recovery information is summarized in Table 1.

| MISSION | DESCRIPTION | DIST FROM LNDG PT TO PLANNED TARGET*, N MI | EVENT TIMES AFTER LANDING, MIN: FLOT. COLLAR ATTACHED | CREW ON SHIP | SC ON BOARD |
|---|---|---|---|---|---|
| **PROJECT MERCURY** | | | | | |
| MA-4 | UNMANNED, 1 REV | 30 | - | - | 82 |
| MA-5 | CHIMPANZEE ABOARD, 2 REV | 9 | - | 85 | 85 |
| MA-6 | MANNED, 3 REV | 39 | - | 20 | 20 |
| MA-7 | MANNED, 3 REV | 238 | 118 | 254 | 491 |
| MA-8 | MANNED, 6 REV | 4.7 | 10 | 43 | 43 |
| MA-9 | MANNED, 22 REV | .7 | 8 | 36 | 36 |
| **GEMINI PROGRAM** | | | | | |
| G-II | UNMAN, SUBORBITAL | 14 | 20 | - | 90 |
| G-III | MANNED, 3 REV | 60 | 30 | 72 | 167 |
| G-IV | MANNED, 4 DAYS | 44 | 20 | 57 | 136 |
| G-V | MANNED, 8 DAYS | 92 | 50 | 91 | 235 |
| G-VI-A | MANNED, 16 REV | 7 | 30 | 64 | 64 |
| G-VII | MANNED, 14 DAYS | 6.4 | 12 | 32 | 64 |
| G-VIII | MANNED, 7 REV | 1.1 | 49 | 186 | 195 |
| G-IX-A | MANNED, 3 DAYS | 0.4 | 3 | 52 | 52 |
| G-X | MANNED, 3 DAYS | 3.4 | 5 | 27 | 54 |
| G-XI | MANNED, 3 DAYS | 2.7 | 7 | 24 | 59 |
| G-XII | MANNED, 4 DAYS | 2.6 | 6 | 28 | 67 |
| **APOLLO PROGRAM** | | | | | |
| AS-201 | UNMANNED, SUBORBITAL | 40.6 | 43 | - | 151 |
| AS-202 | UNMANNED, SUBORBITAL | 205 | 173 | - | 508 |

*DISTANCES ARE BEST ESTIMATES BASED ON REPORTED RECOVERY SHIP LOCATIONS, NETWORK TRACKING DATA, AND TM RECORDS

TABLE 1 SUMMARY OF RECOVERY INFORMATION

## Landing Areas

In developing a recovery plan for an earth-orbital mission, provision is made for all possible landing situations by using five general categories of landing areas as follows: (1) launch site, (2) launch abort, (3) primary, (4) secondary, and (5) contingency.

The launch-site landing area is the vicinity of the launch site where landings could occur following an off-the-pad abort or an abort occurring immediately after launch. This area requires special recovery support because of the problems associated with the many types of coastal terrain on which the spacecraft could land (i.e., swamp, marsh, beach, surf, deep water, palmetto-covered areas, and built-up areas). Because of the possibility of injury to the flightcrew as a result of (1) a landing on the coastal terrain, (2) a higher than normal spacecraft descent rate, or (3) launch-vehicle or spacecraft fires and toxic fumes in the landing area, the recovery forces must be able to provide medical aid and other emergency assistance to the flightcrew. To do this, a number of vehicle types having unique capabilities are employed in the launch-site recovery area, but the helicopter is the principal means of retrieving the flightcrew in a launch-site abort situation.

The recovery forces are deployed to positions from which they have excellent visibility of aborts in the launch-site area. This observation is considered to be the primary method of spacecraft location; however, assistance in locating the spacecraft is available, if needed, in the form of impact-prediction information from a computer. Also, the spacecraft recovery beacon would be activated to provide an electronic location aid during spacecraft descent. In addition to helicopters, special amphibious vehicles and small boats are employed so that all possible landing and recovery situations can be supported. A plan view of the launch-site recovery area and a typical deployment of these special vehicles are shown in Fig. 8.

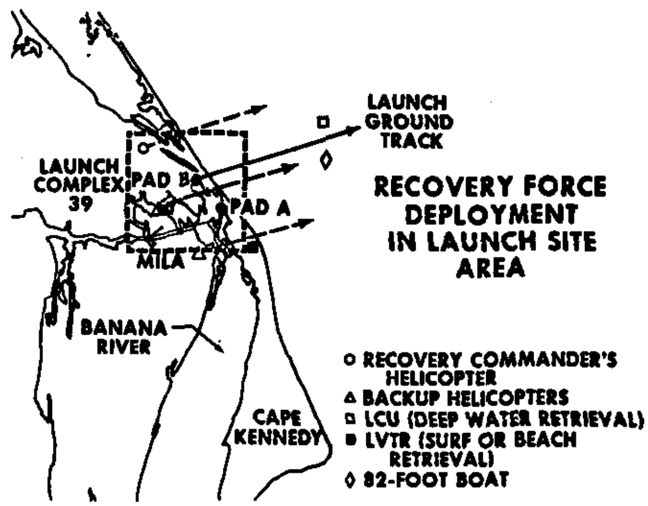


FIGURE 8. RECOVERY-FORCE DEPLOYMENT IN LAUNCH-SITE AREA

The launch-abort areas are those in which a landing could occur following an abort during the launch phase of flight. Recovery support for areas of this category has been very important during past programs and will continue to be so, especially during those missions which will employ newly developed launch vehicles. The recovery vehicles usually provided to support these areas consist of ships, such as destroyers and fleet oilers, and aircraft which are airborne during the launch phase. These aircraft provide location and on-scene assistance support and are capable of reaching the spacecraft within 4 hours after a spacecraft landing along the launch-abort ground track. The ships would provide a retrieval capability. In planning the positions of ships and aircraft to provide optimum recovery support in these areas, the operational capabilities of the launch-vehicle and spacecraft-propulsion systems to provide range control in different abort cases are taken into consideration. Typical support in this area is shown in Fig. 9.

The primary landing area is defined as that area in which the probability of a landing occurring is sufficiently high to warrant the requirement for primary recovery-ship support. Primary recovery-ship support is considered to be an aircraft-carrier-type ship with its higher level of available

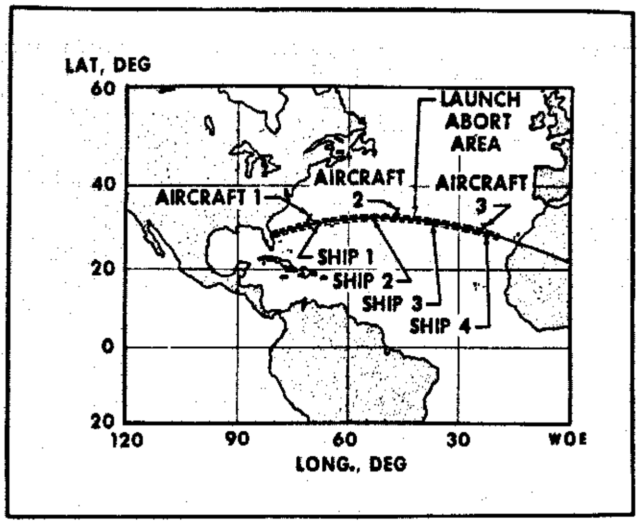


FIGURE 9. RECOVERY-FORCE DEPLOYMENT IN LAUNCH-ABORT AREA

support capabilities which include the following:

1. Aircraft for recovery operations — both fixed-wing and helicopters
2. Aircraft for NASA logistics requirements
3. Communications facilities
4. Medical facilities
5. Spacecraft postretrieval handling facilities

The selection of the primary landing area is also based on factors such as its proximity to the tracking network, statistical weather information, daylight-darkness considerations, and recovery force logistics.

The secondary landing area is defined as the area in which the probability of a landing occurring is sufficiently high to warrant the requirement for at least secondary recovery-ship support. Secondary recovery ships are those (usually destroyers and fleet oilers) which are deployed in direct support of recovery operations other than the primary recovery ship.

For low-inclination orbital missions, a four-zone concept for deployment of primary and secondary recovery-support forces was adapted. The four zones are located in the West Atlantic, East Atlantic, West Pacific, and Mid-Pacific Ocean areas. The West Atlantic Zone was selected as the one in which end-of-mission landings would normally occur; therefore, it contains the aircraft-carrier-supported primary landing area, and the secondary landing areas are located within or near the four zones.

By providing the carrier-borne helicopters with electronic locating equipment, as discussed earlier, it has been possible to completely support the end-of-mission landing area with the carrier and its air group. A fixed-wing aircraft, designated Air Boss, serves as an air controller and is utilized by the on-scene commander. Typical disposition of aircraft in the vicinity of the carrier is shown in Fig. 10. After search helicopters have located the spacecraft, swimmers are dropped to provide on-scene assistance, and one of the helicopters in the area may be used to return the spacecraft crew to the carrier. In addition, fixed-wing communications-relay aircraft relay all radio transmissions in the recovery area back to the ship and to various control centers. Following retrieval of the spacecraft, fixed-wing aircraft are utilized to expeditiously transport data removed from the spacecraft to designated locations.

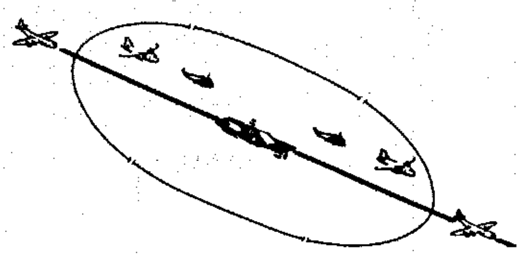

FIGURE 10. RECOVERY-FORCE DEPLOYMENT IN PRIMARY LANDING AREA

During a mission, periodic target points are selected at appropriate intervals (usually once per spacecraft revolution), and recovery ships are repositioned accordingly, within prescribed areas, in the event that the spacecraft must be landed prematurely. In most cases, areas which lie within or near one of the four recovery zones can be selected; thus, the primary and secondary recovery-ship support is made available. As is well known, the presence of a secondary recovery ship in the West Pacific became very beneficial when trouble developed during the Gemini VIII flight. After analysis of the situation, it was determined that the mission should be terminated before the primary landing area could be reached. Consequently, the spacecraft was brought down during its seventh revolution in the Western Pacific Zone. During the 8-day Gemini V mission, the value of this kind of planning was proved when, during the early orbits of the mission, trouble developed with the spacecraft electrical-power source. The very presence of these periodic target points with primary and secondary recovery forces on station allowed the flight to continue until the problem could be better evaluated. Eventually, the condition of the electrical-power source was stabilized, and the mission was subsequently carried out to its planned duration.

Contingency landing areas are all areas outside the previously described areas within which landing could possibly occur. For identification purposes, these areas fall within four sectors of the earth: Sector A, Atlantic Ocean; Sector B, Indian Ocean; Sector C, Western Pacific Ocean; and Sector D, Eastern Pacific Ocean. The probability of landing in these areas warrants the support of contingency land-based aircraft. The locations of these sectors and typical contingency aircraft staging bases are shown in Fig. 11. For an orbital mission, aircraft from these bases are capable of reaching any point on the spacecraft ground track within 18 hours of notification. If a contingency landing must be made, retrieval of the spacecraft and crew would be an after-the-fact situation in which merchant ships or recovery ships, redirected from the primary or secondary landing areas, would be utilized.

Recovery Control Centers and Communications

The control of recovery forces is exercised through an arrangement of Recovery Control Centers in communication with the recovery forces through a

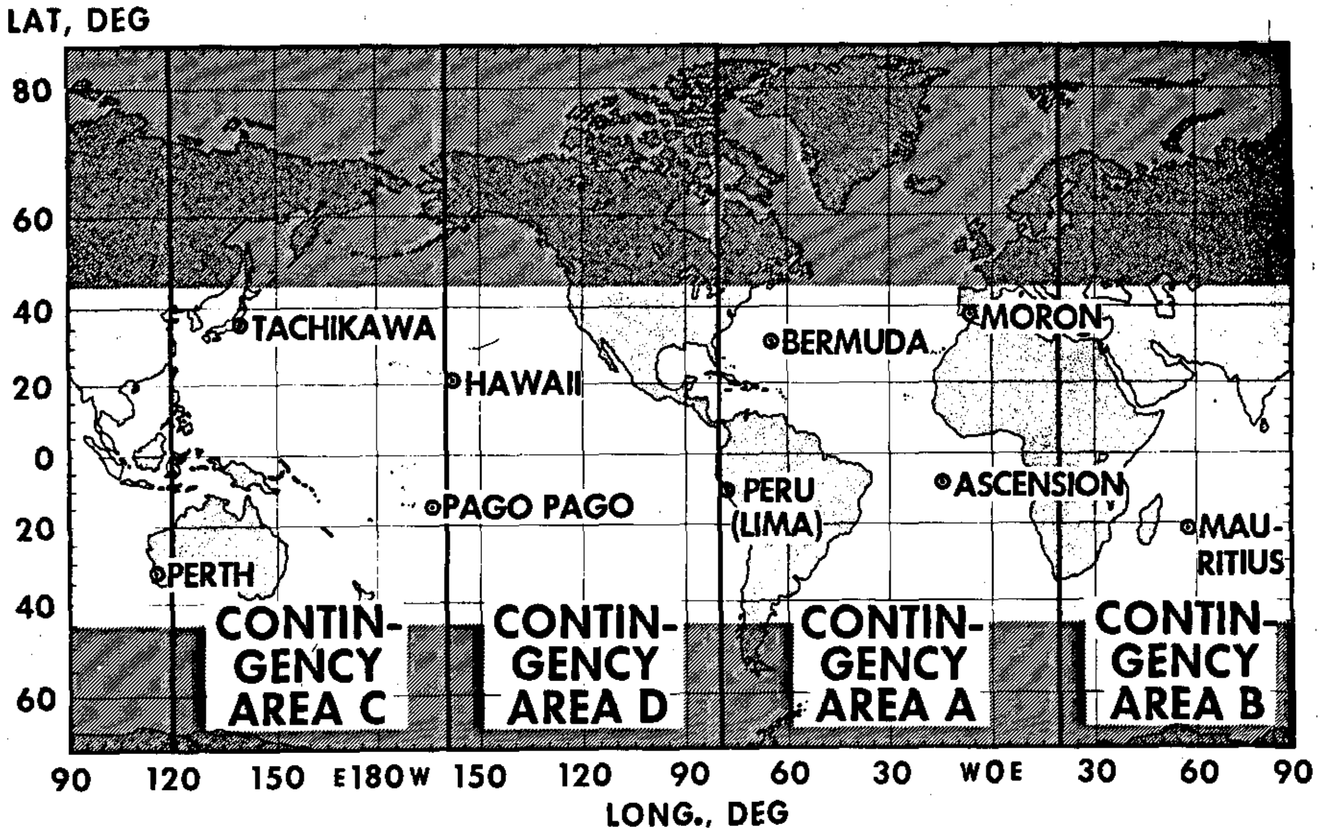


FIGURE 11. CONTINGENCY SECTORS AND AIRCRAFT STAGING BASES

worldwide network. The primary interface between recovery operations and other mission-operations activities occurs in the Mission Control Center at the Manned Spacecraft Center. The Mission Control Center also serves as the overall Recovery Control Center.

As shown in Fig. 12, all recovery forces in the Atlantic area are controlled through the Recovery Control Center at Cape Kennedy, while another center in Hawaii serves this function for the Pacific area. Contingency recovery forces in command areas other than the Atlantic and Pacific are controlled from Recovery Control Centers in Europe (for the Africa-Middle East area), in the Panama Canal Zone (for the South America area), and in Florida (for the North America area). These centers were established to take advantage of existing DOD organizations and arrangements.

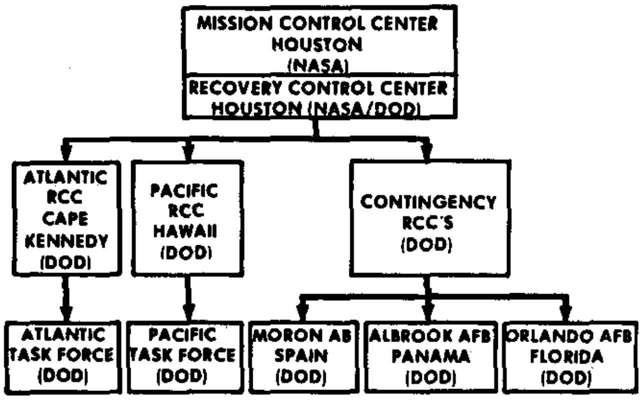


FIGURE 12. APOLLO RECOVERY COMMAND AND CONTROL

Also, during a mission, special communication links are activated through diplomatic channels so that arrangements may be made for any special recovery aircraft, overflight clearances, or requests for entry permission, if required by recovery personnel. Also established are communications procedures to alert merchant ships in case of contingency landing.

In addition to their use for command and control of recovery forces, worldwide communications are required for the monitoring of force status, for keeping forces informed of flight progress, and for adjusting the positions of recovery forces. The repositioning of recovery forces is necessary because of such conditions as changes in the launch azimuth, alteration of the spacecraft ground track caused by the precession of the earth, and changes in weather conditions within a zone.

It is worth mentioning that little change in the recovery-support posture is anticipated in converting from orbital missions to lunar missions. As in the orbital missions, the Atlantic recovery forces will be positioned for launch-abort situations and will then shift into the previously established Atlantic recovery zones after a successful launch. The end-of-mission area will be located in the Pacific Ocean because an extensive area is required for the large spacecraft terminal footprint and because better reentry tracking facilities are available. Added to the recovery support for lunar missions, however, will be prepositioned ships in several deep-space abort areas in which a landing could occur in the event of an abort prior to insertion of the spacecraft into a lunar orbit.

## Training for Safe Recovery Operations

A direct relationship exists between the conducting of a safe recovery operation and the amount, type, and quality of training practiced by recovery units. The DOD units involved in recovery operations are operational units that devote a relatively small part of their time to space-flight operations. For that reason, and because of the fact that DOD units and field personnel are usually reassigned from mission to mission, a considerable amount of training is required. The same recovery equipment previously described is handled and operated by assigned DOD recovery personnel under operational-like conditions. Prior to their deployment, swimmers and pararescuemen are trained in the procedures for flotation-collar installation. Where possible, these personnel are trained with the same units with which they will be working during mission deployment; that is, swimmers with helicopter squadrons and pararescuemen with the aircrews assigned to the mission. In these training sessions, the importance of teamwork is stressed. All ships assigned to support recovery operations are provided with boilerplate spacecraft to allow practice in retrieval procedures prior to missions and while en route to stations. Manuals describing retrieval operations are distributed to recovery forces. Briefings on spacecraft-handling procedures are conducted to prevent injury from spacecraft pyrotechnic devices and from the toxic propellant. Instructions are given to recovery personnel concerning the latest changes in spacecraft hardware or in any special equipment which may affect their tasks. Extensive spacecraft-familiarization courses and recovery-techniques training are also conducted for NASA recovery personnel, who are deployed to recovery forces as technical advisors.

Perhaps the most important training conducted is a series of worldwide nighttime and daytime simulations involving deployed recovery forces, Recovery Control Centers, and communications personnel. A typical primary-landing-area simulation requires that all forces be in position in the area, as called for on the day of recovery. A spacecraft equipped with location beacons is placed in the water in the vicinity of the carrier. A given landing situation is simulated by means of messages transmitted from the Recovery Control Center. This is followed by the locating, on-scene assistance, and retrieval simulations, as initiated by the responsible forces. Voice-relay aircraft are also exercised to pass information to the Recovery Control Center. Simulations such as these are also conducted in secondary landing areas. In these simulations, aircraft locate the recovery-beacon-equipped practice spacecraft and vector the recovery ship to the spacecraft for retrieval. These simulations afford an excellent opportunity for ships and aircraft to check communications procedures, as well as to reveal any coordination problems.

Other simulations exercise the communications that link the various Recovery Control Centers and the worldwide aircraft staging bases. Messages are exchanged simulating spacecraft-landing information, the launching of aircraft, situation reports, on-scene descriptions, and deployment of pararescuemen. Diplomatic links are exercised in the securing of overflight clearances for situations in which they are required. Non-nominal and emergency situations are also included in the simulations in order to exercise recovery forces to the fullest extent. Examples of these are land landing, postlanding power failures, crew injuries, and survival situations. Special week-long simulations in the launch-site area are conducted to subject those forces to the many possible situations that may be encountered.

An attempt is made to gain every benefit possible from these simulations and the postsimulation debriefings to improve operational techniques and to increase recovery-force proficiency. In this manner, through the continuous buildup of experience and extension of capabilities, all recovery units will be prepared for more complex programs.

## Concluding Remarks

A review of manned space-flight recovery shows that it has been highly successful. The reasons for its success have been outlined; however, the most important reason is the careful attention given to details, both the details of the hardware and the details of the training. It behooves those involved in recovery planning not to become complacent because of the successes already achieved, but to pursue diligently the programs that have led to safe recovery. The NASA and the DOD plan to do this, with even greater attention given to the training programs because of the more complex hardware being used.

In looking toward the future, manned-space-flight planners need to be concerned not only with present-day programs, but also with problems that will be encountered in the future. A land-landing capability has always been a goal in the minds of many who plan manned space flight. The development of this capability will bring forth more problems, but will afford solutions to some that now exist. At the present time, operational-development work with land-landing systems is being conducted in an effort to identify some of the problems. Also, the increased duration of missions poses problems in the manning of recovery zones. Decisions will have to be made in regard to the amount of time that recovery forces will be required to be on-station during these long-duration missions, which may bring about entirely new recovery-support concepts. Because of the desirability to fly missions with high-inclination orbits in the future, another recovery problem to be considered concerns the support required for these missions. Since the vehicles for high-inclination missions will be launched toward the colder latitudes, the resulting spacecraft ground tracks will also extend into areas where the waters present a more hostile environment. All these problems must be solved to provide for the safety of the flightcrews and recovery personnel.

These problems, however, will be solved with the same thoroughness and diligence that have been applied to all manned-space-flight recovery endeavors to date. Careful attention is being given to these problems, and NASA is working very closely with the DOD in efforts to solve them. It is felt that when the time comes to fly missions of this type, the recovery-support posture will be on a level with that of the present as far as operational safety is concerned. Operational safety has been and always will be the paramount concern in manned-space-flight recovery.