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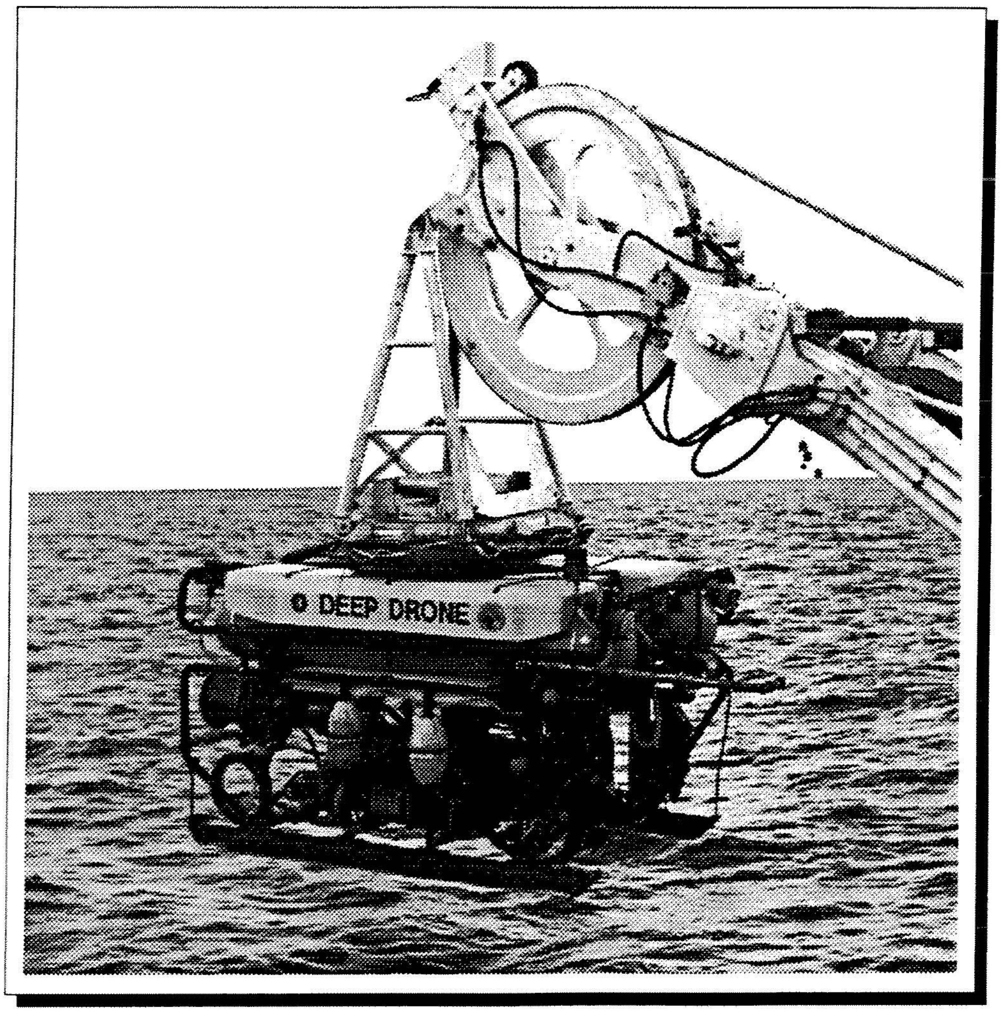
COMMERCIAL AIRCRAFT SALVAGE OPERATIONS



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FOREWORD

The Supervisor of Salvage (SUPSALV), U.S. Navy maintains an around-the-clock, worldwide deep-ocean search and recovery capability. The four aircraft search and recovery operations described in this report examine the command and management aspects of each operation, as well as technical perspectives.

For all their successes, the key to maintaining a deep-ocean recovery capability is the validity of continuously upgrading equipment and procedures. This involves comprehensive post-operation critiques which feed an active research and development effort.

We have prepared this report to provide future salvage officers and engineers with a perspective of the evolving capability of deep-ocean recovery.

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EXECUTIVE SUMMARY

This report contains aircraft salvage report overviews of Korean Airlines (KAL) Flight 007, Air India Flight 182, South African Airways Flight 295, and United Airlines Flight 811. Among other issues, these overviews illustrate the evolution of recovery/salvage equipment and procedures.

Aircraft salvage operations are usually conducted in two distinct phases: search followed by recovery. Towed sonar is the primary search tool; divers, submersibles or remotely operated vehicles are the primary recovery tools for completing the salvage operation.

To locate aircraft wreckage, a primary search area is defined with all available data, including radar tracks, projected flight paths, meteorological data, positions of floating wreckage, and information obtained from local observers. A projected impact position is plotted from this data. This position becomes the reference point from which the search area is developed.

Salvage techniques for a particular operation depend upon various factors. Once the basic method is chosen, suitable salvage and support vessels are selected. Techniques range from divers placing small pieces of wreckage in baskets, to remotely operated vehicles (ROVs) or manned submersibles attaching lift lines to wreckage and passing the lines to a lift vessel.

Although salvage operations were not implemented in the KAL Flight 007 operation, valuable lessons were learned during the search phase that were applied to subsequent, successful recovery operations.

Each of the salvage operations described set a new depth record for aircraft salvage by the U.S. Navy. With those records came valuable advances in deep-ocean salvage technology.

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CHAPTER 1

INTRODUCTION

1-1 INTRODUCTION

Since the earliest days of aviation, aircraft have been lost at sea. Recovery of aircraft — or portions of aircraft — lost at sea is attempted for several reasons. The most common reason is to determine the cause of the crash so that design or material flaws may be corrected. Other reasons include recovering the intrinsic value of the aircraft and its contents, and preventing military information or equipment from falling into unauthorized hands.

The technology used for locating and recovering lost aircraft limited the success of early recovery operations. Techniques, though crude, remained unchanged for many years. Searches with grapnels, wire drags, trawls, or divers were slow, difficult, and often unsuccessful. Mine location and shadowgraph sonars significantly improved the probability of locating aircraft wreckage.

Today, location and recovery of aircraft from depths of 20,000 feet is possible because of developments in:

- Surface and underwater precision navigation systems
- Pingers or acoustic beacons carried by aircraft to indicate their underwater locations
- Side-scan sonars that can search in the most difficult underwater terrain
- Remotely Operated Vehicles (ROVs) with onboard sonar, video, and work packages
- Fiber-optic cable and telemetry systems for control of ROVs
- Applications of computer technology in positioning and tracking systems
- Dynamic positioning systems in surface support platforms
- Motion-compensation systems to reduce dynamic loads on lift lines and umbilicals.

Most early deep-ocean operations were carried out using a combination of Navy operational and technical assets and private commercial organizations. Major operations, such as the search for the USS THRESHER (SSN-593) and the recovery of an atomic weapon lost off Palomares, Spain, usually achieved excellent results. However, following the operations, the Navy and commercial teams involved were disbanded, and there was little organized follow-through. Over time, deep-ocean search and recovery expertise in the Navy— especially as applied to aircraft recovery — has become centered in the Naval Sea Systems Command, Supervisor of Salvage (SUPSALV). The centralization of such capability in SUPSALV has accelerated the evolution of technology and operational expertise. The lessons of past operations are assimilated easily, and there is little tendency to repeat the mistakes of the past.

1-2 SCOPE

This report provides historical documentation of SUPSALV's search and recovery efforts in four significant commercial aircraft accidents between 1983 and 1990.

These operations, discussed in Chapters 2 through 5, have provided valuable lessons that have enhanced our capabilities in the art of deep-ocean search and recovery. Each incident had its particular difficulties, and each incident provided wisdom to be used in later recoveries.

CHAPTER 2

KOREAN AIRLINES FLIGHT 007

2-1 INTRODUCTION

On 31 August 1983, Korean Airlines (KAL) Flight 007, a Boeing 747, enroute from New York to Seoul via Anchorage, disappeared over the northern Sea of Japan. The aircraft had apparently flown off course into restricted air space of the Soviet Union. A Soviet jet shot down the KAL aircraft near Sakhalin Island. Figure 2-1 shows the flight path of KAL Flight 007.

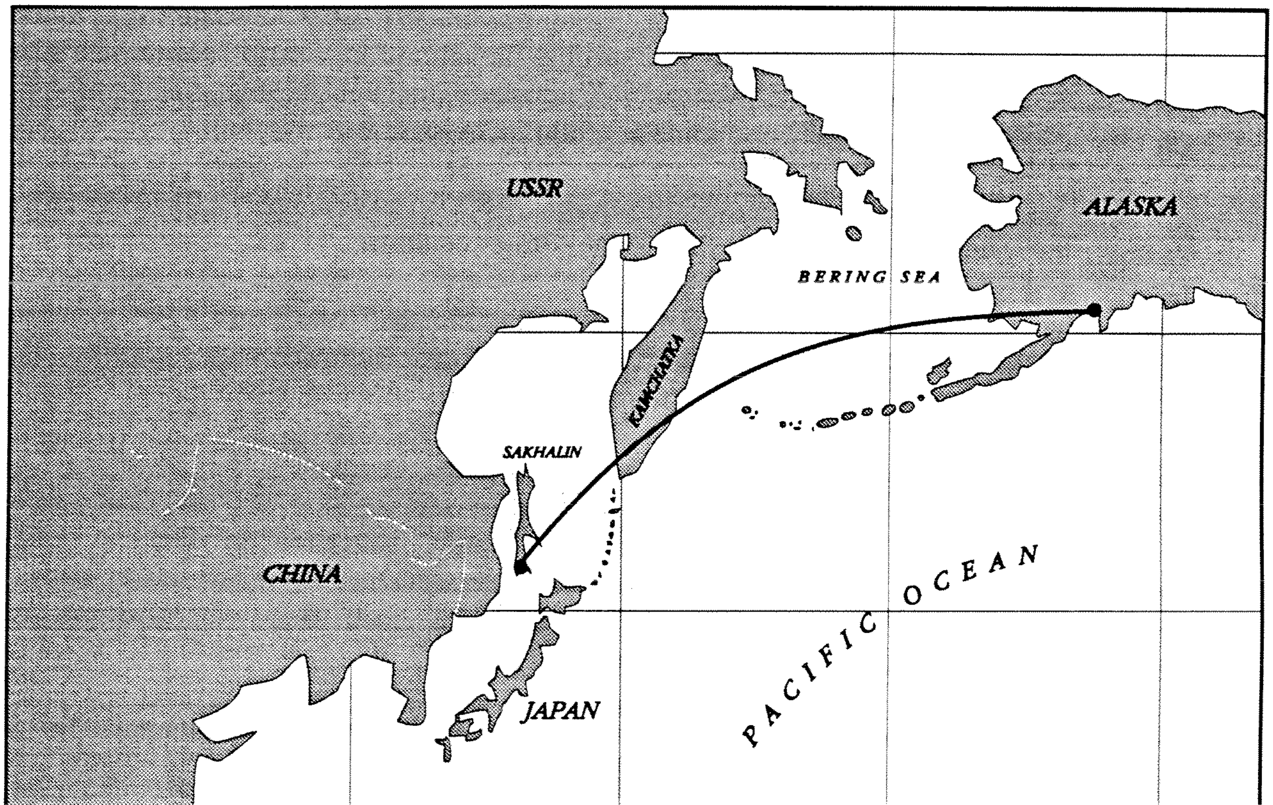


Figure 2-1. KAL 007 Flight Path.

Immediate international uproar and condemnation followed Soviet confirmation that they had deliberately shot the aircraft down. Locating and recovering aircraft debris, data recorders, and the remains of 269 passengers, one of whom was a member of the United States Congress, became a matter of very high priority for the United States and Korean governments.

2-2 TASKING

On 1 September, United States Air Force aircraft and Navy ships began a Search and Rescue (SAR) operation. The SAR surface search included the USS ELLIOTT (DD-967), USS BADGER (FF-1071), and the USCGC MUNRO (WHEC-724). The SAR operation ended after 10 days.

The Korean Government requested U.S. Government help in locating the aircraft. On 7 September, the Chief of Naval Operations tasked Naval Sea Systems Command, Supervisor of Salvage (SUPSALV) with the responsibility of locating and recovering wreckage from the crash. The following day, SUPSALV commenced mobilization planning.

SUPSALV directed their Remotely Operated Vehicle (ROV) operations contractor, Eastport International, Inc., to ship the ROV DEEP DRONE to Japan and to assist in the search, and their search contractor, Steadfast Oceaneering, Inc., to mobilize the SUPSALV Towed Pinger-Locators (TPLs) and two side-scan sonar systems for locating the aircraft's acoustic beacon and debris. Commander-in-Chief Pacific Fleet (CINCPACFLT) directed Commander Submarine Development Group One (SUBDEVGRU ONE) to mobilize a third side-scan sonar system.

A U.S. Air Force Special Assignment Airlift Mission (SAAM) and commercial flights were used to transport the search equipment from the United States to Japan.

Following the SAR phase, Commander, Seventh Fleet established Task Force 71 — a dedicated, multi-unit, sea-air search and recovery task force — to locate and recover the aircraft. Figure 2-2 shows the search and recovery task group organization.

Although the search and recovery operation was directed and executed by the U.S. Navy, it was truly a multinational effort. Representatives were present from the U.S. Navy and from countries with missing citizens. The International Civil Aviation Organization provided an on-scene impartial observer board. The three chartered Japanese vessels that served as aids to navigation and logistic support craft were treated as U.S. Flag vessels, since they were operating under SUPSALV's Western Pacific Salvage Contract.

Following the conclusion of the search, Commander in Chief, Pacific, summarized the KAL operation in a message paraphrased as:

> *The performance of ships, aircraft, personnel, and specialized equipment was superb. In spite of constant Soviet harassment, adverse weather, and lack of success, morale remained high. Not since the search for the H-bomb off of Palomares has a search effort of the magnitude or impact as this one been undertaken.*

Despite not reaching the goal of aircraft recovery, this operation:

- Demonstrated the validity of existing Navy contingency plans for worldwide salvage
- Provided extremely valuable search lessons
- Showed the effectiveness of the USN/USCG relationship.

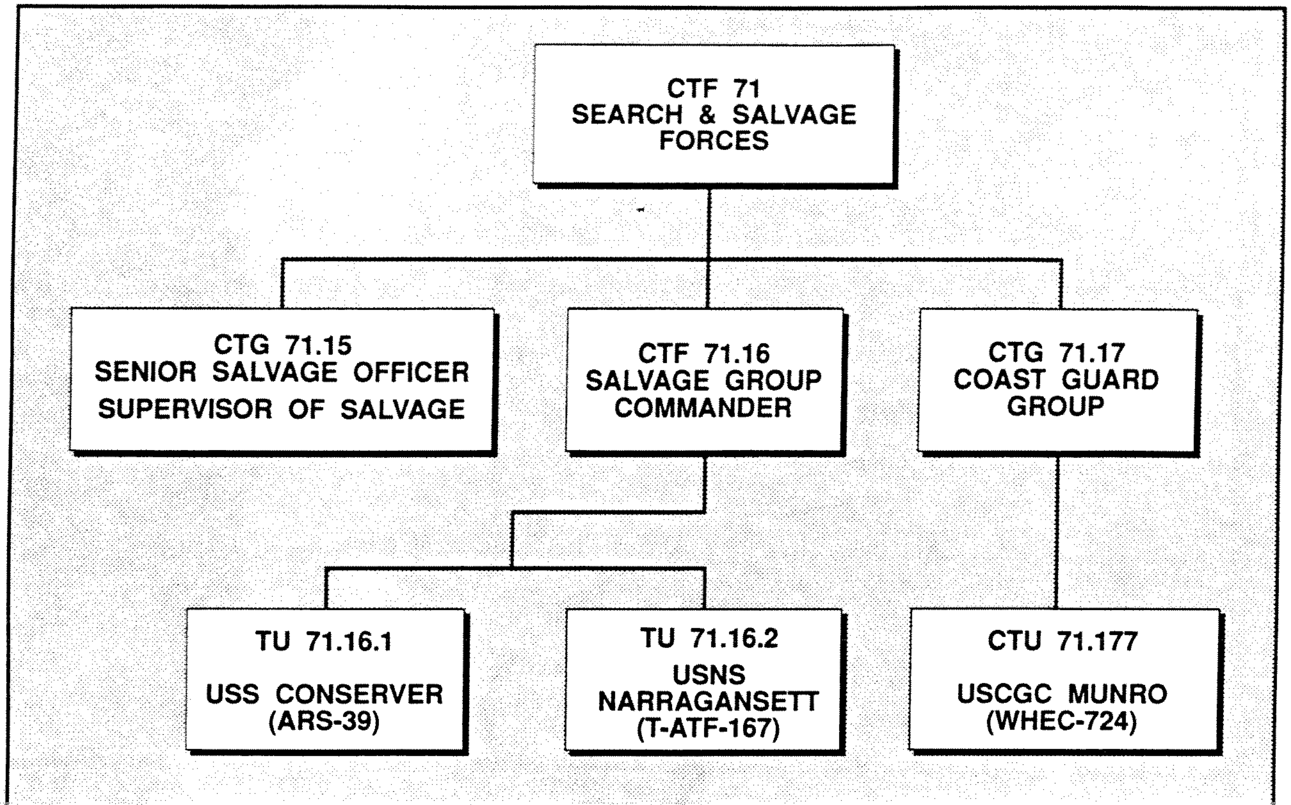


Figure 2-2. Search and Salvage Forces Organization.

2-3 OPERATIONS PLAN

A two-phase working plan followed establishment of the search and recovery task force. The first phase, search, ultimately would cover an irregularly shaped area of about 225 square miles that lay no closer than 12 miles to the Soviet Moneron and Sakhalin Islands. The area was defined from a CINCPACFLT assessment of the crash location and radar track information provided by the National Security Agency. This would be expanded until all probable areas had been covered. Search forces received extensive direction concerning operating within the area boundaries and approaching Soviet territory. Side-scan sonar, TPL, and ROV searches covered areas west, northwest, and north of Moneron Island, as shown in Figure 2-3.

When the debris field boundaries were established, the second phase, aircraft recovery, would begin. As it turned out, there was to be only one phase — the unfruitful search.

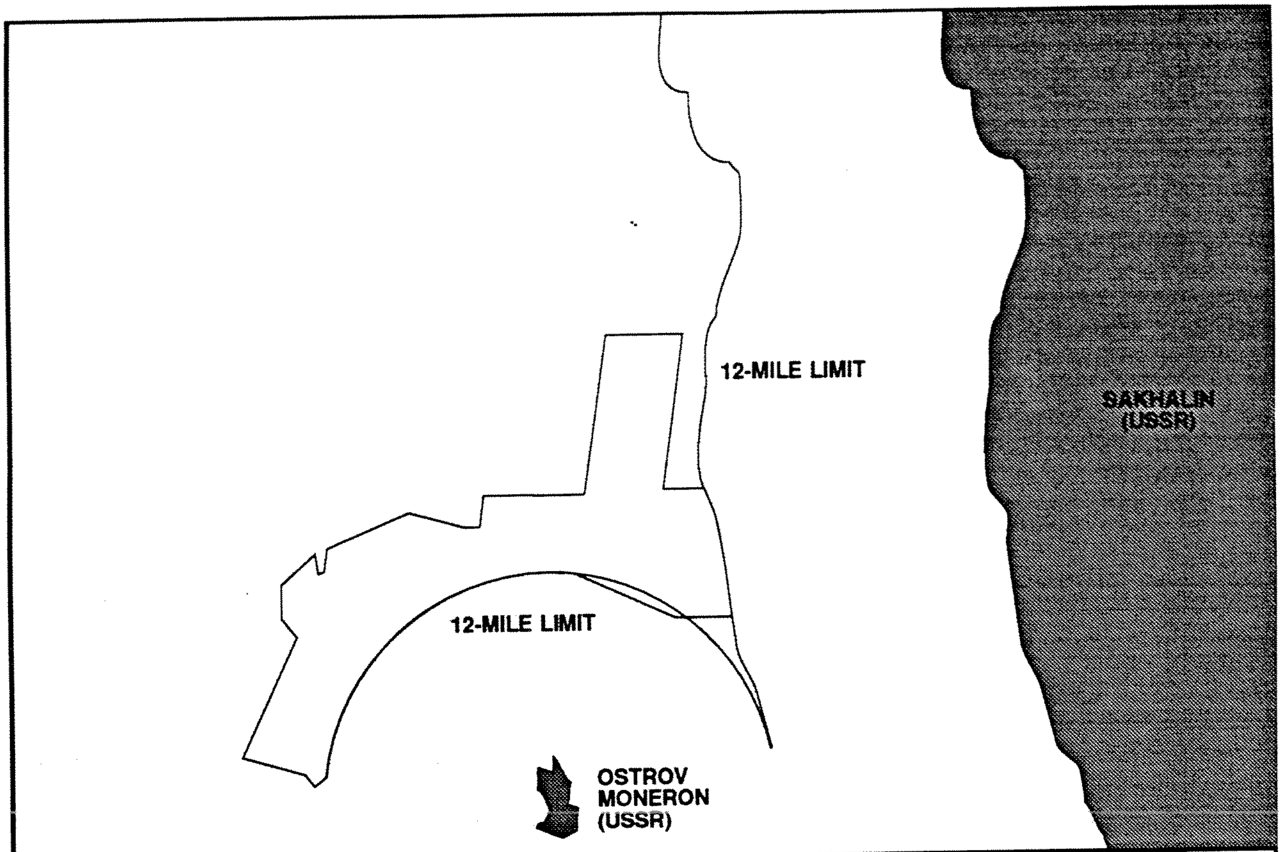


Figure 2-3. KAL Flight 007 Search Area.

Initially, two ships carrying TPL and towed sonar systems would cover the primary search area on search lines running north/south and east/west with 500-foot spacing. A third ship with only a TPL would augment the search operation. The depth in the search area varied between 400 and 2,500 feet. Areas of high interest, determined by the TPLs, would be prosecuted in detail with side-scan sonar. Objects located by the sonar would be documented and, if desired, recovered by the ROV. As the search progressed, acoustic signals were picked up by the TPLs; however, none was conclusive enough to pinpoint the beacon's location. The signals were spotty, intermittent, difficult to re-acquire, and never pinpointed or even confirmed as having originated from an aircraft marker beacon. When the pingers' battery life was exceeded, active side-scan sonars became the primary search tools.

2-4 SEARCH OPERATIONS

2-4.1 Search Plan. Based upon the information available at the time, a search plan was devised that would result in a comprehensive search of the irregularly shaped search area. While exercising great caution to remain well within the defined search area to avoid intrusion into restricted Soviet territorial waters, the plan called for:

- Deploying TPLs along pre-planned search lines to pick up acoustical signals from the aircraft's pinger.

- Deploying side-scan sonars to locate pieces of wreckage and document the debris field if possible.

- Deploying ROV DEEP DRONE to confirm and document suspect objects located by side-scan sonar.

2-4.1.1 Towed Pinger-Locators. At the beginning of the search, ships towed the TPLs at varying depths along pre-established search lines. On at least one occasion, a TPL was hung vertically near the bottom as the support ship lay dead in the water. The results of both listening methods were negative. Although searchers heard some underwater signals over several days, the sources could not be confirmed as aircraft acoustic beacons.

2-4.1.2 Side-Scan Sonars. Side-scan sonar operations began as it became obvious that acoustic beacons were not going to be located by the TPLs. Side-scan sonars were used, with sufficient tow cable and support equipment to cover all potential search areas.

2-4.1.3 Remotely Operated Vehicle. ROV DEEP DRONE, operated by a contractor crew from USNS NARRAGANSETT (T-ATF 167), provided a 6,000-foot-deep salvage capability. Figure 2-4 shows DEEP DRONE on the T-ATF fantail. DEEP DRONE could:

- Prosecute targets identified with side-scan sonar
- Photo-document objects
- Visually search designated areas
- Recover objects.

DEEP DRONE conducted six target identification and search dives. The dives, ranging between 4.5 and 20.5 hours, totaled 74 hours and 22 minutes bottom time. The deepest dive was 2,500 feet.

2-4.1.4 Photo-Documentation. DEEP DRONE documented all contacts with video and still cameras. Visibility and bottom characteristics were favorable for photo-documenting aircraft debris, but none was found.

2-4.2 Navigation Systems. Precise surface and subsurface navigation systems were required to complete the search and ROV operations. Data from both systems was fed into an integrated navigation system to maintain a plot of ship, ROV, and side-scan sonar tracks. Two factors disrupted navigation — heavy weather and Soviet harassment.

2-4.2.1 Surface Navigation. OMEGA and Loran-C navigation systems were considered, but gave errors as great as three miles — far too large for precision searching. Satellite navigation systems gave reliable positioning approximately once per hour — not frequently enough to maintain precise plots. A microwave horizontal positioning system aboard two moored ships was

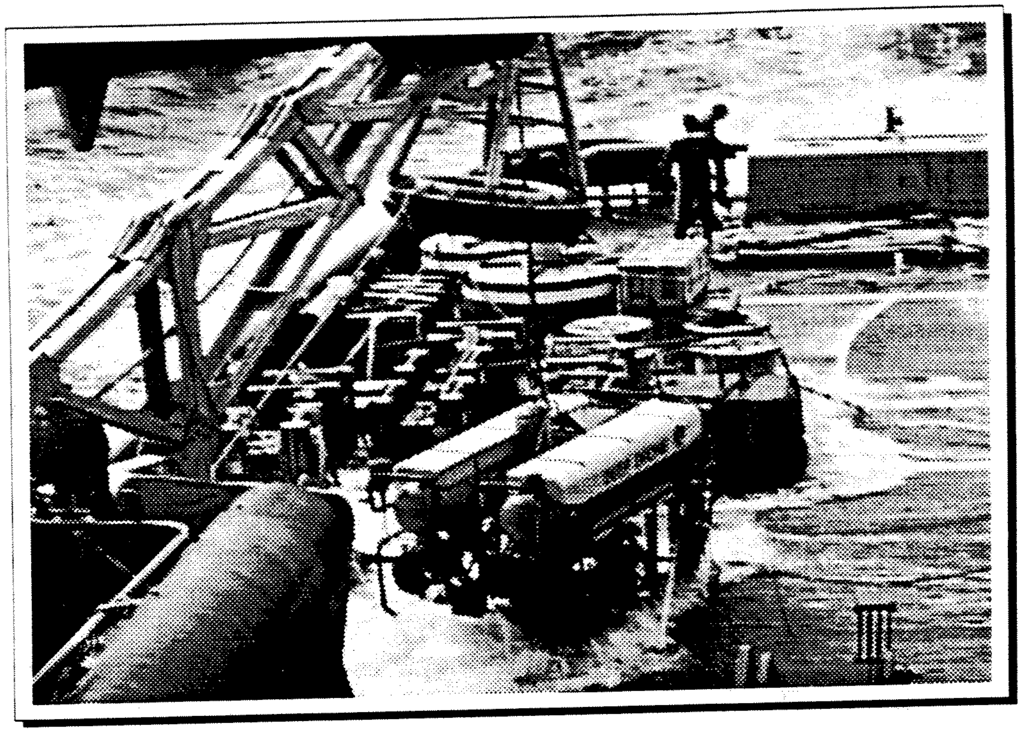


Figure 2-4. DEEP DRONE on T-ATF Fantail.

utilized during part of the search, with some success. Much of the area was searched using ship's radar and visual bearings to Moneron Island for navigation. Both of these techniques proved sufficiently accurate, considering the large size of the target being sought.

2-4.2.2 Subsea Navigation. Two types of subsea navigation systems were employed during the search and ROV operations. An ultrashort-baseline (USBL) system was used to track the DEEP DRONE relative to the surface ship. During the side-scan search of the southwest (deep) portion of the search area, a long-baseline (LBL) navigation system was utilized. This system consisted of an array of 10 transponders that were interrogated as the ship transited over the area, and enabled a real-time track with greater accuracy than radar plots offered.

2-4.3 Search Support Vessels. USS CONSERVER (ARS 39), USNS NARRAGANSETT (T-ATF 167) and USCGC MUNRO (WHEC 724) directly supported the TPL and side-scan sonar search operations. With her large clear stern, NARRAGANSETT was well suited for supporting both the side-scan and ROV DEEP DRONE inspection systems. Versatile CONSERVER assisted in rigging mooring systems for the surface navigation ships and served as the primary Navy logistics support ship. This report does not discuss those USN ships assigned to Task Force 71 in roles not directly related to search operations.

NAVSEA chartered two Japanese support vessels, KAIKO MARU 3 and KAIKO MARU 7, to serve as fixed surface navigation platforms and the Japanese salvage ship, M/V OCEAN BULL for logistics support and mooring systems recovery.

2-4.4 Search Chronology. Table 2-1 is a chronology of the search phase on the KAL Flight 007 operation. The total time spent searching for the aircraft was 52 days.

Table 2-1. Search Chronology.

DATE	EVENT
31 August 1983	Korean Airlines Flight 007 shot down.
1 September	SAR begun by 5 USAF aircraft.
5 September	Surface SAR expanded to include USS ELLIOTT (DD-967) and USS BADGER (FF-1071).
7 September	USCGC MUNRO (WHEC-724) added to SAR mission. U.S. Navy Senior Officer Present Afloat - Commander Task Force 75.
8 September	DEEP DRONE system trucked to Andrews AFB, Maryland, for further transport to Japan.
9 September	USAF C-141 loaded out with DEEP DRONE system, departs Andrews AFB enroute Hakodate, Japan.
10 September	C-141 transporting DEEP DRONE lands in Hakodate, Japan. Cargo unloaded within one hour after landing. SAR terminated. Search and recovery phase begins. Mobilization began with search equipment and mooring equipment shipped to Japan for load-out on the support ships.
11 September	Task Force 71 formed for search and recovery operations.
11-12 September	USNS NARRAGANSETT (T-ATF 167) loaded out with DEEP DRONE system and Submarine Development Group One side-scan sonar.
13 September	NARRAGANSETT, with SUPSALV embarked as CTG 71.15, sails from Hakodate, enroute operations area near Moneron Island.
14 September	MUNRO loaded out, underway for search area.
15 September	NARRAGANSETT arrives in the search area. TPL and side-scan search begun from NARRAGANSETT and MUNRO.
16 September	0757: MUNRO TPL gains intermittent contact. CONSERVER TPL confirms intermittent acoustic signals in same general area. 1800: MUNRO begins active side-scan search for aircraft debris .
18 September	DEEP DRONE launched at 46 34.6N, 141 17.4E to check sonar contacts. All were rocks and coral.
19 September	Intermittent signals continue.

Table 2-1 (Continued). **Search Chronology.**	
DATE	**EVENT**
20 September	Contact prosecution continues with all systems. NARRAGANSETT TPL used in vertical position with ship dead in the water to pinpoint contacts, with negative results.
21-23 September	Long-baseline acoustic navigation system set up for DEEP DRONE operation. System calibrated and tested with varying degrees of success. Various TPL surveys conducted from NARRAGANSETT. DEEP DRONE acquires various unrelated targets.
24 September	CONSERVER receives deep-ocean winch, 16,000-foot cable, and extra personnel and equipment for side-scan sonar.
28 September	Pinger search with sonobuoys dropped from P-3 was negative.
1 October	NARRAGANSETT secures side-scan search effort because of bad weather and high seas. MUNRO and CONSERVER continue searching.
2 October	NARRAGANSETT resumes search.
4 October	Bad weather forces KAIKO MARUs to slip mooring and steam. Searching continues.
5 October	Weather causes excessive water over fantail of NARRAGANSETT and stops search effort.
7 October	NARRAGANSETT resumes search. KAIKO MARUs return to mooring. MiniRanger navigation system placed onboard.
13 October	CONSERVER starts side-scan sonar search with third system. DEEP DRONE conducts visual search of contacts identified by MUNRO sonar.
14 October	KAIKO MARU 3 dragged from moor by Soviet trawler. Mooring re-rigged by CONSERVER. Navigation position re-established.
15 October	Gale force winds cause moorings to slip. NARRAGANSETT search suspended.
16 October	Soviet trawler drags KAIKO MARU 3 out of moor.
21 October	60-square-mile high-probability area completed with side-scan sonar. Weather continues to be very poor.
22-25 October	NARRAGANSETT search suspended.
25-26 October	ROV checks targets, with negative results.
27 October	DEEP DRONE checks MUNRO contacts, with negative results.
29 October	Heavy seas break DEEP DRONE operator and vehicle huts loose from securing points. NARRAGANSETT search operations ended for return to port.

Table 2-1 (Continued). Search Chronology.	
DATE	**EVENT**
1 November	DEEP DRONE systems re-secured and operating. NARRAGANSETT returns to search area.
2 November	DEEP DRONE on bottom, searching for contacts. Gaps identified in areas previously searched.
5 November	All search gaps covered with side-scan sonar. Demobilization plans commence.
6 November	1700: Operation terminated.
15 November	All demobilization completed.

The side-scan towed by MUNRO searched relatively shallow waters, because it was fitted with a short tow cable. NARRAGANSETT and CONSERVER, with long tow cables, were assigned to search the deeper areas. In time, the entire search area would be searched by side-scan sonar.

Several contacts acquired during the side-scan sonar search warranted visual investigation by DEEP DRONE. In each case, the contacts were rock formations. Objects sighted by the ROV included a fishing net, tin can, shoe, oil drums, soup pan, magazine, and rag. No debris from the aircraft was found.

As the operation progressed, new search areas were established, based on further information from local fisherman and Japanese Self Defense Force radar track data. A systematic search of these areas by the three platforms produced negative results.

2-4.5 Search Problems. Because the Soviets refused permission for search personnel to enter Soviet territory, shore-based precision navigation was unavailable. This forced searchers to rely on less accurate navigation systems. Ultimately, the entire search area was covered, but considerable time was lost because multiple passes were required to ensure thorough search coverage.

Because navigation base stations could not be set up ashore, moored ships served as platforms for the base stations. However, the ships were not in place until long after the operation started, and storms and Soviet harassment caused them to trip from their moors on several occasions.

Direct interference by Soviet ships caused searchers to abort search lines to prevent collisions or loss of tow cable. This resulted in a significant loss of time, since the lines generally had to be completely re-run.

Winter storms with high seas impeded an orderly search. Search and ROV operations from the T-ATF were canceled several times because the fantail was awash. In one instance, DEEP DRONE operating and vehicle vans tore from their rigging chains, damaging the system and making it inoperative.

2-5 RECOVERY OPERATIONS

No recovery operations were carried out because the KAL Flight 007 debris field was never located.

2-6 SUMMARY

The performance of personnel, ships, and equipment throughout the search operation was outstanding. Despite constant frustration from repeated Soviet harassment and interference, often miserable weather, and no debris being discovered, the morale of search personnel remained high. The search force — an *ad hoc* grouping of U.S. Navy, civil service, contractor, U.S. Coast Guard, and foreign personnel, and the support ships listed in Table 2-2 — functioned as a highly integrated and professional team.

Table 2-2. Search and Search Support Ships.

SHIP	SEARCH ROLE
USCGC MUNRO (WHEC 724)	Supported SUPSALV TPL and contractor-operated side-scan sonar systems.
USS CONSERVER (ARS 39)	Supported SUPSALV TPL and contractor-operated side-scan sonar systems. Aided in rigging mooring systems for surface navigation ships. Served as logistics support ship.
USNS NARRAGANSETT (T-ATF 167)	Supported SUPSALV TPL, ROV DEEP DRONE, and COMSUBDEVGRU ONE side-scan sonar systems.
KAIKO MARU 3 and KAIKO MARU 7	Japanese support vessels chartered by NAVSEA as fixed surface navigation platforms. These ships moored in water 600 to 1,000 feet deep, 19 to 26 miles from Sakhalin Island.
M/V OCEAN BULL	Japanese salvage ship chartered by NAVSEA, acted as logistics support ship and recovered mooring systems.

Because DEEP DRONE never found anything on the bottom associated with KAL Flight 007, it can be reasonably concluded that the aircraft did not crash within the search area. Although plagued with setbacks, delays, and problems, the search covered the intended area completely. Commander-in-Chief, Pacific estimated a 95-percent chance that the wreckage lies closer than 12 nautical miles to Soviet territory. Had the Soviet Union permitted the task force to search within their territorial waters, searchers probably would have found the aircraft.

The close cooperation among SUPSALV's commercial contractors, SUBDEVGRU ONE, U.S. Coast Guard, and fleet personnel greatly aided the search operation. There were many instances when contractor, Navy, and Coast Guard personnel worked together to repair equipment and stand watches. Navy personnel performed diligently to moor and re-moor the navigation station ships. Without this teamwork, the operation would have taken much longer. The importance of all hands to the success of the operation must be established at the outset. The search experts cannot succeed without fully committed support from all hands.

All relevant information must be made available to the search and recovery analysts as early in the planning process as possible. Significant intelligence data was available within various U.S. and Japanese agencies by 6 September, but was not received in its entirety by the Task Force Commander until 45 days after the incident. Continuous plan modification was required as "new" intelligence data was received or as the situation in the operating area changed.

CHAPTER 3

AIR INDIA FLIGHT 182

3-1 INTRODUCTION

On 23 June 1985, Air India Flight 182, a Boeing 747, enroute from Toronto, Canada to New Delhi, India via Montreal and London crashed into the North Atlantic Ocean approximately 100 miles southwest of Cork, Ireland. The flight path for Air India 182 is shown in Figure 3-1.

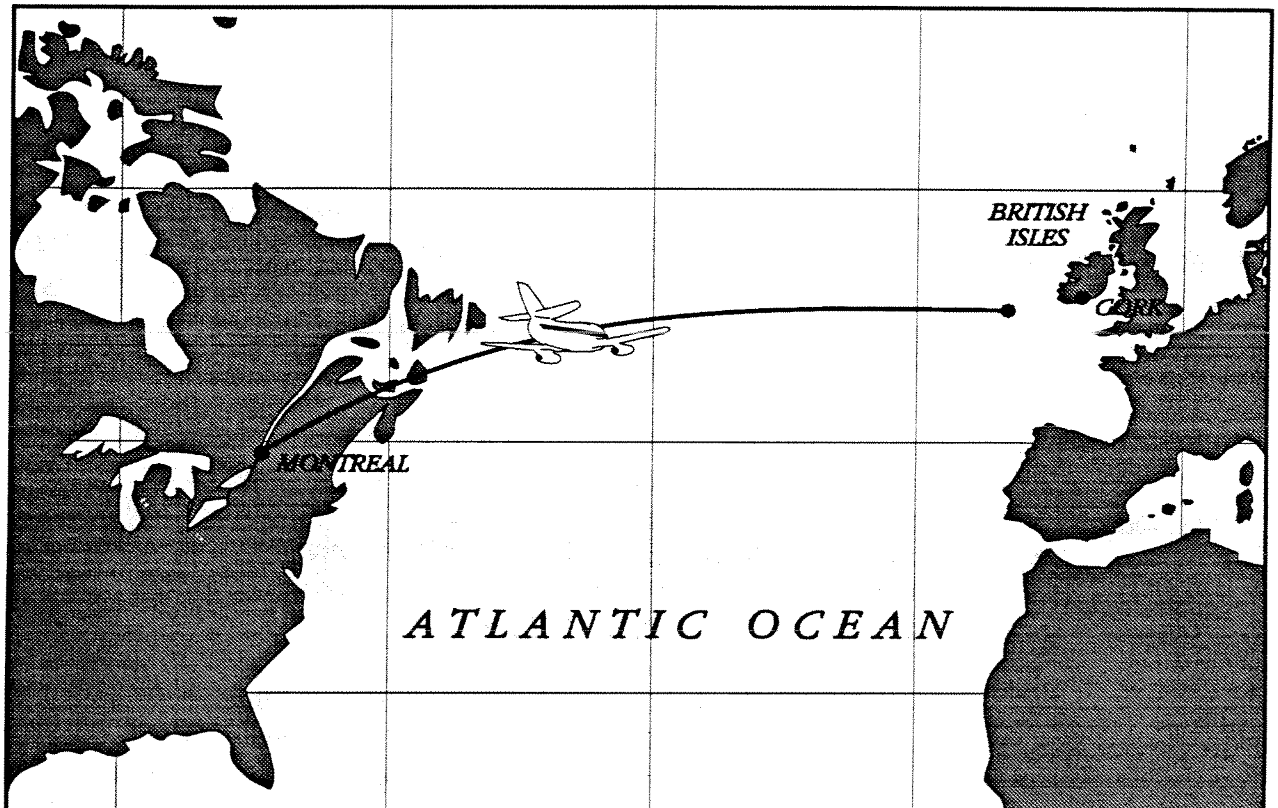


Figure 3-1. Air India Flight 182 Intended Flight Path.

Callers to U.S. newspapers, professing to represent extremist groups, claimed responsibility for destroying the aircraft with explosives. However, none of the floating wreckage recovered showed explosion damage. Of the 329 people reported missing, 130 bodies were recovered, and the causes of death were reported as drowning or impact trauma, not explosive force.

On the same day as the Flight 182 crash, there was an explosion in the baggage handling area at Narita Airport in Tokyo, Japan. The explosion occurred in baggage from an Air India Flight originating in Montreal. Shortly after these Air India incidents, a Japan Airlines Boeing 747 crashed, resulting in the deaths of 520 persons. Mechanical failure of a bulkhead in the rear of the aircraft apparently caused the Japan Airlines crash.

Safety boards and the aircraft manufacturer were anxious to locate and retrieve the Air India wreckage to determine the exact cause of the crash. If there were similar structural failures in both the Air India and Japan Air Lines crashes, immediate corrective action was required. If the use of explosives was evident, different action was appropriate.

Soon after the crash, an international investigating team headed by the Indian Government was commissioned to determine the cause of the crash. Participating countries included the United Kingdom, India, the United States, Canada, France, and Ireland. Support services, ships, search and recovery equipment, personnel, and command and control were furnished by the participating nations.

3-2 TASKING

The Governments of India and Canada initially asked the U.S. State Department for help in the search for the missing aircraft. On 27 June, the Chief of Naval Operations tasked Naval Sea Systems Command, Supervisor of Salvage (SUPSALV) to furnish Towed Pinger-Locators (TPLs), operators, technical support personnel, and advisors necessary to support the search. SUPSALV immediately tasked Eastport International, Inc., and Steadfast Oceaneering, Inc., to mobilize the SUPSALV TPLs and a side-scan sonar system.

The Indian Accident Investigation Team chaired a meeting at Cork Airport on 29 June with officials from the concerned countries. At this meeting, SUPSALV presented an overview of deep-ocean search and recovery, outlining the general phases typical of this type of operation, as well as emphasizing the risk. Attendees agreed that the Canadian Accident Identification Board (CAIB) would coordinate the search phase from Cork, with representatives from the Canadian Coast Guard, Indian Navy, and SUPSALV assisting.

For the final phase of the project, CNO directed SUPSALV to formalize the recovery plan. The safety boards, aircraft manufacturer, and SUPSALV jointly established recovery priorities based on the ROV photographs of the debris field. The CAIB accepted the plan and asked the U.S. Navy to go ahead with the aircraft recovery, in conjunction with the Canadian Coast Guard Ship (CCGS) JOHN CABOT. SUPSALV tasked DONJON Marine Co., Inc., to provide a commercial lift ship to support the SUPSALV Flyaway Deep Ocean Salvage System (FADOSS).

3-3 OPERATIONS PLAN

The operation's objective, as set by the CAIB, was to locate and recover the cockpit voice and flight data recorders. The plan allowed for recovery of aircraft debris if the data recorder information was not adequate for the investigation. Because the data recorders had acoustic beacons, TPLs were chosen as the primary search equipment. TPL systems from the United States and the United Kingdom, operated from ships of opportunity, would be used to locate the position of the acoustic beacons assumed to have been activated following the crash.

Concurrent with the TPL search, SUPSALV side-scan sonar assets were on site to:

- Augment the data recorder search
- Record debris locations
- Establish the boundaries of the entire debris field.

In addition to the TPL and side-scan sonar efforts, the Canadian Safety Board chartered an ROV to:

- Conduct a visual and sonar search independent of the TPL and side-scan operations
- Recover the data recorders
- Complete a photogrammetric survey.

Hull-mounted sonar mapping systems onboard some of the support vessels used for towing TPLs and ROV support augmented the specialized search systems.

Data recorder recovery would conclude the search operation. Emphasis would then shift to a salvage operation to recover aircraft wreckage. After recorder recovery, debris mapping by the SUPSALV side-scan sonar would provide the basic data upon which the photogrammetric survey could be based. When all debris had been identified visually, the investigation team could set recovery priorities.

3-4 SEARCH OPERATIONS

The primary objectives were to:

- Locate the flight and voice data recorders
- Recover the recorders if possible
- Map the total debris field.

Canadian Air Force aircraft transported all the Navy-owned, contractor-operated equipment from the United States to Ireland. The equipment and operators were deployed in ships furnished by the safety board.

In most aircraft salvage operations, there are distinct search and recovery phases. In this incident, the two phases overlapped; the data recorders were recovered during the search phase. The recovery was possible because of the mix of equipment in the search. The ROV used for random search could visually confirm data recorders located by the TPLs and recover them quickly.

Because the towed search systems operated in the same general area as the ROV, extra care regarding operating spaces and procedures was taken.

3-4.1 Search Plan. After analyzing recorded flight navigation data, the Cork Coordination Center defined the preliminary search area as 50-59N to 51-07N and 12-13W to 12-55W — an area of nearly 336 square miles. Further data evaluation gave a best estimated water entry position of 51-02N, 12-51W. This position served as the focus for defining a high-probability search area that extended 2 NM west, 8 NM east, and 4 NM north and south from the water entry point.

Initially, two ships steamed independently along north/south grid lines while towing TPLs at a depth of 300 feet — below the 230-foot thermocline. Search paths were 3,300 and 4,900 feet wide, overlapping for 100-percent bottom coverage.

A third ship supported the ROV SCARAB I. In the large search area, SCARAB I searched randomly for the data recorders and other debris. (The ROV SCARAB II was used during the recovery phase of the operation.)

Following the initial, unsuccessful search of the area, a SUPSALV search specialist, Thomas B. Salmon, revised the search procedures, and the TPL was lowered as deep as its cable would permit. Using this technique, the flight data recorders were located in approximately 6700 fsw, 0.60 nautical miles north and 1.4 nautical miles east of the assumed water entry point. Figure 3-2 shows the general and high-probability search areas and positions for aircraft debris and data recorders.

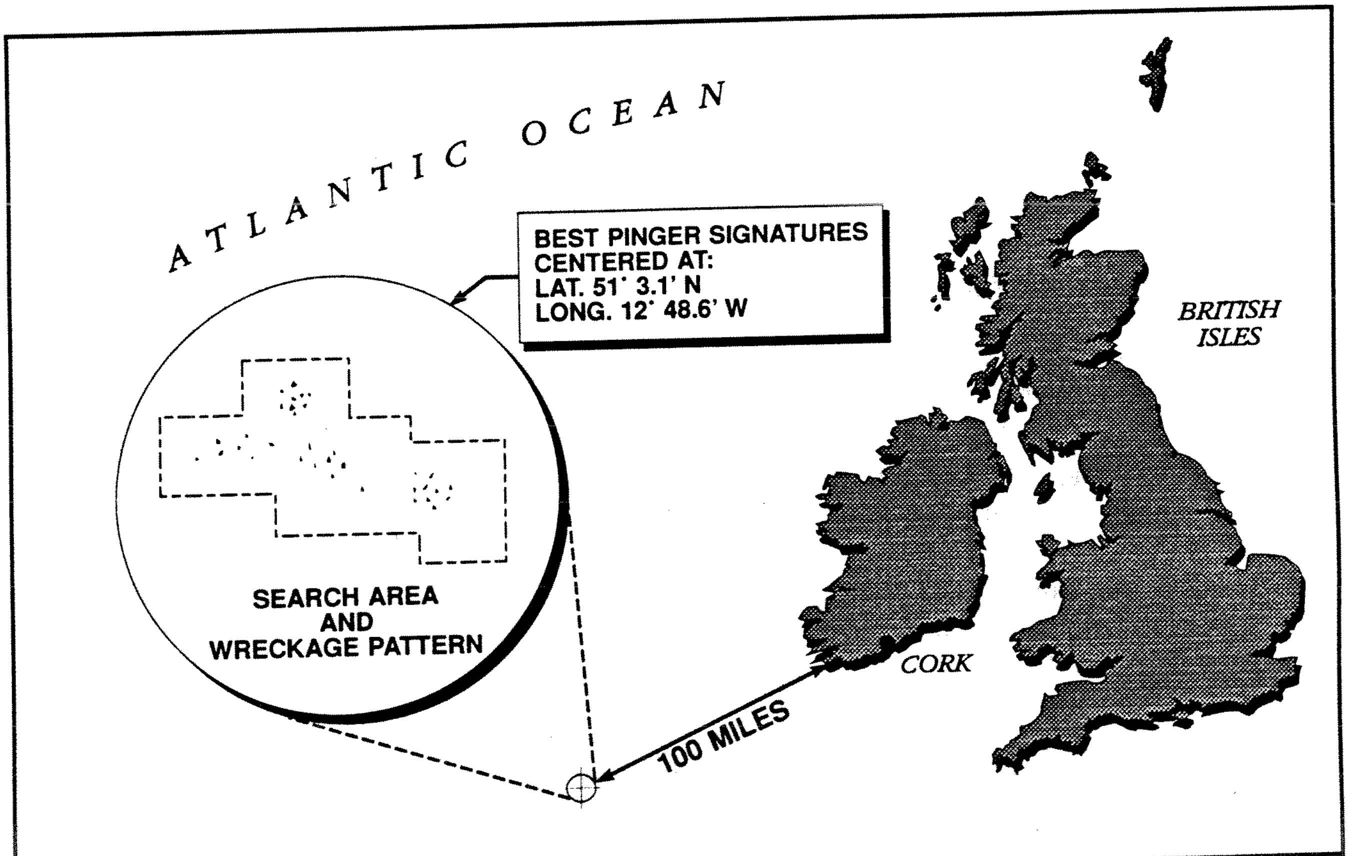


Figure 3-2. Air India Flight 182 Search Area.

3-4.2 Search Systems. Two TPLs, one ROV, and one towed side-scan sonar were mobilized for the search operation.

3-4.2.1 Towed Pinger-Locators. The decision to search for the recorders with TPLs proved sound; the data recorders were located after only eight days of searching. If the aircraft's acoustic beacons had not been operating, the search undoubtedly would have taken much longer.

Contractors operated SUPSALV's TPL system from the Irish Navy vessel L E AOIFE. This system detects frequencies between 27 and 45 kHz, the range that includes the data recorder acoustic beacon frequency. Figure 3-3 shows the SUPSALV TPL system.

The second TPL system came from the United Kingdom Department of Transportation Accident Investigation Board and was mobilized aboard the chartered UK vessel M/V GARDLINE LOCATOR. This TPL was operationally similar to SUPSALV's system.

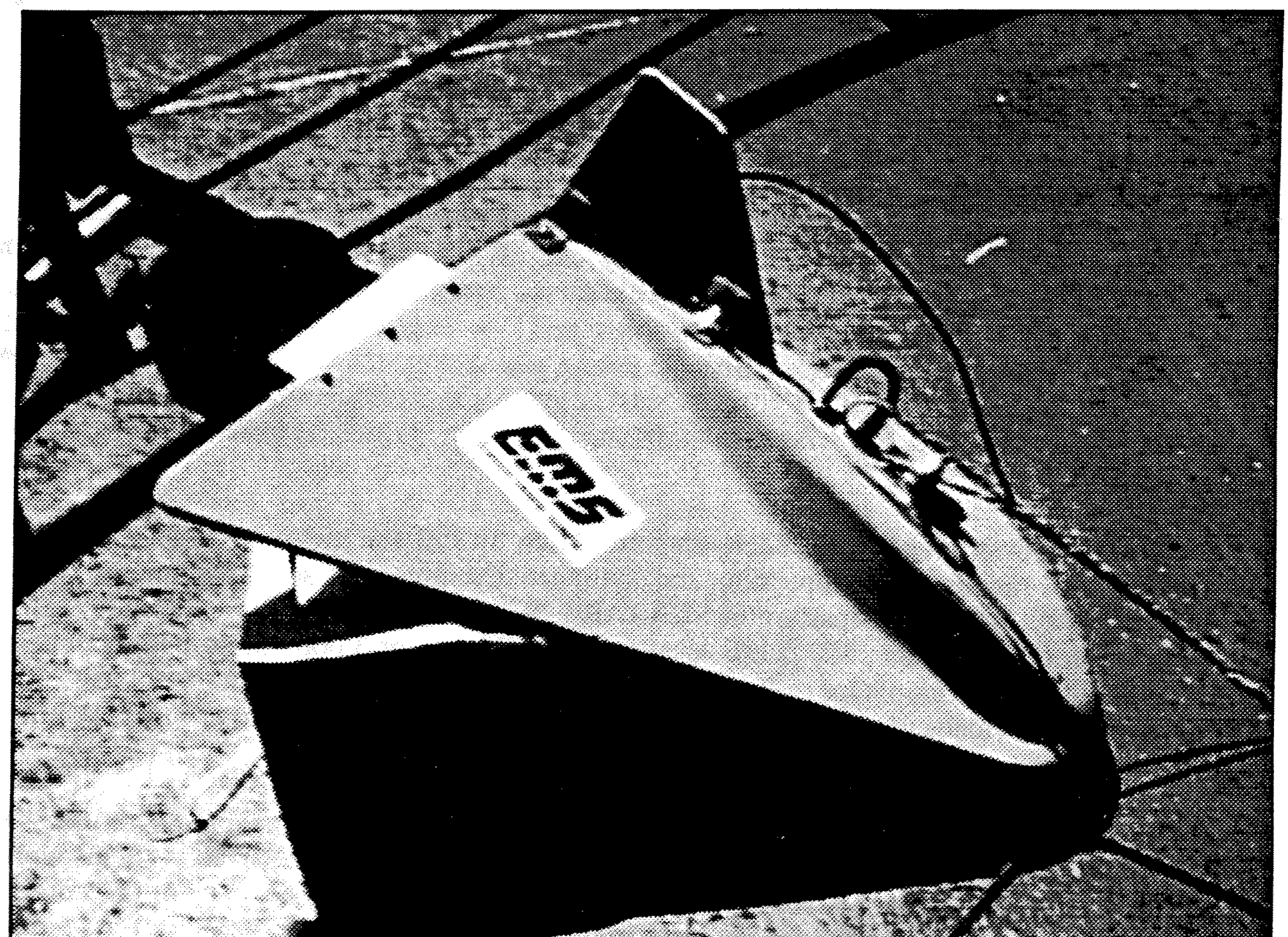


Figure 3-3. Towed-Pinger-Locator (TPL).

3-4.2.2 Side-scan Sonar. Contractors operated the side-scan sonar from the Irish Navy ship L E EITHNE. For the survey, the sonar fish was towed along grid lines spaced 600 feet apart. The sonar scanned 660 feet on each side, giving an 80-foot overlap on each grid line, ensuring 100-percent coverage. The side-scan survey produced 118 positions of large debris. Many smaller pieces were strewn about the large ones. The sonar-generated debris field followed a 100-degree axis and was 1.5 by 5 nautical miles. This portable system consisted of:

- Underwater towfish
- 24,000 feet of tow cable
- Towing and salvage winch
- Graphic recorder.

3-4.2.3 Remotely Operated Vehicle. The tethered, ROV SCARAB I was chartered by the Canadian Government for search and recovery of the recorders. SCARAB — an acronym for Submersible Craft Assisting Repair and Burial — is used primarily for recovering damaged underwater communications cables and burying repaired cables in depths to 6,000 feet. A large safety factor designed into the vehicle allowed it to operate at the 6,700-foot depth of the Air India wreckage.

Although ROVs are not primary tools for large-area searches, the presence of SCARAB I helped in avoiding the delays normally experienced in mobilizing a salvage system. The ability to identify promising contacts during the search phase increased overall operational efficiency.

After recovering the recorders, SCARAB I departed. SCARAB II arrived in Cork aboard the CCGS JOHN CABOT on 9 July. Eastport International operated SCARAB II within designated search squares, guided by a subsea transponder grid. A creeping-grid technique moved the transponders within the search area. Upon acquiring a sonar contact, the ROV went to the target to take video and still pictures. The target was assigned a designation number, and its position was recorded by the ALLNAV navigation system computer. Over 400 items were located and catalogued.

3-4.2.4 Photo-Documentation. Photo-documentation by still and video cameras began during the SCARAB I random search operation and continued after side-scan sonar mapping of the area was completed. After the departure of SCARAB I, SCARAB II spent over 1,400 hours on the seabed recording more than 400 debris locations and taking over 3,000 35mm photographs and over 100 hours of video tape. Positions were accurately pinpointed within 33 feet. The photographs and videos gave the investigating staffs sufficient information to prioritize debris for the recovery operation.

3-4.3 Navigation Systems. As in past search and recovery operations, navigation accuracy was critical. Both surface and bottom navigation systems had problems. The surface systems worked well during daylight hours but were less accurate at night. Bottom systems were inaccurate, at times, because transponder frequencies were similar to those of ship-generated noises.

3-4.3.1 Surface Navigation. Accurate, continuous electronic positioning is mandatory in any search. Search area coverage must be 100 percent. The systems available for this search were difficult to use because the signals diminished during hours of darkness. The recurring signal loss caused gaps in the search areas that could have caused searchers to miss weak signals from the acoustic beacons.

The surface precision-navigation system was an Over-the-Horizon (OTH) system. In a manner similar to Loran-C, the system tracked signals received from a transmitting chain of master and slave stations. A calculator converted the time differences between signals received from selected stations to grid references.

3-4.3.2 Subsea Navigation. Photogrammetric documentation of hundreds of debris pieces by the ROV could not have been accomplished satisfactorily without a reliable and highly accurate subsea navigation system that integrated ROV and surface ship position data.

An integrated microcomputer-based system was used to display the positions of the surface ship, ROV, way points, transponders, and targets. The system accepts inputs from the ship's OTH navigation equipment, pit log, gyro compass, and ROV positioning devices.

The undersea portion of ALLNAV is a Long-Baseline (LBL) acoustic system that operates on ranges from an array of seabed transponders. Four transponders positioned 200 feet above the seabed make up the acoustic field needed for positioning information. When interrogated, the transponders transmit signals that reach the receiver in a time proportional to the distance between the transponder and receiver. Transponders are interrogated by both the ship and the ROV, allowing determination of the position of both.

Figure 3-4 is a diagram of the LBL position-determining system for ROV operations.

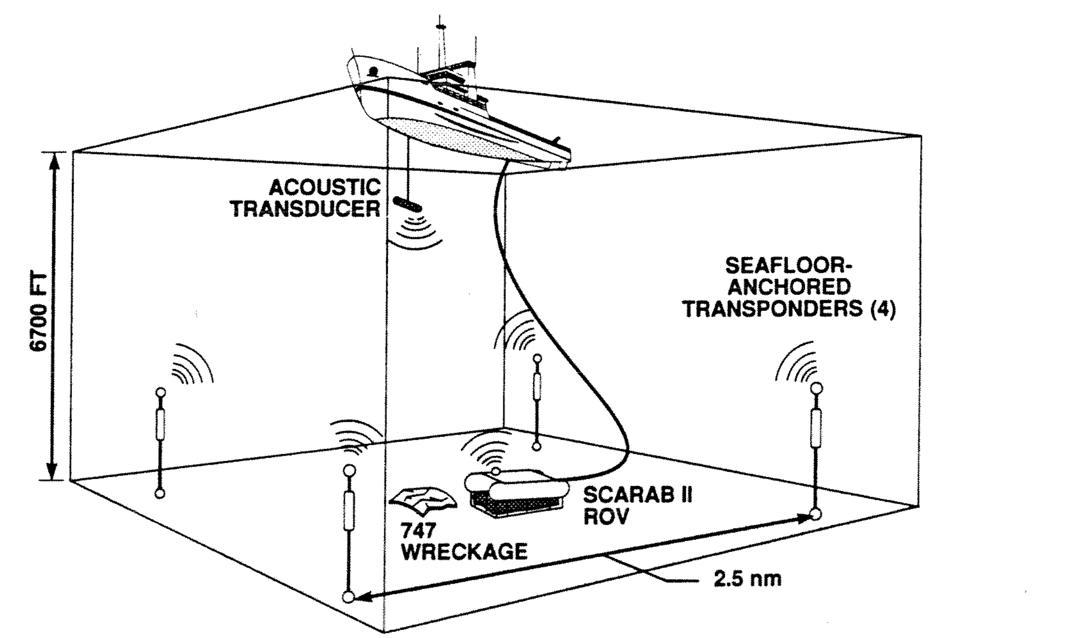


Figure 3-4. Positioning ROV by Long-Baseline System.

3-4.4 Search Support Vessels. Five ships were utilized to complete the search. Canadian Coast Guard ship CCGS JOHN CABOT and Canadian chartered vessel M/V LEON THEVENIN supported SCARAB I random search and SCARAB II photo-mapping operations respectively. Two Irish Navy ships, L E AOIFE and L E EITHNE, supported U.S. Navy TPL and side-scan sonar search operations. The M/V GARDLINE LOCATOR, a United Kingdom chartered vessel, supported the operation with TPL and hull-mounted side-scan sonar and deep-water echo sounder.

3-4.5 Search Chronology. Table 3-1 is a chronology of key events in the search and recorder recovery phases of the operation. The total time from the search operation's start to recovery of both data recorders was only 13 days.

3-4.6 Search Problems. Although the recording devices were recovered successfully during the search phase, there were technical and operational problems. Minor malfunctions of the search systems, support ships, and navigation systems were overcome and had little negative impact on progress.

Loose control of search assets had a negative effect on the search. Search vessels crossing the search area frequently interrupted efforts to localize pinger signals with TPLs. Poor search discipline that permits interference with primary search methods is one of the greatest hindrances to effective search effort.

Table 3-1. Search Chronology.

DATE	EVENT
23 June 1985	Air India Flight 182 crashes.
26 June	India requests U.S. assistance.
27 June	SUPSALV TPL system tested and shipped to Ireland.
28 June	SUPSALV TPL arrives Cork.
29 June	M/V GARDLINE LOCATOR begins search with UK TPL.
30 June	L E AOIFE begins search with SUPSALV TPL.
01 July	Primary search area redefined. About 80% of the new area searched.
02 July	M/V GARDLINE LOCATOR begins side-scan sonar search. M/V LEON THEVENIN begins search with SCARAB I. About 150 square miles searched to date.
04 July	L E AOIFE gains high-confidence contact at 50-59N, 012-40W. Search area reduced to 4 square NM.
06 July	U.S. and UK TPLs confirm position of flight and voice recorders at 51-02.6N, 012-48.6W.
07 July	SCARAB I identified numerous aircraft debris. SUPSALV side-scan sonar operating from L E EITHNE.
10 July	SCARAB I recovers cockpit voice recorder.
11 July	SCARAB I recovers flight recorder.
13 July	Recorders transferred to Indian government for study.
14 July	SUPSALV side-scan sonar contractor completes debris mapping of area. SUPSALV TPLs and side-scan sonar demobilized.

Large areas are searched most effectively by tracking quickly and accurately along predetermined grid lines with the most effective search tool. In this operation, the side-scan sonar ship was ordered to remain at least 1.5 nautical miles from the independently operating and randomly searching SCARAB. As the side-scan is the more effective search tool, the reversed priorities prevented an orderly grid search. The need to interrupt search lines to remain clear of the ROV unnecessarily extended the operation. A strong and clearly defined at-sea chain of command, with properly defined operational priorities, is required to prevent mutual interference among searchers.

Other problems and obstacles encountered during the search included:

- A thermocline at 230-foot depth. The thermocline did not affect TPLs towed below the zone, but did reduce the effectiveness of hull-mounted sonars and ROV tracking systems.

- A towed side-scan sonar malfunction occurred when L E EITHNE was searching in the high-probability area.

- Improperly tuned sonar on SCARAB I prevented location of the acoustic beacons for several days.

- Ship's service generator problems prevented JOHN CABOT from operating for several days.

- The SUPSALV deep-ocean winch failed several times during side-scan sonar operations.

3-5 RECOVERY OPERATIONS

Inconclusive evidence from the data recorders regarding the cause of the crash prompted the safety boards to pursue recovery of aircraft parts. The photo-documentation by SCARAB I during and after the data recorder recovery laid the ground work for debris recovery operations.

3-5.1 Recovery Plan. The basic recovery plan was to use an ROV and its support ship to attach lift lines to debris pieces, then pass the lines to a lift ship, which would complete the recovery. Once the lift lines were passed to the lift ship, the debris was raised to the surface and placed on deck.

3-5.2 Recovery Support Vessels. The two support ships were the Canadian cable ship CCGS JOHN CABOT and the chartered offshore supply vessel KREUZTURM. Adequate deck space for lift equipment and debris storage was the primary criterion for selecting KREUZTURM as a lift ship.

3-5.3 Recovery Procedures and Equipment. Recovery demanded a coordinated effort between the two ships and the ROV. To retrieve large pieces, the ROV secured attachment devices to a 1-inch aramid fiber lift line. After rigging was completed by the ROV, the bitter end of the lift line was attached to a buoy on the surface. The buoy was brought aboard KREUZTURM, and the lift line was taken to power. The ROV and support ship moved to rig the next piece on the priority list or to fill the collection basket. At the same time, the lift ship would retrieve the previously rigged item with the FADOSS equipment and portable crane. The procedure was repeated to recover 30 high-priority items totaling over 5,000 pounds. In theory, the plan was excellent; however, because of frequent ROV equipment malfunctions and umbilical or lift line fouling, many delays were encountered.

To recover small pieces, KREUZTURM lowered a basket to the seafloor as a repository for debris collected by SCARAB II. JOHN CABOT retrieved filled baskets. One basket recovery was successful; a second attempt failed when the debris washed out of the basket because of heavy seas and ship's roll when the basket was near the surface.

3-5.3.1 Lift System. SUPSALV's state-of-the-art lift system and a portable crane were mobilized for the recovery operations. The great depths of the lift called for motion-compensated lift equipment to prevent the lines from parting due to strains induced by ship motions in heavy seas. The FADOSS was installed in the support ship to reduce such dynamic loading on the lift line. FADOSS probably was the system most critical to the operation. Figure 3-5 shows the ram tensioner system.

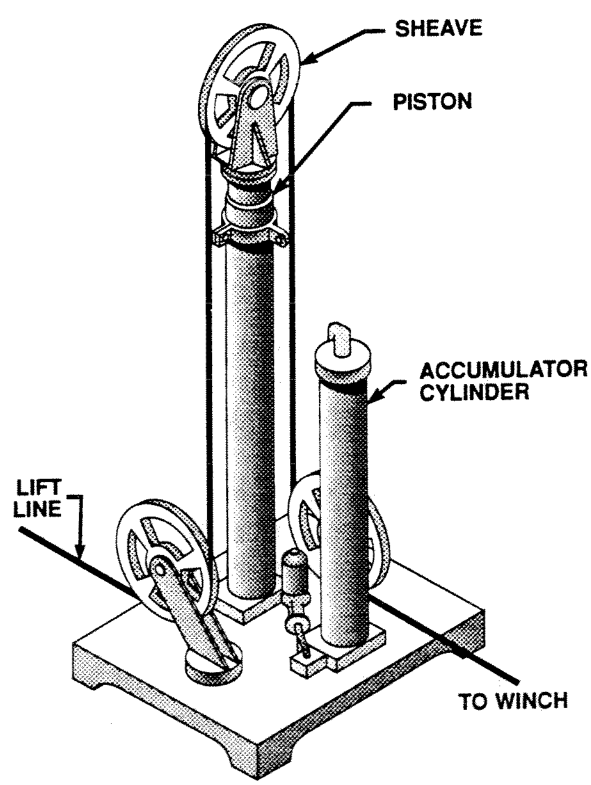


Figure 3-5. FADOSS Ram Tensioner System.

3-5.3.2 Underwater Systems. The ROV SCARAB II, nearly identical to SCARAB I which was employed in the search operation, was the primary underwater tool for recovery operations. The ROV's main functions were to:

- Relocate prioritized debris
- Rig attachment devices or lift bridles
- Rig lift lines
- Place items into a lift basket
- Aid in passing the lift line to the lift ship.

ROV movements were coordinated with those of the lift ship to recover large debris, and debris recovery continued for about one month after the salvage lift system demobilized. However, only a small amount of material was recovered by SCARAB II after the FADOSS was terminated.

3-5.3.3 Attachment Devices. The contractor fabricated attachment devices to secure the lift line to aircraft pieces. This well-designed equipment proved very reliable in lifting heavy pieces to the surface. As investigators were concerned about creating new damage or holing, damage caused by the devices was recorded diligently. Figure 3-6 shows lift line attachment devices developed for rigging wreckage in the Air India recovery operations.

3-5.4 Recovery Chronology. Table 3-2 is a chronology of key events noted during the aircraft recovery. The total recovery time following mobilization and arrival at the crash location was 21 days.

3-5.5 Recovery Problems. Problems during the recovery operation included:

- The availability of spare parts became critical to the continuity and timely completion of the recovery operations. The traction winch required repairs due to corroded connections and faulty directional control valves.

- SCARAB II required repair and parts replacement.

- The level wind system on the storage reel winch had design problems. The computer-controlled level wind was too complicated for the operators to repair effectively.

- SCARAB II's umbilical and the lift line often fouled when attempting to rig the line to the object. A swivel between the working end of the lift line and the ROV solved the problem.

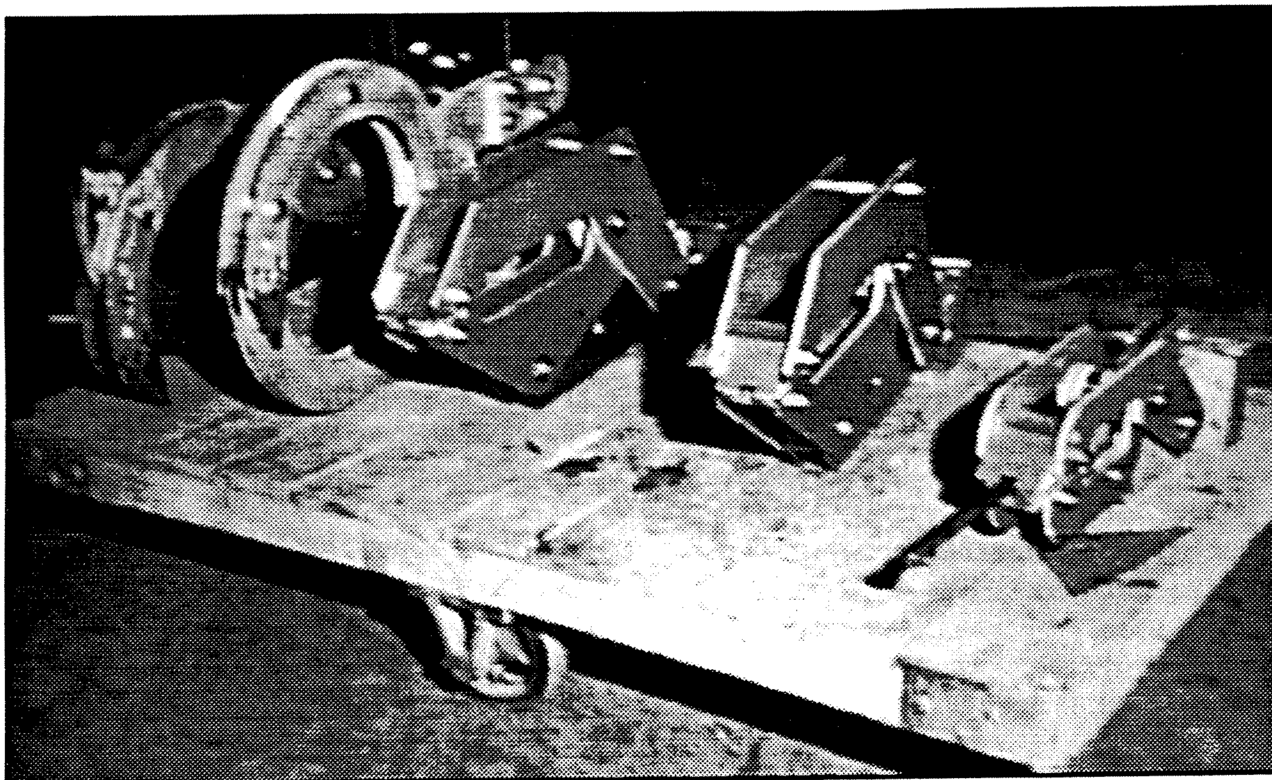


Figure 3-6. Lift Line Attachment Devices.

Table 3-2. Recovery Chronology.

DATE	EVENT
11 September 1985	SUPSALV chairs meeting to formulate recovery plan.
17 September	SUPSALV begins mobilization of lifting equipment.
19 September	NTSB requests USN to commence aircraft recovery. CNO tasks SUPSALV to provide technical assistance and equipment necessary to complete recovery before winter. SUPSALV tasks contractor to begin recovery effort.
4 October	KREUZTURM arrives at Cork, Ireland for equipment load-out.
9 October	Mobilization complete. Salvage ships enroute to operations area.
11 October	SCARAB II picks up first aircraft piece. Lift basket used to transfer pieces to surface.
15 October	First large debris piece recovered with FADOSS system onboard KREUZTURM.
31 October	Ninth and final lift completed. KREUZTURM departs for demobilization. SUPSALV underwater salvage effort completed.
6 November	FADOSS equipment and personnel demobilized.
9 December	SCARAB II operations terminated.

3-6 SUMMARY

Typical of most at-sea operations, the Air India search and recovery mission encountered problems, many of which were rectified in the field. The six ships and associated search and recovery equipment from the four participating countries — the U.S., Canada, Ireland, and Great Britain — are listed in Table 3-3. Early in the SCARAB II operations, two seafloor transponders generated spurious readings. Contractor technicians discovered that the transponder frequencies were very close to those corresponding to self-generated noise from the support ship's thrusters. Deploying two lower-frequency, substitute transponders eliminated the problem.

Earlier in 1985, the SUPSALV deep-ocean winch that supports side-scan sonar search had stored and deployed coaxial cable during sea trials of SUPSALV's ORION search system. When the coaxial cable was changed out for standard armored sonar cable in preparation for the Air India operations, spooling machinery capable of spinning the sonar cable onto the reel under tension was not available. As a result, cable kinking problems developed during the operation. As corrective action, the cable was paid out to the last wrap on the drum and reeled in under tow tension. This tensioning prevented possible tow cable damage under high-loading conditions.

The Fastnet Pulse 8 positioning system used during side-scan survey operations was adequate during daylight, but suffered from the same nighttime signal attenuation as the long-range OTH Decca system. Although surveying continued on a 24-hour basis, data acquired at night was suspect and made plotting more difficult.

In oceangoing operations, conditions are seldom ideal. The strength of a search and recovery mission always lies in the ability of on-site personnel to improvise, innovate, and do whatever is necessary to accomplish the mission, despite sometimes temperamental equipment.

Despite initial evidence to the contrary, chemical analysis of the recovered wreckage enabled the safety boards to determine that an explosion caused the crash of Flight 182. Because this objective was achieved, the operation was a complete success.

Recovery of the recorders from 6,700 feet of seawater was the deepest ocean salvage to date. The operation was a major step in the Navy's ability to salvage objects from the deep ocean.

Table 3-3. Search and Recovery Support Vessels.

SHIP	SEARCH/RECOVERY	DATA RECORDER RECOVERY ROLE
M/V GARDLINE LOCATOR (UK charter)	Towed UK TPL: searched with hull-mounted side-scan sonar, deep-water echo sounder.	Helped verify aircraft pinger locations.
L E AOIFE (Irish Navy)	Towed USN TPL.	Located pingers.
M/V LEON THEVENIN (Canada charter)	Supported SCARAB I random search.	Supported SCARAB I data recovery.
L E EITHNE (Irish Navy)	Towed SUPSALV side-scan sonar system to map debris field.	
M/V KREUTZTURM	Recovery. Primary debris lift platform utilizing the FADOSS and portable crane.	
CCGS JOHN CABOT (Canadian Coast Guard)	Assisted side-scan team; supported SCARAB II photo-mapping operations.	

CHAPTER 4

SOUTH AFRICAN AIRWAYS FLIGHT 295

4-1 INTRODUCTION

On 28 November 1987, South African Airways Flight 295, a Boeing 747, enroute from Taipei, Taiwan to South Africa, crashed into the Indian Ocean shortly before a scheduled stop at Plaisance Airport, Mauritius. Figure 4-1 shows the path of SAA Flight 295.

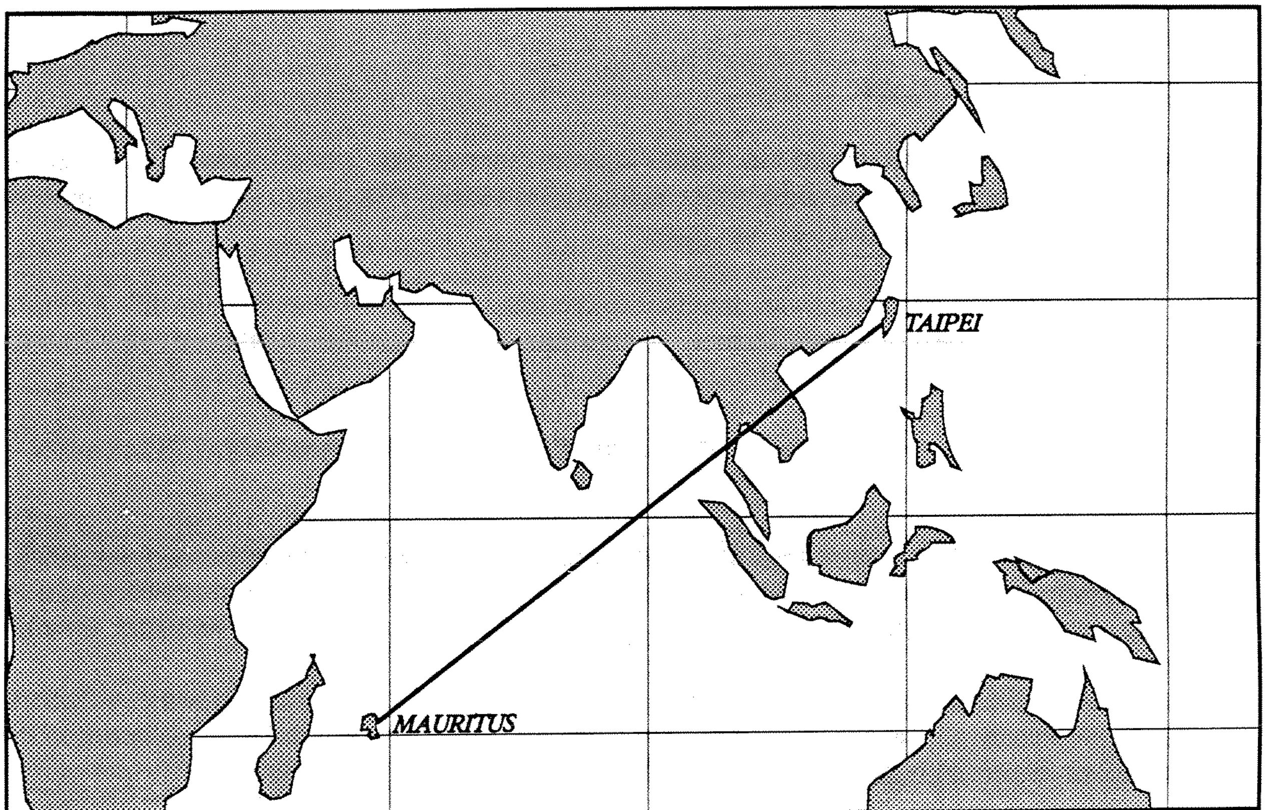


Figure 4-1. South African Airways Flight 295 Flight Path.

Both South African Government (SAG) and South African Airways (SAA) officials wanted to locate and recover the flight data recorders and wreckage from the aircraft to determine the cause of the crash. Just before the crash, the pilot reported smoke in the cockpit of the passenger/cargo aircraft. Speculation of a deliberate explosion was discounted by the SAG-headed international inquiry commission. Air and surface Search and Rescue (SAR) units discovered many pieces of floating debris. Debris positions produced a latitude and longitude upon which searchers based their datum.

4-2 TASKING

Soon after the crash, SAG requested U.S. Government assistance in locating the aircraft. The primary basis for asking the United States for aid was the U.S. Navy's history of successful deep-ocean aircraft salvage. Due to the humanitarian nature of the operation, the request received favorable response in spite of the Anti-Apartheid Act of 1986. As cooperation with SAG was politically sensitive, the State and Defense Departments maintained a high level of interest throughout the operation.

The Chief of Naval Operations tasked Naval Sea Systems Command, Supervisor of Salvage (SUPSALV) to mobilize equipment and technical experts to locate the aircraft. SUPSALV tasked their search operations contractor, Oceaneering International, Inc., to conduct both the Towed Pinger-Locator (TPL) and side-scan sonar searches.

4-3 OPERATIONS PLAN

The initial objective was to locate the flight data recorders or the aircraft debris field. Because the aircraft data recorders had underwater acoustic beacons, TPLs were chosen for the search. The search operation consisted of two phases:

- A TPL search phase was intended to continue for the 30-day beacon life or until the acoustic beacons were located. Concurrent with the search, a support vessel mapped seafloor contours.

- A side-scan sonar search was executed following the unsuccessful TPL search.

A recovery operation would follow location of the wreckage. The South African Department of Civil Aviation (DCA) considered that essential elements of the operations plan included development of a detailed map of major wreckage on the seafloor, as well as recovery of all data recorders, the after section of the fuselage, and the horizontal and vertical stabilizer assembly.

Recovery would be difficult and time-consuming because of the physical difficulty of operating in depths in excess of 14,000 feet, ships operating 130 miles at sea, and ROV operations based on spotty precision navigation. The objectives of the recovery phase were to:

- Photo-document the debris field and catalog debris positions for recovery.
- Recover selected items.

Wreckage was to be photo-documented in great detail as the recovery progressed. Even if nothing were recovered from the seafloor, the thousands of photographs and video tapes would give the commission a significant amount of evidence for the investigation.

4-4 SEARCH OPERATIONS

The primary search objectives were to:

- Locate the flight and voice data recorders using TPLs
- Identify the debris field and specific objects in the field using a sonar search for possible recovery.

4-4.1 Search Plan. SUPSALV and search personnel developed the two phased search plan whereby a primary search area would be determined based on:

- The position information on floating debris obtained from the initial SAR mission
- Data from a drift buoy, launched and monitored by a U.S. Navy P-3 aircraft based in Diego Garcia.

From the extrapolated positions, searchers outlined a 168 square mile search area (8 by 21 nautical miles) with its center at 19-06.46S, 50-48.16E.

The original plan called for two SUPSALV TPL systems -- one towed by a salvage vessel and one intended as a backup system if needed -- and the side-scan sonar search system, Deep Ocean Search System (DOSS). TPL test pingers would help determine the optimum search pattern and lane spacing based on the effective TPL detection ranges and water depth. As it turned out, both TPL systems, towed by two salvage vessels, JOHN ROSS and WOLRAAD WOLTEMADE were needed to ensure complete coverage of the total search area of 1,005 square miles within the 30 day life expectancy of the aircraft pinger batteries. The search plan also considered the use of other types of search equipment such as a listening array from the S.A Institute for Marine Technology, and a Simrad fish-finding and Plessey pinger locator.

An ARGO navigation system augmented by the Magnavox Global Positioning System and Magnavox 1107 Transit Satellite navigation system would provide TPL surface navigation.

Planned search procedures and techniques were refined as the search phase proceeded.

4-4.2 Search Systems. Two U.S. Navy TPL systems were the primary search tools for the initial phase. Each system consisted of a towed depressor containing a hydrophone and electronics, a tow cable and winch, and an operator-console housing the topside electronics.

The sonar search system was a contractor-owned Deep Ocean Search System (DOSS). DOSS was designed to work at full ocean depth. Multiplexed signals sent through a 30,000-foot coaxial cable resulted in recordings of extremely high quality for the operating depth. Dual sonar frequencies gave searchers the capability of having high resolution to identify targets or increased side-look range.

A mixture of other systems augmented the SUPSALV search equipment. Some provided information that aided in determining the debris field location; others were ineffective. This equipment included:

- Listening array. Assembled by the South African Institute for Maritime Technology. This device was ineffective, as it was unable to detect the test pinger.

- Simrad fish-finding system. This passive listening system, operated from support vessel R/V AFRICANA, recorded one contact that was the basis for establishing Search Area 2 in the sonar search phase.

- Plessey pinger locator. This system was unable to detect a test pinger, but was part of the electronic package that augmented the R/V AFRICANA system.

- Sea Beam survey system. This system, carried aboard the R/V SONNE, produced a detailed seafloor contour map.

Other equipment enhanced the side-scan sonar performance in the sonar search phase. Searches in extremely deep water with towed sonar can be risky if there are rapid changes in the seafloor profile. A deep echo sounder system onboard the side-scan support ship warned the search team of rapid seafloor profile changes. Profile information reduced the chance of towfish-seafloor contact and resulted in a more consistent sonar run.

4-4.3 Navigation Systems. Precision navigation requirements for the search phases were no different from those of other deep-ocean operations. Continuous, accurate navigation signals are mandatory to ensure 100-percent seafloor coverage with any search system. With 100-percent overlap on each sonar run, searchers avoid gaps in the search pattern. Navigation accuracy during the TPL search was less than optimum. Precision navigation coverage was available about 18 hours per day. Navigation relied upon intermittent satellite fixes and dead reckoning during periods of poor navigation signals. Operators became more adept at following the planned search tracks as knowledge of prevailing set and drift increased during the operation.

4-4.3.1 TPL Surface Navigation. An ARGO navigation system was based at shore sites on Mauritius, Rodrigues, and Cocos Island. The medium-range, Over-the-Horizon (OTH) system could position the search vessel within a ± 5-yard radius at ranges up to 400 miles during the day. At night, the range reduced drastically to 150 miles. The distances from the shore stations to the search site far exceeded the night range.

Two systems augmented ARGO — the Magnavox Global Positioning System (GPS) and Magnavox 1107 Transit Satellite navigation system. Because the GPS system was not fully operational, satellite positioning was available only part time. During periods of ARGO and GPS non-availability, the Magnavox Transit equipment produced fixes once every one and one-half hours, with intermediate dead reckoning plots incorporating manual speed and course inputs. Because no vessel turns were made until an updated satellite fix could be recorded, there were no position-fixing gaps between survey lines.

4-4.3.2 Side-Scan Surface Navigation. Following the TPL search, ARGO was replaced with the Geoloc navigation system. This OTH, low-frequency, long-range system furnished reliable navigation information around the clock. Geoloc had a range of approximately 620 miles and was immune to the tropospheric and skywave interference common to other medium- and long-range precision navigation systems. Geoloc typically provided 15- to 30-foot accuracy.

4-4.3.3 Subsea Navigation. Searchers considered a Long-Baseline (LBL) navigation system, but determined that it was unnecessary for the side-scan sonar search. This decision was based on cost, mobilization and deployment time, and incompatibility with DOSS.

4-4.4 Search Support Vessels. Military and commercial assets participated in the SAR mission. The navigation accuracy of sonobuoys from the U.S. Navy P-3 aircraft resulted in data that proved crucial to determining a highly reliable datum.

The several vessels that participated in varying roles during both phases of the search included:

- South African ocean tug charters M/V WOLRAAD WOLTEMADE and M/V JOHN ROSS for SUPSALV TPL system support and SAG offshore vessel charter, M/V VETYVER, for shuttle and logistics support
- South African Navy ship, SAN TAFELBERG, for helo and navigation station support
- German research vessel charter, R/V SONNE, for seafloor contour charting and photographic support
- South African Fisheries research vessel, R/V AFRICANA, for hull-mounted sonar listening search
- Singapore offshore vessel charter, M/V OMEGA 801, for SUPSALV side-scan sonar system support.

There were very few problems encountered with this flotilla, even though some of the ships had never participated in this type of operation.

4-4.5 Search Chronology. Two TPL systems, towed by the salvage vessels JOHN ROSS and WOLRAAD WOLTEMADE, covered the search areas. Lane spacing for the TPL towing ships was one mile. The TPLs were towed at a speed of 2.5 to 3 knots, in depths ranging between 4,800 and 6,400 feet. Because the effective range of the TPLs was just over one mile, this lane spacing produced a 100-percent overlap. This degree of overlap was prudent because of frequently insufficient precision navigation.

The German Research Vessel SONNE was in port in Mauritius as the TPL search was in progress. The vessel carries a Sea Beam bottom mapping system and camera sled capable of operating in 20,000-foot depths. At the invitation of SAG and concurrent with the TPL search, SONNE produced a detailed seafloor contour map.

After all hope of locating the pingers was exhausted, the TPLs were demobilized and plans for the sonar search were implemented. Upon review of TPL contacts, the primary search area was refined.

The SONNE seafloor survey information provided the basis for revising sonar search procedures. Selecting the most efficient and safest axis along which to run the search lines was simplified because the survey presented an accurate picture of the direction and degree of seafloor slope. Searchers decided to tow in a westerly direction along 10-NM-long grid lines with a 980-foot lane spacing to achieve 100-percent overlap. Running downhill reduced the chances of the towbody's hitting the seafloor. Figure 4-2 shows the seafloor contours in the search area. Deep-Ocean Transponders (DOT) were deployed to marked targets recorded by the side-scan sonar.

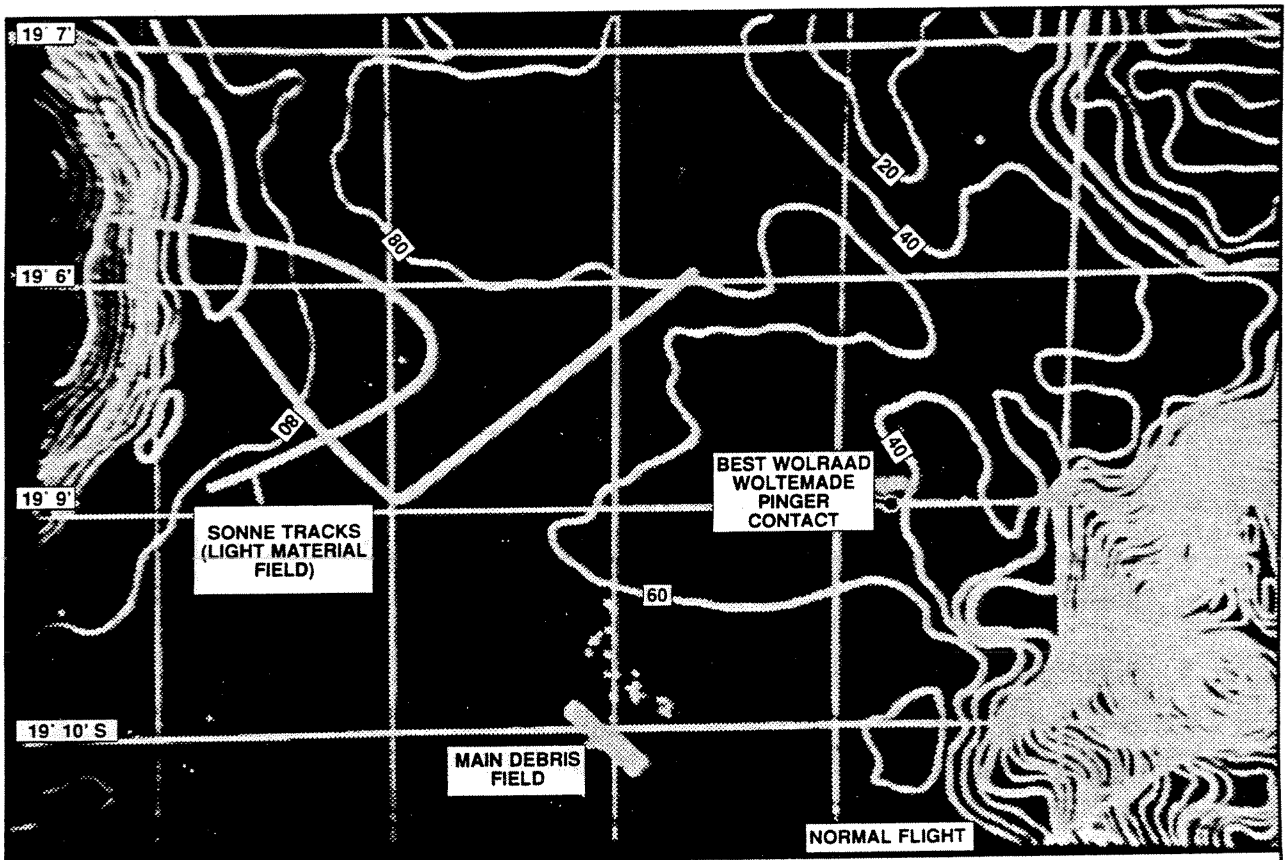


Figure 4-2. Seafloor Contour Chart.

Table 4-1 is a chronology of key search events of the South African Airways Flight 295 operation. The total time spent actually searching for the aircraft was about 25 days.

4-4.6 Search Problems. This operation encountered the myriad small problems expected in complex, deep-ocean searches. The pingers did not operate. It appeared that their batteries had melted in a fire before the aircraft crashed. A TPL was lost while being towed over a submerged mountain peak in an uncharted area. The navigation problems in the TPL phase — lack of 24-hour availability of any single navigation system — were eliminated in the sonar search phase when the Geoloc OTH system became the primary positioning system. Although some systems did not perform as expected or in conformance with design, the overall performance of the equipment was good, particularly as this was the deepest search for aircraft debris yet conducted in any ocean. As advisor to the operation, SUPSALV assisted SAG in screening out underqualified operators.

Table 4-1. Search Chronology.

DATE	EVENT
28 November 1987	South African Airways Flight 295 crashes. SAR begins with local assets. At 1730, aircraft debris spotted at position 19-04S and 59-36E.
3 December	U.S. and S.A. Governments sign agreement to use U.S. assets.
4 December	SUPSALV directed to assist in aircraft location.
5 December	TPL search equipment mobilized to Mauritius.
11/12 December	M/V WOLRAAD WOLTEMADE and M/V JOHN ROSS commence TPL search. R/V SONNE commences hydrographic survey of area with Sea Beam system.
14 December	M/V WOLRAAD WOLTEMADE reports possible pinger signal recorded as target S2 at position 19-08S and 59-39E.
17 December	R/V AFRICANA joins the search with hull-mounted sonar.
24 December	M/V WOLRAAD WOLTEMADE loses TPL and over 12,500 feet of cable. Returns to port for demobilization next day.
2 January 1988	Phase I TPL operations concluded. Ships return to port for demobilization.
3 January	Phase II planning and mobilization continues.
9 January	Phase I demobilization completed.
23 January	M/V OMEGA 801 departs for search area.
26 January	Side-scan sonar search begins.
29 January	Debris field identified. Field axis 120°/300°T, centered at 19-10.9S and 59-37.95E.
30 January	Debris area marked with deep-ocean transponders.
2 February	Debris field mapping completed.
8-12 February	Second debris mapping done with EG&G sonar system for system comparison with *smart fish* records.
16 February	Phase II demobilization completed. Phase III planning and execution proceeding.

4-5 RECOVERY OPERATIONS

The aircraft recovery operation was to include complete photo documentation of the debris field before recovery of high-interest items. SAA awarded the salvage contract to Eastport International, Inc., because of their past successes in aircraft wreckage salvage — notably the space shuttle CHALLENGER and Air India Flight 182. This phase was a commercial venture, with SUPSALV advising the SAG and SAA , and providing a representative on scene throughout the recovery phase. SUPSALV furnished some Navy-owned, contractor-operated equipment to support ROV operations.

Planning for this phase began during the search portion of the operation, although the salvage contract was not awarded until three months after the debris field was mapped with sonar. Following contractor selection, an intensive four months were spent assembling and mobilizing salvage equipment.

Eastport International engineered and purpose-built the ROV GEMINI for this type of photomapping and salvage mission. To support the ROV, highly specialized and complex vehicle handling, seafloor navigation, and lift systems were assembled. While most components or concepts of all support systems had been operated individually, they had not been integrated into a single salvage system and operationally tested as such. Technical and operational testing took place after the system was assembled on scene during actual working dives with GEMINI.

Experts from the Federal Aviation Administration, National Transportation Safety Board, and the Boeing Company were present as advisors for the duration of the recovery phase.

4-5.1 Recovery Plan. Because of the size and depth of the operation, this phase had several distinct steps. The major events of the photomapping and recovery plan included:

- Mobilizing systems and personnel to Mauritius
- Assembling systems onboard the support ship
- Re-acquiring the debris field DOTs placed during sonar debris mapping
- Installing seafloor navigation transponder field
- Surveying and photo-documenting aircraft debris
- Salvaging selected debris
- Salvaging the transponder field and demobilizing.

The Swedish-registered, multi-purpose, offshore maintenance and diving vessel M/V STENA WORKHORSE was used to support the ROV GEMINI and the recovery systems. Once the navigation field was installed and calibrated from the support ship, GEMINI operations were the key to the remainder of the plan. In addition to supplying real-time video and still photograph documentation, the ROV would perform complicated rigging for retrieving aircraft wreckage. Debris was recovered by:

- Lift lines and attachment devices rigged directly to debris
- Lift baskets filled with debris
- ROV manipulators holding material
- Lift lines attached to the ROV.

The initial intent was to survey the entire debris field with GEMINI cameras before retrieving any aircraft wreckage except data recorders. As photomapping progressed, this rule was eased. Side-scan sonar traces showed that the aircraft had broken into hundreds of thousands of pieces upon impact, creating a very complex debris field. To eliminate the need to return to a target in this complex field, targets encountered during photomapping were recovered immediately. The ROV left targets only when technical experts were satisfied with the video coverage provided.

The success of this phase depended upon the dexterity of the personnel directing GEMINI. The ability of the contractor to keep the ROV and salvage support systems operating smoothly was a critical element in the success formula.

4-5.2 Recovery Support Vessel. STENA WORKHORSE served as the GEMINI support vessel. The ship's navigation and dynamic positioning systems allowed operations far at sea and during adverse weather. Deck space for ROV and recovery equipment, as well as debris storage, was as important as the ship's stationkeeping ability. In addition, hotel services and stores for extended at-sea periods for 30 to 40 additional personnel were necessary. STENA WORKHORSE fulfilled all of these operational prerequisites and proved worthy of all assigned tasks. Figure 4-3 shows the arrangement of GEMINI with handling and lift systems aboard STENA WORKHORSE.

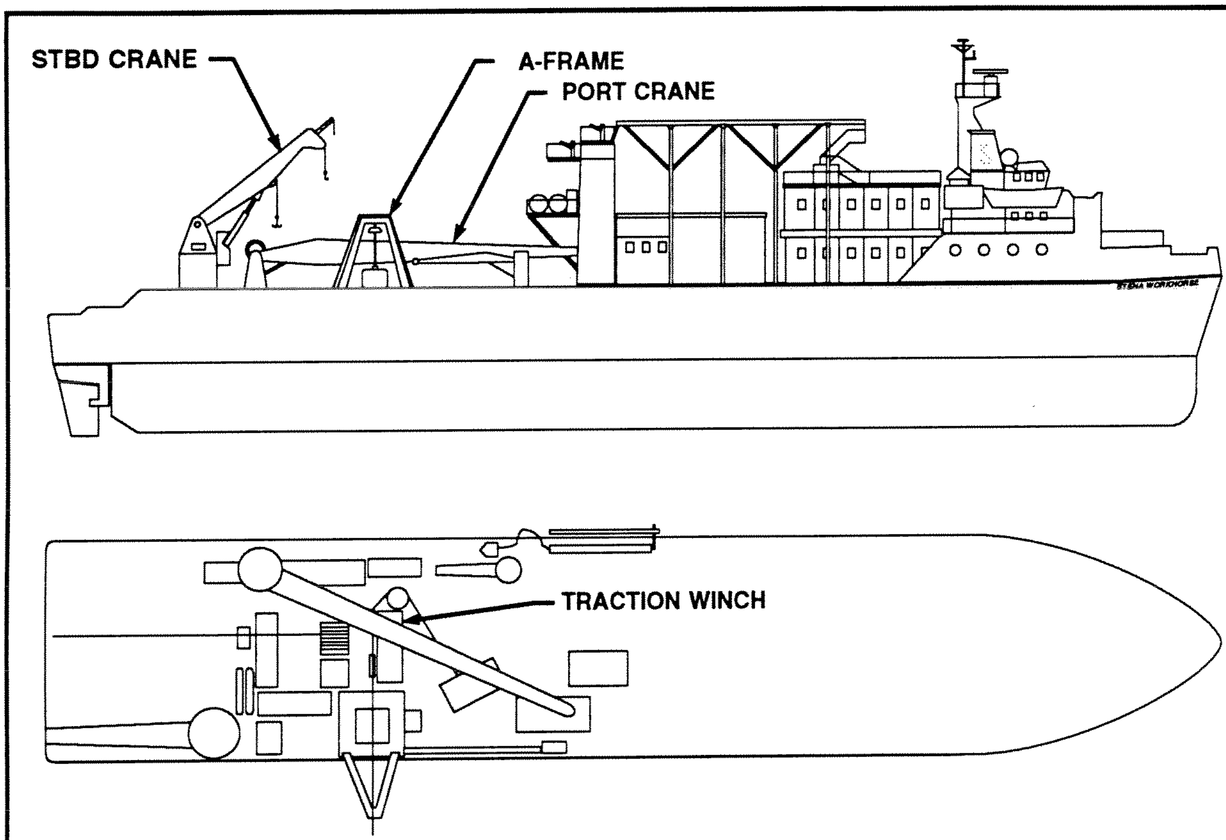


Figure 4-3. STENA WORKHORSE with GEMINI Handling Systems, Lift Systems.

Noise signature was a negative feature of STENA WORKHORSE. Noise interference proved to be a major problem; it masked the seafloor navigation acoustic signals. The noise interference increased in proportion to the amount of propulsion needed to counter high seas and winds. Selectively shutting down machinery eliminated noise interference but also reduced stationkeeping capability. Attempts at baffling the noise from the transceivers were not successful.

Other vessels supporting the recovery phase were:

- UMBRINA. A small motor/sail boat chartered from the mobilization shipyard for shuttling personnel and supplies.

- FREYJA. A small chartered vessel also utilized for resupply between the recovery site and shore base.

4-5.3 Recovery Procedures and Equipment. The great depth from which debris was recovered required specialized techniques and deep-ocean lift equipment. Dynamic loading and secure fastening of lift lines to avoid loss during lifts were major concerns.

Recovery hardware similar to equipment that had proven successful in past salvages was assembled or fabricated. Special attachment devices were made for this operation. Even with the best equipment available, at least two significant targets were dropped while being lifted.

4-5.3.1 Remotely Operated Vehicle. The ROV GEMINI was well suited for this operation with its 20,000-foot depth rating. The 80-horsepower thrusters were powerful enough to ensure maneuverability against current-produced forces acting against more than three miles of umbilical. Redundancy, including eight optic fibers, dual sonars and manipulators, and multiple photo/video systems, increased the ROV's operational flexibility. Figure 4-4 shows the ROV during launch from STENA WORKHORSE.

4-5.3.2 GEMINI Support Systems. ROV support systems are as complex and critical to the operation's success as the ROV. Failure of any component could shut down the operation. Major components of the support systems included:

- ROV umbilical. An ROV umbilical was manufactured specifically for this operation. The 21,440-foot, continuous-length, Kevlar®-strengthened cable delivered power and communications to GEMINI via fiber optics. It also served to launch and recover the ROV. Cable strength was most important because of the dynamic forces acting on the cable during ROV descent and ascent. Several reterminations were necessary during the recovery phase. A catastrophic failure of the cable fiber optics during the early in-water testing resulted in an operational break of over one month. The cable was shortened to 17,000 feet, reterminated, and successfully used in photo-mapping and debris recovery. A 16,600-foot-long, steel-armored, fiber-optic cable was manufactured as a backup to the Kevlar®-strengthened umbilical. This cable was much heavier and required surface shipping to the mobilization site. Fortunately, the steel-armored cable was never put into service; because of dynamic loading, its ability to perform safely was suspect.

- A-frame for launch and recovery. A hydraulically operated, aluminum A-frame designed to launch and recover GEMINI was installed over the starboard wing wall of STENA WORKHORSE. Although the design was similar to other proven recovery devices, this system was used for the first time during actual ROV launch and recovery on site. The A-frame proved satisfactory after considerable structural and vehicle housing alignment problems were overcome.

Figure 4-4. Launching GEMINI.

- Traction winch. During initial operations, the traction winch tore the umbilical. A solution to this problem was found, and the winch proved to be highly satisfactory.

- Umbilical take-up storage reel. The levelwind did not spool cable properly and performed erratically as it took up or paid out cable to the traction winch. Technicians solved these problems during the first at-sea period.

If any one of these systems was down, the ROV could not operate. Failure of one of these critical components while GEMINI was on the seafloor could result in loss of the ROV. Systems for directing the ROV were also critical. However, these systems enjoyed a considerable amount of spare part support and were kept operational at all times because of the technical expertise on scene.

4-5.3.3 Lift Systems. Ship-motion-produced, dynamic loading forces dictated a motion-compensated heavy lift system to retrieve the heavier aircraft pieces. A 25,000-pound-capacity deep-ocean, ram-tensioned traction winch system and a high strength-to-size ratio Kevlar® line reduced dynamic loading and the chance of losing objects during the lift. The 19,500-foot, one-inch diameter, nylon-jacketed Kevlar® line was well suited for deep-ocean lifting. Even with this equipment, some aircraft debris was lost enroute to the surface because lines parted or objects slipped from the attachment tools.

A contractor-designed, seafloor-functioning lift-line reel held all of the Kevlar® line for lifting. With this reel, there was only one line in the water column during ROV operations. Some innovative techniques were required to haul the reel to the seafloor, attach it to objects, recover the vehicle, and retrieve objects without entanglement. These tasks were accomplished by:

- Suspending the reel beneath GEMINI for transport to the seafloor.
- Releasing the reel on the seafloor, retrieving a short pendant, and connecting it to the object to be lifted.
- Returning to the reel and securely attaching the lift line to the pendent.
- Paying out the lift line as the ROV ascended.
- Salvaging GEMINI and passing the lift line through a fairlead block to the traction winch.
- Hauling the reel and attached object from the seafloor to just below the surface with the traction winch. There, transferring the object to another line for the final lift to the deck of the ship.

GEMINI could lift debris weighing up to 1,000 pounds directly from the seafloor with the manipulators or lift lines secured to her frame. To avoid over-stress and damage to the irreplaceable umbilical, the reel-mounted lift line, rather than the ROV, lifted heavy objects. Many lifts were made with wire rope straps passed through a strong point on the object and shackled onto the lift line or ROV lift line. This rigging required a highly skilled ROV operator. However wreckage was lifted, an attachment device bound the lines to the object.

4-5.4 Navigation Systems. Continuous computation of ship, ROV, and target positions was achieved — to a limited degree — by computer integration of surface and subsurface position data. ALLNAV, an integrated navigation system, performed the calculations for precise ship and ROV positioning. This computer-operated system updated all positions automatically after the seafloor navigation grid became operational. Figure 4-5 depicts the various functions and systems integrated by ALLNAV.

The accuracy of the positioning changed throughout the operation. Satellite coverage for surface positioning was not available at all times. Ship operating noises, long distances between transponders and surface receivers, physical properties of the water column, and acoustic masking interfered with the ability to compute accurate positions from seafloor transponders. As the recovery phase progressed and additional transponders were deployed, accuracy improved.

4-5.4.1 Surface Navigation. The Global Positioning System (GPS) supplied accurate positioning information to ALLNAV. GPS inputs were used when the seafloor transponders were installed and calibrated. As GPS coverage was available for only about five hours per day, the acoustic tracking system and a Magnavox Transit satellite system backed up the GPS.

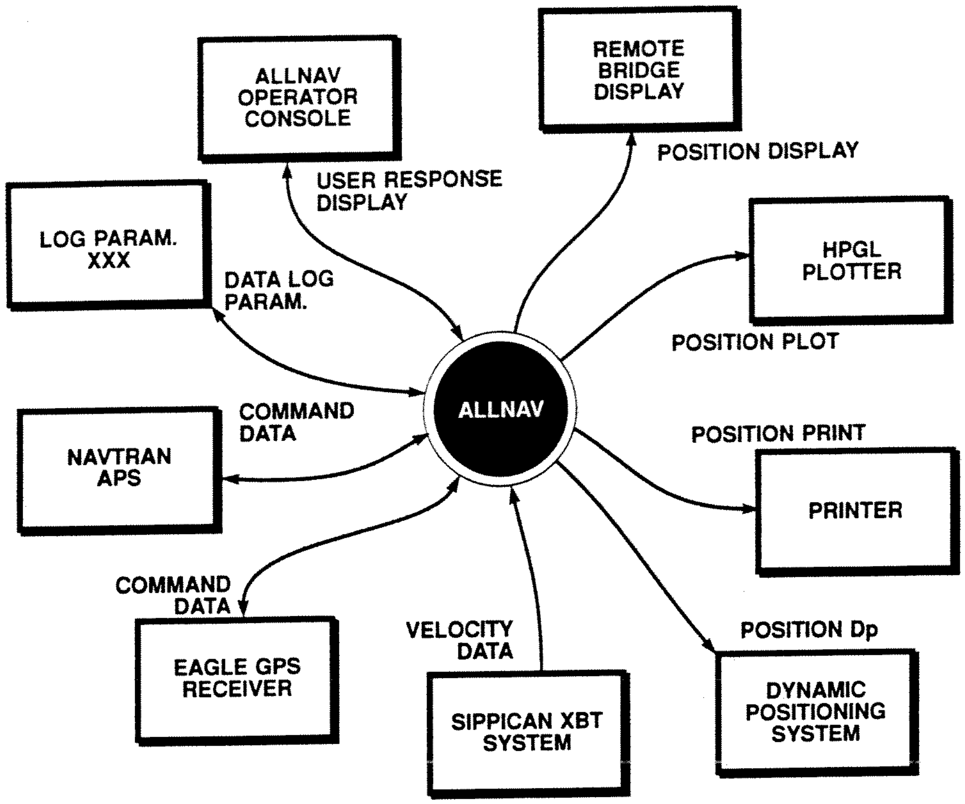


Figure 4-5. ALLNAV Integrated Navigation System.

4-5.4.2 Subsea Navigation. Accurate underwater navigation was critical to the operation's success. A three-transponder, seafloor navigation grid was put into place during the first at-sea period of the recovery phase. The 3-mile-long triangular legs of this Long-Baseline (LBL) navigation system produced a grid that was deemed sufficient to cover the debris field. However, as the support ship moved, it was at or beyond some of the transponders' effective range. A fourth transponder near the debris field datum provided additional navigation data. Two additional navigation grid transponders were placed to improve accuracy when GEMINI was operating at depth.

The navigation system operated as follows:

- The acoustic LBL navigation system tracked the ship relative to the seafloor transponders.
- The ROV was tracked on the seafloor relative to the same transponder net with a Sonardyne ROV navigation (ROVNAV) system.
- The ROV was tracked relative to the support ship with Trackpoint, a high-power acoustic responder.

The ALLNAV integrated navigation system tied all of the various positions together with a CRT color graphics plot, a page plot of the wreckage field, and a magnetic data log. Remote displays and plotters allowed officials to monitor the operation.

4-5.5 Recovery Chronology. Table 4-2 is a chronology of key events during Phase III. After GEMINI reached the seafloor, the photo-mapping and recovery required 71 days.

Table 4-2. Phase III Chronology.

DATE	EVENT
09 May 1988	Salvage contract awarded.
05 September	M/V STENA WORKHORSE departs Singapore with ROV GEMINI onboard.
22 September	STENA WORKHORSE underway for recovery operation.
05 October	Navigation grid operational.
08 October	ROV umbilical optic fibers severed. Operation suspended.
06 November	Shortened umbilical re-installed.
22 November	GEMINI dives to 14,600 feet. SAA 295 wreckage confirmed. Debris mapping commences.
28 December	Spare ROV umbilical stored ashore in reserve.
01 January 1989	Cockpit voice recorder recovered by GEMINI.
01 February	Debris mapping phase completed. Commenced debris recovery phase.
07 March	Aircraft salvage operation completed. Demobilization commences.

4-5.6 Recovery Problems. Equipment problems are expected when salvaging objects from the ocean floor, especially when systems become operational without having been tested as a unit. This operation was no exception. The following were some of the problems encountered:

- Navigation.
  - Surface: Tracking the ship on the surface was difficult at times because no single navigation system offered 24-hour coverage. Dead-reckoning plots were maintained between satellite fixes, using manual course and speed inputs.
  - Subsea: The LBL acoustic system had difficulties because accuracy degraded as the ship moved out of the range of the bottom transponders. This surface ship noise problem was corrected somewhat by deploying additional transponders. In vehicle navigation, the vehicle's hydraulic noise interfered with acoustic tracking.
- Vehicle umbilical. The fiber-optic cable suffered a catastrophic failure during early testing and was out of commission for nearly one month.
- Key debris loss. A significant piece of debris slipped away from the grippers as the GEMINI vehicle neared the surface, due to ship motion.

- Logistics. Expediting cargo through customs to Mauritius for mobilization to the operations site was a continuing challenge.

In the SAA Flight 295 salvage, each equipment problem had to be solved on scene, half a world away from the technical support staffs. The improvisational skill of SUPSALV and contractor personnel was fully tested in overcoming these problems, which were typical of at-sea operations. Solutions were found to enable successful completion of the mission.

4-6 SUMMARY

The SAA Flight 295 search and recovery operation was completely successful and carried out in record-setting depths. The success of this operation demonstrates the advances of search and recovery technology in the brief period — less than two and a half years — between the Air India crash and this crash. But even successful missions are characterized by equipment problems at either the component or system level.

Positioning was a continuing source of frustration to searchers during the TPL search phase. The ARGO long-range OTH system, the primary navigation system used in the TPL search phase, was operative in good weather between approximately 0700 and 1900, at which time it disappeared with the onset of skywave interference at dusk. The Transit satellite was used as a backup reference between 1900 and 0000, followed by the GPS satellite between 0000 and 0700. GPS and ARGO coverage overlapped for about one hour from 0700 to 0800. The GPS satellite provided the fixed reference point crucial to re-calibration of the ARGO system during the overlap period. During the side-scan sonar operations, the Geoloc long-range navigation system replaced ARGO as the primary positioning system, and proved to be both reliable and accurate.

During the side-scan sonar phase, Oceaneering International experienced two problems with its Deep Ocean Search System (DOSS). The 30,000-foot sonar cable slipped on the traction sheaves. This was due to the grease coating applied to new cables (this was a brand-new cable acquired from Woods Hole Oceanographic Institution). Once the cable had been cycled over the sheaves a couple of times, the grease layer had worn off and there was no further problem. The second problem occurred in the 100-kHz side-scan electronics. One channel was inoperative at this frequency, making it impossible to operate the sonar as Oceaneering had intended — i.e., running the system at 50 kHz to locate the debris field and switching to 100 kHz in order to obtain higher resolution for individual pieces in the field. After several futile hours spent trying to repair the channel, technicians elected to run the survey with one 100 kHz and one 50 kHz channel.

A coordinated multinational, multi-agency team effort supported by the ships listed in Table 4-3 contributed to the success of the salvage mission. Among organizations playing crucial roles in the overall project were SAG, SAA, SUPSALV, and contractor personnel.

The SAA Flight 295 operation is particularly noteworthy because it was executed in a remote area with components that had never been integrated and tested as a system. While delays and frustration accompanied this mode of operation, exigencies of the situation required rapid response. The ability of the operators and managers to overcome emergent technical difficulties was a tribute to both their technical competence and perseverance.

Table 4-3. Search and Recovery Vessels.

SHIP	SEARCH/RECOVERY ROLE
M/V WOLRAAD WOLTEMADE	South African ocean tug charter. Supported SUPSALV TPL system. Recorded the most promising pinger contacts.
R/V SONNE	German research vessel charter. Produced seafloor contour charts and photographed high-interest areas during the TPL search. Identified some aircraft debris.
R/V AFRICANA	South African Fisheries research vessel. Conducted hull- mounted sonar listening search for aircraft beacons during the TPL search.
M/V JOHN ROSS	South African ocean tug charter. Supported SUPSALV TPL system.
M/V OMEGA 801	Singapore offshore vessel charter. Supported SUPSALV side-scan sonar system.
SAN TAFELBERG	South African Navy ship. Support role for setting up navigation stations. Provided helo support.
M/V STENA WORKHORSE	Recovery. Swedish offshore maintenance and diving vessel charter. Supported ROV GEMINI and recovery systems.
UMBRINA	Recovery. Small motor/sail vessel charter for personnel and supply shuttles.
FREYJA	Recovery. Small vessel charter for resupply shuttle.
M/V VETYVER	SAG charter. Shuttle and support vessel for both search phases. Transported navigation systems.

CHAPTER 5

UNITED AIRLINES FLIGHT 811

5-1 INTRODUCTION

On 24 February 1989, United Airlines Flight 811, a Boeing 747, was approximately 100 miles south of Honolulu airport passing through 22,000 feet, bound for New Zealand, when a cargo door's securing devices failed, allowing the door and a portion of the fuselage above it to separate from the aircraft. Nine passengers were swept through an opening in the fuselage. The aircraft returned safely to Honolulu.

5-2 TASKING

The National Transportation Safety Board (NTSB) investigation produced evidence of the cause of the failure; in order to be certain, the Board initiated action to find and retrieve the cargo door. Excellent data for the search datum gave a high probability of success. The NTSB requested assistance from the Chief of Naval Operations who, in turn, tasked the Naval Sea Systems Command Supervisor of Salvage (SUPSALV) to conduct the search and recovery effort.

SUPSALV tasked Oceaneering International, Inc., to conduct the search using the SUPSALV ORION sonar system. The SUPSALV Flyaway Deep Ocean Salvage System (FADOSS) was mobilized by the ESSM contractor Global Phillips Cartner, to support the salvage effort. Commander, Submarine Development Group One (CSDG-1), in response to a SUPSALV request, provided the manned Deep Submergence Vehicle (DSV) SEA CLIFF, on board the Deep Submergence Vehicle Support Ship (DSVSS) LANEY CHOUEST, to conduct the recovery.

5-3 OPERATIONS PLAN

This deep-ocean search and recovery operation was straightforward. The search, location, and working depths anticipated were well within the Navy's technical capabilities. The operations plan had two phases — search and recovery.

The search phase employed SUPSALV's newest deep-ocean search system, ORION, deployed from the USNS NARRAGANSETT (T-ATF 167).

The primary recovery system was the DSV-4 SEA CLIFF, operating from the DSVSS LANEY CHOUEST, a chartered offshore supply vessel. This ship also carried SUPSALV's FADOSS to assist in hoisting aircraft debris aboard.

Representatives from the NTSB, Federal Aviation Administration (FAA), Boeing, and United Airlines were present during the entire operation. They provided operational support in aircraft technical matters.

5-4 SEARCH OPERATIONS

The primary search objectives were to locate, identify, and mark the position of the cargo door. To do this, ORION — a side-scanning sonar equipped with a TV camera — would be used to locate the debris field and, if possible, visually verify the field. Because ORION was in the final stages of a major overhaul, the operation was delayed until the system had been put back together. The delay was justified by the quantum improvement of this search system compared with others.

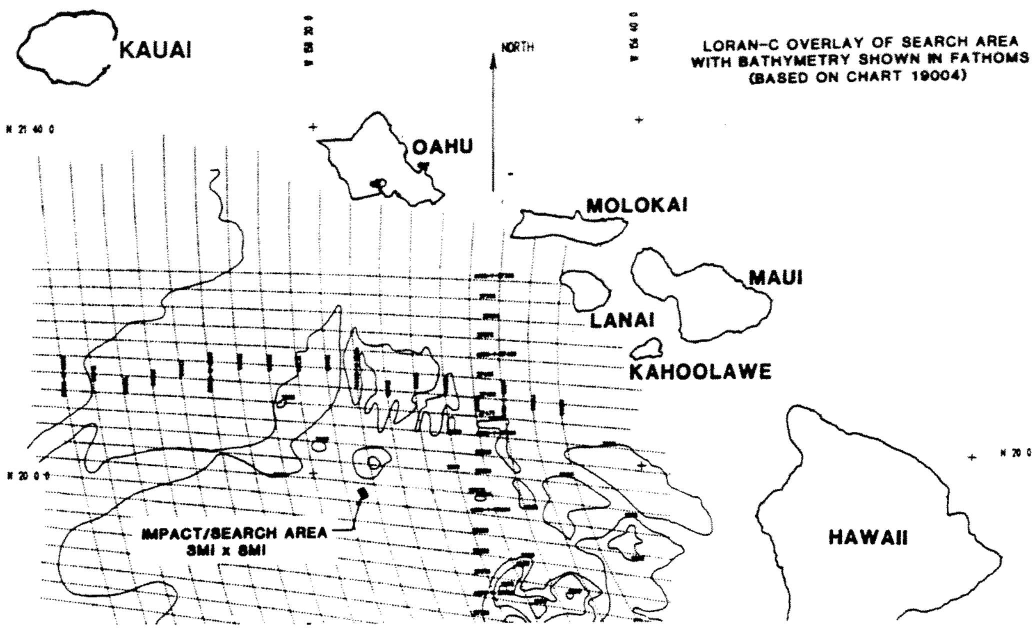
5-4.1 Search Plan. Search operating procedures were based on position information derived from U.S. Navy radar that tracked falling debris and placed the datum about 97 miles south of Honolulu at 19-57.22N 158-27.44W. The source of the positioning data was unusual; aircraft parts falling at sea are seldom tracked by radar. It is more common for the aircraft simply to disappear from the scope, which means the datum must be projected from flight data.

Fifty-seven parallel north-south lines were programmed for the search. Figure 5-1 shows the primary search area with the initial datum and transponder positions.

ORION was to be towed methodically along the north-south lines to ensure 100- percent coverage of the area. Because the lines, numbered 1 through 57, were spaced only 100 meters apart, there was more than enough overlap when adjacent lines were run to avoid gaps in the search. The first search line was through datum along line 28 on heading 180°T. Because winds and currents adversely affected ORION's position behind the towing ship, all subsequent search lines were run to the north.

Contacts were to be further prosecuted with short-range, high-resolution sonar and, finally, visually. After the target judged most likely to be the door was localized by the high-resolution sonar, it was to be positively identified with ORION's video imaging system. It was originally planned for ORION's marker deployment system to place an acoustic pinger near the door to allow searchers or the salvage team to return to the position. As the recovery vehicle, SEA CLIFF, was unable to detect the ORION acoustic beacon, a Deep Ocean Transponder (DOT) was deployed to mark the recovery phase datum. Placing the DOT ended the search phase.

5-4.2 Search Systems. ORION can locate, positively identify, and mark targets in depths to 20,000 feet. The dual-frequency, side-scan sonar operates simultaneously at 50 and 500 kHz. These two frequencies allow location of very small objects at short range and large targets at ranges up to 1,000 meters.



- UNITED FLT 811 CARGO DOOR LOST 24 FEB 1989
- POSITION 19 57' 22W 158 27' 44N
- SEARCH AREA IS 15,000 FT DEEP WITH FLAT BOTTOM

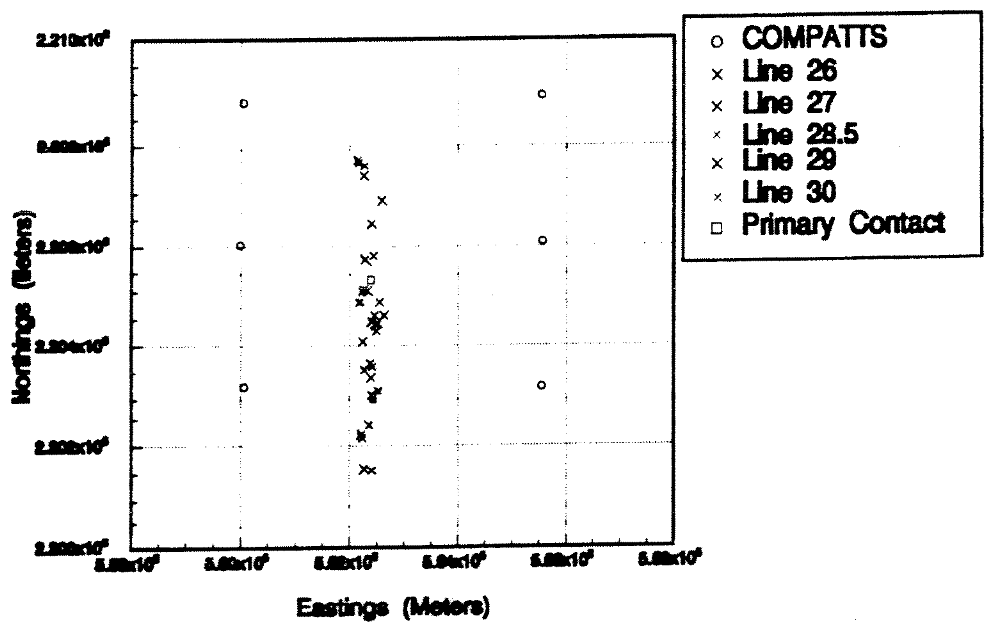


Figure 5-1. United Flight 811 Search Area Information.

Targets are recorded on a paper recorder or optional disk, and displayed on a color video screen. All data is stored automatically by the system for post-search target processing and analysis. A front-looking sonar warns the system operator of obstacles in time to avoid a collision. Targets can be marked by one of six deployable markers stored in the towfish body. Figure 5-2 shows the ORION towfish and handling system.

The sonar is deployed, controlled, and recovered with a handling system installed on the fantail of the support ship. This system consists of a storage winch, hydraulic power unit, traction winch, and a 15,000-pound-capacity, motion-compensated crane. The towfish and handling systems are operated from a control van located on deck. The 36,000-foot-long, triple-armor tow cable houses three electrical conducting copper wires and three data transmitting optical fibers. Figure 5-3 shows the ORION search system load plan on the USNS NARRAGANSETT.

The ORION sonar video enhancement system gives the target interpreter a real-time, color video display that depicts contacts clearly. As ORION is towed along the bottom, acoustic transponders are interrogated to allow the system to calculate the towfish position. Several passes are usually made on a contact for different target perspectives to facilitate identification.

ORION's video system can positively identify targets. The built-in, stern-mounted video imaging system consists of a pan-and-tilt video camera, six adjustable 0- to 500-watt bulbs to illuminate the bottom, and an automatic camera iris. As the sonar fish passes over the object, visual contact can be made. If the towfish does not trail as expected because of current set, the support ship must alter course to ensure that the towfish passes directly over the target. If the towfish cannot pass directly over the target, positive identification with the video imaging system is not possible.

Sensors installed within the towfish body measure towfish:

- Depth
- Heading relative to the ship's heading
- Stability through pitch and roll measurements
- System diagnostics.

5-4.3 Navigation Systems. This search operation required other than line-of-sight precision surface navigation because of the distance of the search area from land. The depth demanded a long-baseline subsea navigation system. Existing systems fulfilled both surface and underwater navigation requirements.

5-4.3.1 Surface Navigation. Global Positioning System (GPS) equipment (utilizing Trimble 4000 AX GPS receivers) was installed in NARRAGANSETT for precision surface navigation during search operations.

5-4.3.2 Subsea Navigation. Six Computing and Telemetering Transponder (COMPATT) transponders deployed on the bottom near the outer boundaries of the search area provided precision subsea navigation. A towfish-mounted transducer following ROVNAV direction interrogated the transponders as it was towed through the grid. Towfish position was computed from transponder responses. The system can analyze recorded information to calculate target positions with an accuracy of one meter.

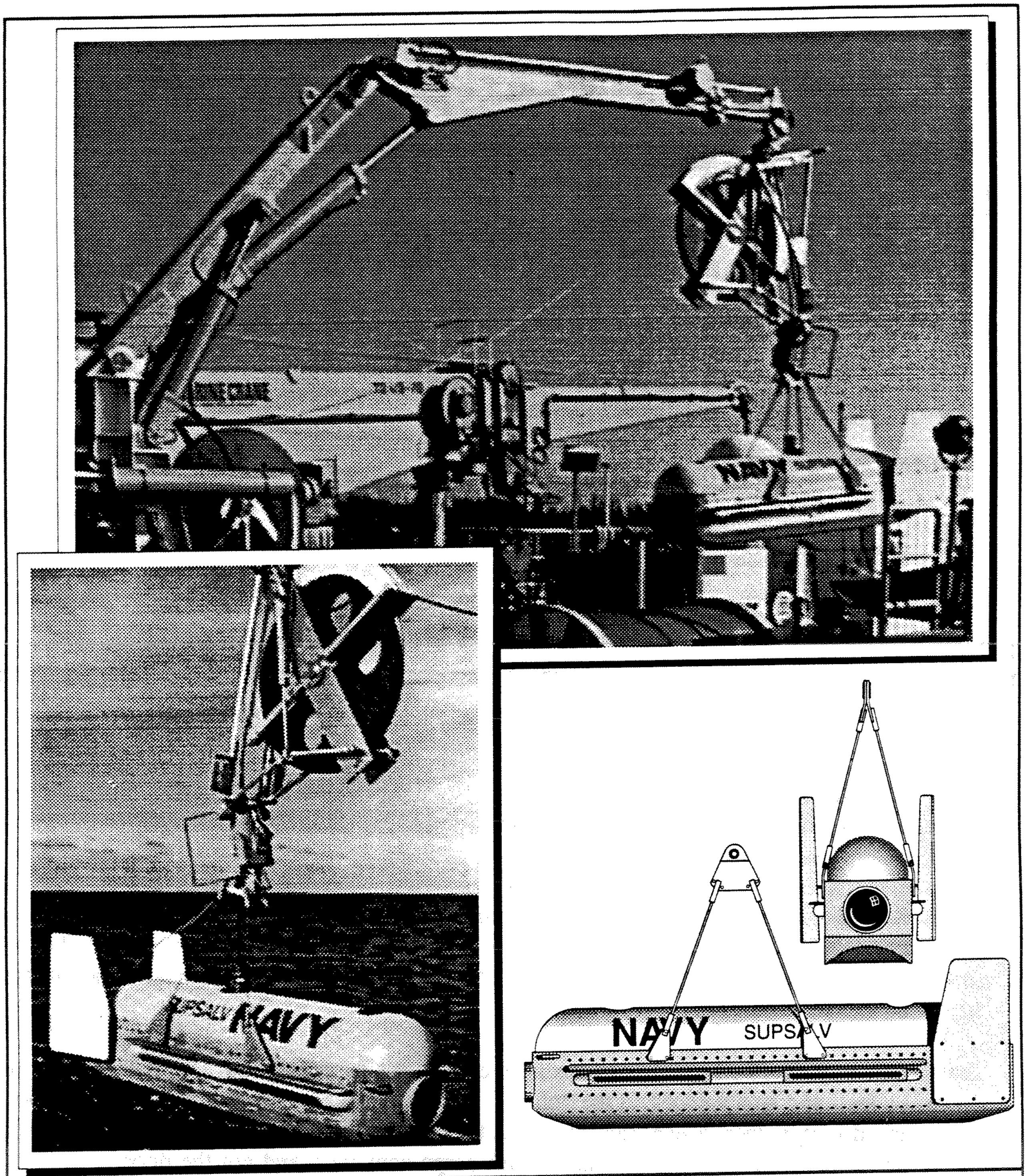


Figure 5-2. ORION Towfish and Handling System.

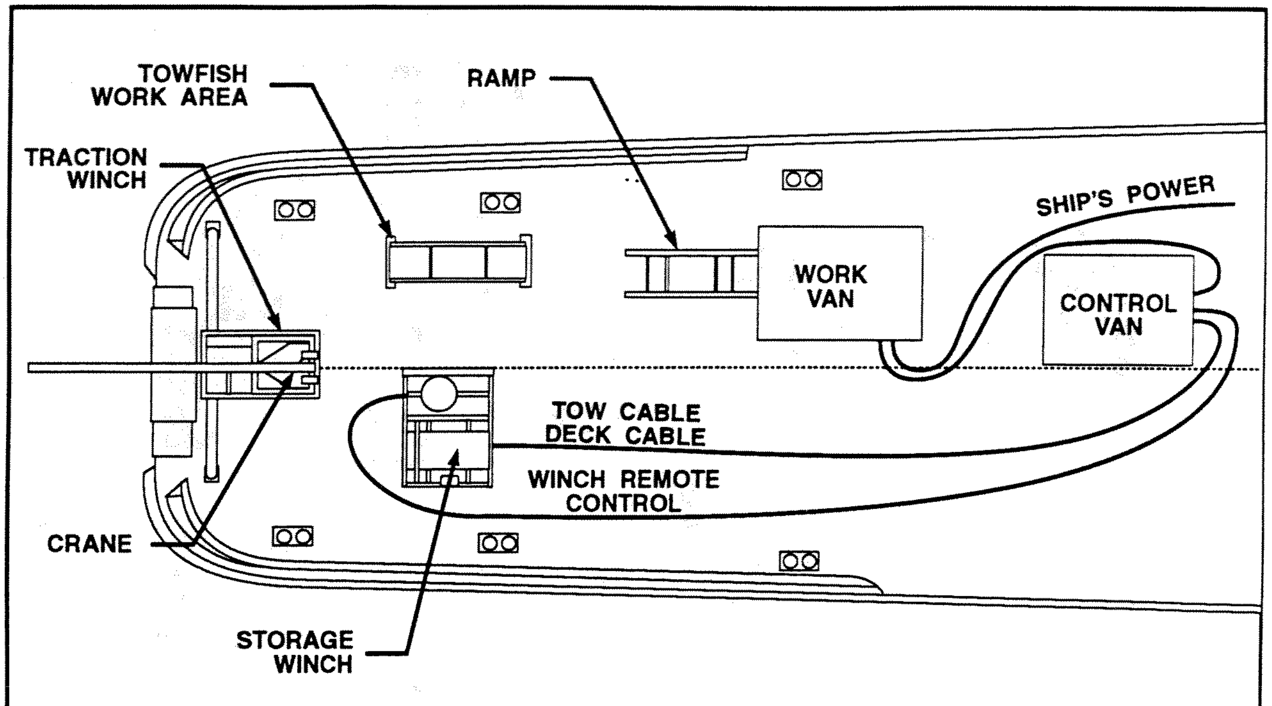


Figure 5-3. ORION System on T-ATF.

5-4.4 Search Support Vessels. With her large stern area to support the ORION search system and excellent manuevering ability at slow search speeds, USNS NARRAGANSETT was well suited to support the search phase.

5-4.5 Search Chronology. Table 5-1 is a chronology of the key events of the search phase. The accurate datum, coupled with the ORION side-scan sonar search system, resulted in target identification on the first run. Debris was recorded on all later runs until more than 40 targets had been marked accurately.

One target in particular appeared to meet the criteria for the cargo door. It was metallic, about 10 by 11 feet, and was wedged in the bottom. This piece was assumed to be the cargo door and was marked with a deep-ocean transponder as the datum for the recovery phase. Ultimately, the target turned out to be a section of an aircraft cargo container, and not the door.

The time required to complete the search, not including transit and underwater navigation calibration and recovery, was approximately four days. This was a remarkable accomplishment when compared to other, more protracted searches in water of comparable depth.

Table 5-1. Search Chronology.	
DATE	**TIME AND EVENT**
24 Feb 1989	Cargo door falls from aircraft.
18 July 1990	ORION arrives in Hawaii.
19 July	0700: ORION load-out and in-port system checks commence.
22 July	1600: NARRAGANSETT underway for search area. Trouble-shooting electronic systems.
23 July	0920: Deployment and calibration of seafloor navigation system commence.
24 July	Baseline acquisitions and calibration continue.
25 July	1030: ORION towfish deployed for system check.
26 July	0400: Start of line 28, the main N/S search line. 0418: Possible contacts recorded. 1334: Start of line 29. 1350: First targets recorded. Several small targets recorded on subsequent passes.
28 July	0501: End of line 27. Five contacts recorded.
29 July	0311: End of line 28.5. Fifteen contacts recorded. 1357: Deep Ocean Transponder (DOT) deployed at 19-65.42N, 158-24.44W as a marker for the recovery phase. DOT dropped within 50 meters of the best estimated position.
30 July	1700: All except two seafloor navigation transponders recovered. Proceed to Honolulu.
31 July	0930: Alongside Bishop Point, Hickam AFB for demobilization.

5-4.6 Search Problems. As in all deep-ocean operations, equipment malfunctions occurred. None was long-term, and none caused excessive delays in the search. Contract personnel were able to identify and solve each problem that arose. The major problem was that the ORION video imaging system was inoperative during the search. The camera's iris failed in the closed position, so the camera was blind and operators were deprived of a positive identification capability.

Minor problems included:

- The cable counter did not register the correct amount of cable payed out. When the counter showed 28,000 feet out there was only one wrap of wire left on the winch; an error of about 4,000 feet.

- Winds and surface currents affected steerage considerably when ORION was towed along the north-south lines. The problem was more severe on southerly courses than northerly ones.

- The software interface problems with the ROVNAV navigation system required about three days to resolve before the system was operating correctly. Contractor personnel repaired ROVNAV with components on hand after isolating the problem at the receiver board.

- The traction winch stern wheel leaked gear oil and suffered intermittent loss of control.

- Degradation of GPS navigation signals — the full constellation of satellites was not yet deployed — was severe enough to interrupt the search each day for several hours.

- Two COMPATT transponders, costing $20,000 each, were lost during retrieval attempts. The glass Benthos buoyancy spheres may have imploded because of flaws. Full-ocean-depth syntactic foam buoyancy modules, which are more reliable than glass spheres, are being used to replace the existing buoyancy spheres.

5-5 RECOVERY OPERATIONS

The debris field and targets identified during the search phase were adequate to continue with the recovery. The main target had distinguishable dimensions and was located near the projected datum. Searchers were highly confident that a debris field in an otherwise clean bottom area was from Flight 811 door and fuselage pieces. Based on the searchers' conclusions, the NTSB asked the Navy to proceed with the recovery.

5-5.1 Recovery Plan. The recovery plan called for the manned submersible SEA CLIFF, operating from the DSVSS LANEY CHOUEST, to complete the operation. Personnel in SEA CLIFF would rig pieces for recovery and either grasp pieces in the vehicle's manipulators and transport them to the surface or recover the wreckage by the SUPSALV motion-compensated FADOSS.

5-5.2 Recovery Support Vessels. The DSVSS LANEY CHOUEST is SEA CLIFF's support ship and is rigged to support the submersible. The amount of deck space available for the FADOSS was limited. Figure 5-4 shows SEA CLIFF being launched from LANEY CHOUEST.

5-5.3 Recovery Procedures and Equipment. SEA CLIFF has an operational depth of 20,000 feet, well in excess of the 14,200-foot working depth of this operation. The vehicle has 144 man-hours of life support. With three personnel on board, the maximum dive time is 48 hours. The dive plan for this operation called for dives no longer than 12 hours including transit time to and from the bottom. Most dives required about five hours for transit, leaving about seven hours bottom time for each dive. SEA CLIFF has one forward and four trainable side thrusters for maneuvering. Other features include video and still cameras, underwater lights and strobes, navigation equipment, sonar, and manipulators.

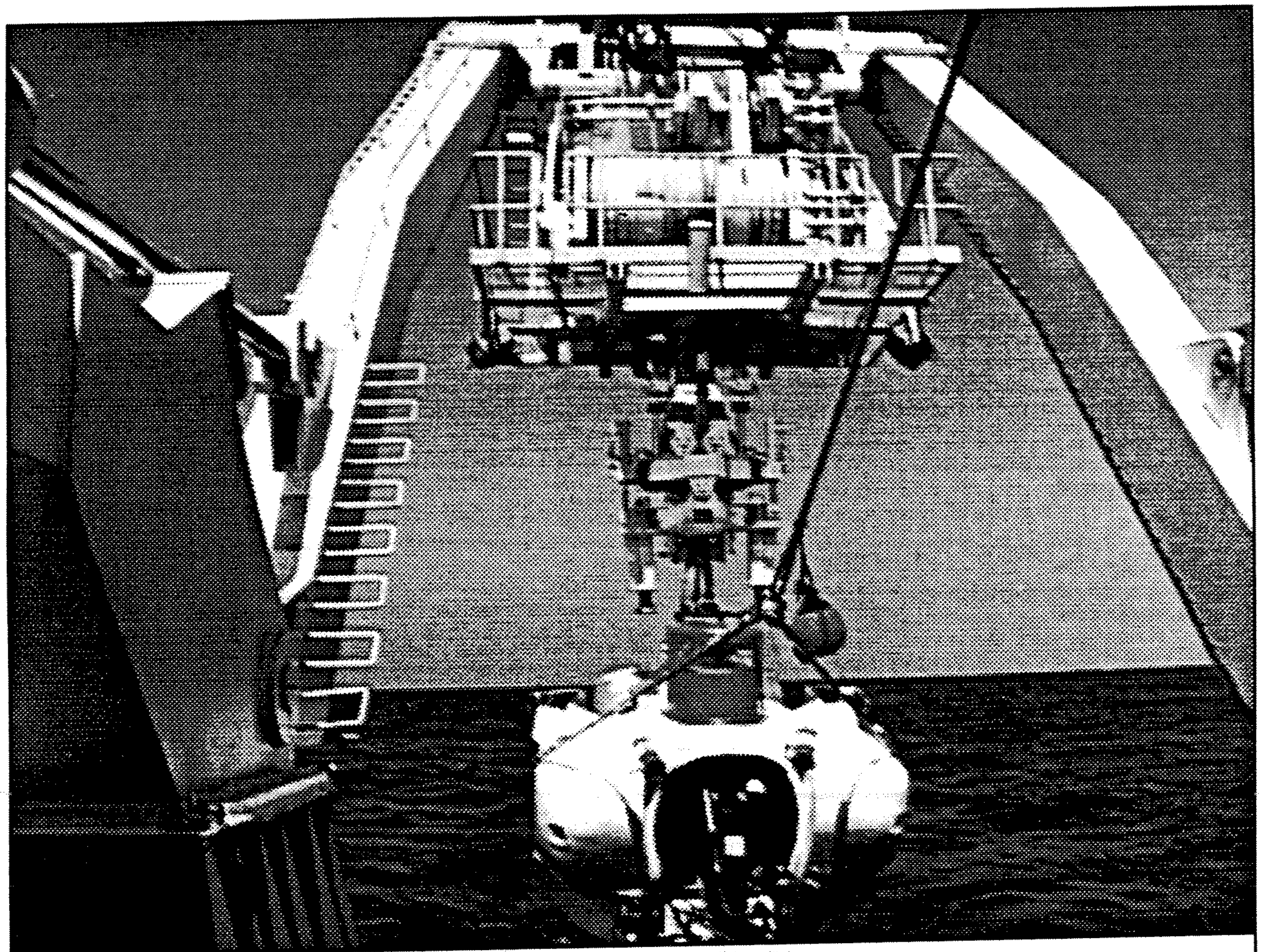


Figure 5-4. SEA CLIFF Being Launched.

SEA CLIFF manipulators carried the cargo door and other debris to the surface. After divers attached lift lines from the debris to a pontoon, SEA CLIFF operators released the objects from the manipulators. The debris was supported by the pontoon until the submersible was recovered and secured on board. The debris was then hauled to and lifted aboard the DSVSS LANEY CHOUEST.

These procedures proved to be less than satisfactory because of the potential for damaging the manipulators and losing the recovered wreckage before lift lines were attached. An important piece of fuselage brought to the surface on the seventh dive was lost. Also, the upper half of the cargo door fell from the manipulators but was held fast by a wire rope preventer strap that had been attached before lifting the piece from the bottom.

5-5.4 Recovery Chronology. Table 5-2 is a chronology of key events of the United Airlines Flight 811 cargo door recovery. The total recovery time, from SEA CLIFF mobilization at Hickam AFB to cargo door offload, was about 18 days. The support ship, DSVSS LANEY CHOUEST with SEA CLIFF embarked, took an additional 13 days transit from San Diego to Hawaii.

The FADOSS system was employed only to lift objects from the surface to the ship's deck. One half-inch-diameter Kevlar® line served as the lift line. The system gave the salvage team a proven system to lift weights beyond the 500- to 600-pound limit of SEA CLIFF.

Table 5-2. Recovery Chronology.	
TIME/DATE	**EVENT**
14 September 1990	DSVSS LANEY CHOUEST arrives at U.S. Navy Submarine Base, Pearl Harbor, Hawaii with SEA CLIFF embarked; later departed for the operations area.
15 September	Underwater navigation transponders deployed and calibrated. SEA CLIFF makes first dive for indoctrination and familiarization. Observed seat cushions, small piece of fuselage skin, and part of cargo container.
16-19 September	Hurricane Marie terminates operations; LANEY CHOUEST returns to port.
19-21 September	Dive 2 aborted because of battery problem in SEA CLIFF, forces return to port for repairs.
21 September	1500: Dive 3 begins. Searched to north of datum for heavier items. Observed some non-aircraft debris, interior window frame, recovered a pump.
22 September	0530: Dive 3 terminated.
23 September	0130: Dive 4 begins. Searched south of datum. Dive terminated at 1445. Observed clothing, small box, and unrelated pipe.
24 September	1530: Dive 5 begins. Recovered 3 large pieces of cargo container, metal cylinder, oxygen service access panel that confirmed Flight 811 debris.
25 September	0515: Dive 5 terminated.
26 September	0435: Dive 6 begins. Searched east and found three seat frames and suitcases.
26 September	1300: Lower half of cargo door located when maneuvering in a westerly direction. Recovered vehicle and door from 14,167 feet in 18 hours.
27-29 September	SEA CLIFF battery scanner failure causes delay and return to port.
30 September	0135: Dive 7 begins. Fuselage piece from above door hinge picked up. Piece lost from SEA CLIFF manipulators on the surface. Dive terminated.
1 October	1015: Dive 8 begins. Upper half of cargo door recovered. Recovered transponders.
2 October	0015: Vehicle and four transponders on deck. Returned to Hickam AFB and offloaded. Operation complete.

Figure 5-5 shows data developed during the recovery operation.

5-5.5 Recovery Problems. Bad weather, equipment malfunctions, and the nature of manned submersible operations resulted in a relatively long time to complete this successful operation. Specific problems were:

- Turnaround time for the submersible was about 24 hours, resulting in considerable non-operational time between dives.

- The submersible's simple tool package limited the methods of attaching lift lines to the debris, and the lift capacity of the submersible limited the weight that could be recovered.

- SEA CLIFF experienced battery and battery scanner problems that resulted in three to four days lost operating time.
- Rigging time was long. The large aircraft piece picked up on dive 7 took 11.5 hours to rig and recover.
- Weather forced the salvage ship into port for about three days in the middle of the operation.

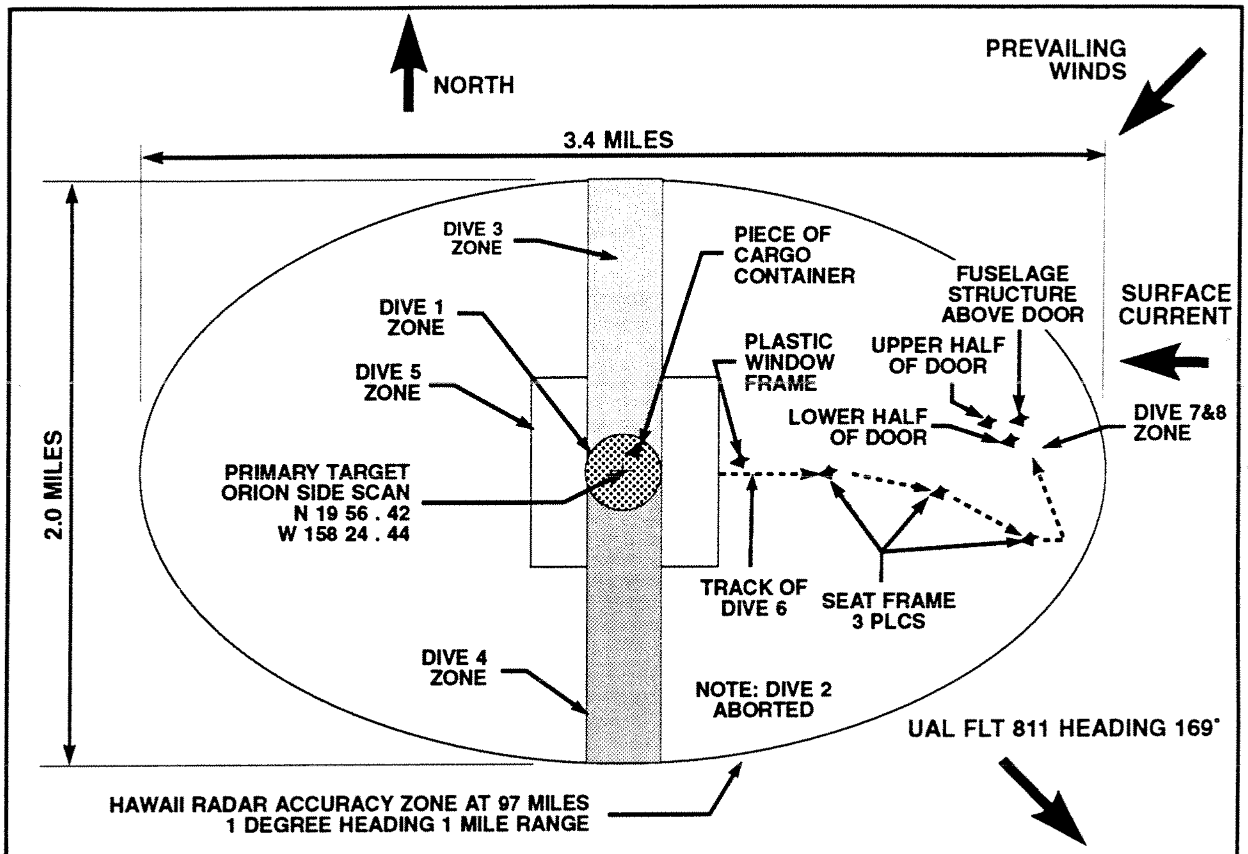


Figure 5-5. Recovery Dives Data.

5-6 SUMMARY

The United Airlines cargo door salvage operation, an operation that a few years earlier would have been deemed remarkable because of the depth and technology, was almost a routine operation. Two items are worthy of particular note.

The ORION search system had received thorough operational testing before this job. Deep-ocean technology is extremely difficult; the venue is the most difficult in which man works. While system completeness and comprehensive testing is desirable, it will not preclude problems during at-sea operations.

The problems associated with the manned submersible were characteristic of these vehicles. They include limited dive time and battery life. Although ROVs offer advantages such as extended dive time, lift capacity, and real-time video feedback to topside investigators, manned submersibles are a viable tool for deep-ocean salvage that should be considered whenever such operations are planned.

CHAPTER 6

CONCLUSIONS

6-1 INTRODUCTION

The deep-ocean operations described in this report each had unique conditions and problems that required innovation and imagination to solve in the field. Upon analysis and application of lessons learned, each major search and recovery operation should increase the base of knowledge for similar operations. The operation does not have to be successful to improve techniques, equipment, or operating procedures. In fact, often the failures have the clearest lessons to teach. This final chapter draws the lessons of the four operations together to present general conclusions applicable to deep-ocean search and recovery.

6-2 SEARCH SYSTEMS

The advent of TPLs and acoustic beacons with approximately 1.5-mile signature ranges has improved potential search efficiency by orders of magnitude using TPLs as a rapid, coarse-grain method of searching a large area, often augmented by side-scan sonar as a fine-grain method of searching a reduced area of interest. Often a salvage mission is a two-phased — search and recovery — operation in which the search phase involves both a TPL search of a large area and a side-scan coverage of a derivative smaller area. The two search methods are complementary. If the requirement for a sonar survey appears likely, the side-scan should be mobilized at the same time as the TPL system.

The ORION search system with its real-time video imaging is a major advancement in search system technology. As often occurs with high-technology electronic systems, early field operations may disclose minor problems that are solved as they arise. Time must be allowed to correct these performance perturbations during the system's break-in period.

6-3 RECOVERY SYSTEMS

Thorough pre-deployment checks and operation of all equipment should be standard operating procedure to avoid costly deployment of inoperable equipment. Equipment should always be deployed with a full allowance of spare parts.

Present design of motion-compensation equipment has effectively reduced incidents of catastrophic line failure from dynamic loading. The FADOSS is reliable and fits easily onto ships of opportunity. Specific performance measurements — weight of object being lifted, loads on the system, period of ship's roll, and sea state — should be recorded on every lift to complement information about failures or problems. Historical data on lifts in different sea states can identify FADOSS operational limitations.

The most difficult part of recovery operations is bringing material from the seafloor to the deck of the ship. In the Air India Flight 182 recovery, many interesting pieces of debris fell out of the recovery basket because of the sea-induced motions of JOHN CABOT. A heave compensator, coupled with a securable cover for the basket, could have prevented the losses.

In the United Airlines Flight 811 cargo door recovery, material was lost when it was brought near the surface with the submersible's manipulators and handled again for final lifting. Experience shows that debris is recovered most effectively when handling is minimized, and it is brought through the air/water interface quickly. The most effective lifts are those in which grabbers are attached to the wreckage on the seafloor and single lifts carry the debris from the seafloor to the deck.

If the traction winch speed is slow, several hours are required to recover several thousand feet of line. Because the sea can change dramatically during the time required for a single lift, the lift attempt is at the mercy of the elements. Winches that can haul line through the motion-compensation system at a higher rate are being developed.

Both ROVs and manned submersibles are viable tools for underwater recovery. As robotics capabilities improve, and sensor and data transmission systems become more sophisticated, ROVs offer some distinct advantages as primary deep-ocean recovery tools.

Personnel on the seafloor have the advantage of being able to see the debris in place and to change plans quickly, based on the conditions on the seafloor. Conditions at depth, particularly low temperatures and dampness, limit operator effectiveness and bottom time. ROVs can remain on the seafloor as long as systems do not fail or surface conditions do not force a halt in the operation. Because humans in manned submersibles are in a dangerous environment, loss of any capability or system on the vehicle may mean an aborted dive and delay in operations until the submersible is 100-percent operable. At the discretion of the on-scene manager, ROVs may be permitted to dive with some systems inoperable. Operators in a manned submersible rig for object recovery with manipulators, just as ROV operators do. Operator skill in working with manipulators is the critical factor.

Tethered ROV recovery operations allow real-time direction from the experts who watch the video screen along with the ROV operator. Important pieces of debris can be photographed or recovered at the direction of the investigators — not at the discretion of submersible operators, who are not aircraft experts. During the Flight 811 cargo door recovery, submersible operators mistook baggage material for fuselage skin. An expert eye might have been able to distinguish the debris.

The choice between an ROV and manned submersible for a particular operation should be based upon the conditions of the operation and the advantages and disadvantages offered by each type of vehicle. In general, the limitations that manned submersibles place on operations make ROVs the better choice.

6-4 SHIPS

As this report shows, there are many types of ships suitable for search support platforms. Characteristics — such as the low freeboard aft in the T-ATF 166 Class and offshore supply vessels — that are desirable in a particular set of conditions may be unsuitable for slightly different conditions. Operations planners must remain open-minded, and must not hesitate to use unconventional platforms for search support. MUNRO, a type of ship not usually used as a search platform, performed well in the KAL Flight 007 search, particularly during heavy weather. The MUNRO could continue towing the side-scan sonar when the T-ATF terminated operations because her fantail was awash and maneuverability in heavy seas was poor.

Deep-ocean search and recovery is a high-technology business with acoustic devices that ship-generated noises may render ineffective. In selecting platforms for deep-ocean operations, planners should consider the type, frequencies, and magnitude of self-generated noise in candidate vessels and how that noise will affect their search and recovery systems.

6-5 LOGISTICS

By their nature, deep-ocean search operations often take place in remote locations where base support for the offshore operation is difficult. Unforeseen technical and operational problems can be expected in every operation, for Murphy, not Neptune, truly rules the deep ocean. To reduce the effect of these problems, an excellent home base and remote base logistics setup must support the operational organization. A thoroughly planned and efficient logistics operation reduces delays and keeps costs down. Manning, equipment, and support must be planned and mobilized for the worst case.

6-6 OPERATIONAL PROCEDURES

Sometimes the requirement or desire for an immediate start will preclude all the forethought and planning that normally precedes a search — as was the case with KAL 007. A hasty start may prevent:

- Complete development of the overall goals and objectives
- Establishment of broad search areas and individual assignments within those areas
- Complete identification of all required assets and spares.

In these cases, searchers must be aware of the planning shortcomings and compensate for them as soon as possible.

In large search operations, locating the salvage task group commander on a search platform can be inefficient. Co-locating the salvage task group commander and the task force commander can:

- Improve coordination and understanding of the whole operation.
- Reduce radio reporting requirements within the task force.

Placing multiple systems aboard a ship can reduce overall productivity if the systems do not operate simultaneously. For instance, a side-scan system located on the same ship as the ROV effectively forces a choice between side-scan or ROV operations. In locating assets, the search commander must consider the goal of the operation and balance the placement of the assets against the projected work of each floating platform.

In large, complicated operations, a master chart produced during planning and given to all participating parties affords everyone a better understanding of the overall strategy. The master chart should be updated at least daily.

Sea mounts, rapidly changing depths, and other hostile conditions can destroy the search equipment or cause gaps in areas searched. Seafloor mapping during the SAA Flight 295 operation greatly improved the efficiency and productivity of the side-scan sonar systems by allowing planning of operations to reduce the possibility of towfish collisions with the seafloor. This type of system should be considered when operating in areas with uneven bottom topography.

Deep-ocean operations may be interrupted or terminated at any time by weather, equipment failure, economic limitations, and other events. To gain the maximum advantage from the operation, underwater vehicles should be rigged to maximize the opportunities of every dive. For example, manned submersibles and ROVs should be rigged to recover objects on every dive. Every dive should be planned as though it is the last opportunity to work on the bottom.

Similarly, each dive should include photo-documentation of debris and bottom conditions by both ROVs and manned submersibles. Photo-documentation allows trained, technically qualified observers to view the debris on the seafloor and provide their input to the recovery operation. Sound technical input based on photo-documentation can result in efficient use of valuable dive time. If the operation ends unexpectedly, photographic records may have to take the place of recovered wreckage in the accident analysis.

The success of an operation includes not only accomplishing its goals, but providing lessons for later operations. Detailed, accurate, complete, and orderly case files, detailed situation reports, and accurate final reports are necessary to determine and retain the lessons of an operation.

Post-operation reports should include drawings showing equipment layout and detailing procedures to rig and lift pieces. Techniques for lifting heavy items through the water/air interface to the deck safely or easily should be reported in detail.

The suitability and success of operational techniques and procedures, especially those improvised in the field, should be documented fully so that future operations will not waste time employing techniques with a low probability of success.

6-7 SUMMARY

From long operational experience, SUPSALV has learned that effective employment of rapidly developing search and recovery technology is the key to successful aircraft salvage. SUPSALV has established contracts for an around-the-clock, worldwide search and recovery capability. The U.S. Navy is the world's leader in deep-ocean search and recovery operations because of its broad experience and because the lessons of each operation have been analyzed and applied in subsequent operations. As the accounts in this report show, deep-ocean operations are complex and require the most advanced technology available. Although they are technology-dominated, their complexity puts a high value on human experience and the human ability to react to changing situations.