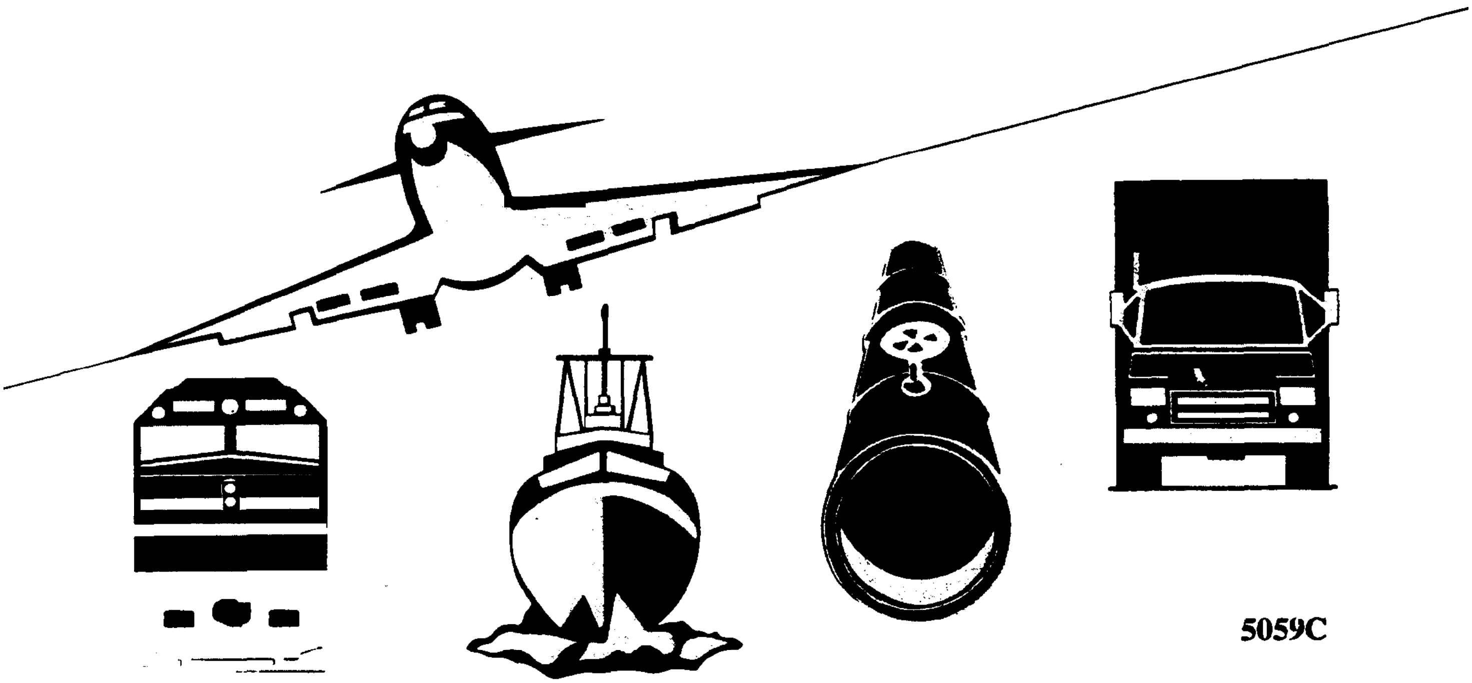
PB92-910402
NTSB/AAR-92/02
(SUPERSEDES NTSB/AAR-90/01)

NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

AIRCRAFT ACCIDENT REPORT

EXPLOSIVE DECOMPRESSION-- LOSS OF CARGO DOOR IN FLIGHT UNITED AIRLINES FLIGHT 811 BOEING 747-122, N4713U HONOLULU, HAWAII FEBRUARY 24, 1989



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Adopted: March 18, 1992
Notation 5059C

Abstract: This report explains the explosive decompression resulting from the loss of a cargo door in flight on United Airlines flight 811, a Boeing 747-122; near Honolulu, Hawaii, on February 24, 1989. The safety issues discussed in the report are the design and certification of the B-747 cargo doors, the operation and maintenance to assure the continuing airworthiness of the doors, and emergency response. Recommendations concerning these issues were made to the Federal Aviation Administration, the State of Hawaii, and the U.S. Department of Defense.

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EXECUTIVE SUMMARY

On February 24, 1989, United Airlines flight 811, a Boeing 747-122, experienced au explosive decompression as it was climbing between 22,000 and 23,000 feet after taking off from Honolulu, Hawaii, en route to Sydney, Australia with 3 flightcrew, 15 flight attendants, and 337 passengers aboard.

The airplane made a successful emergency landing at Honolulu and the occupants evacuated the airplane. Examination of the airplane revealed that the forward lower lobe cargo door had separated in flight and **had** caused extensive damage to the fuselage and cabin structure adjacent to the door. Nine of the passengers had been ejected from the airplane and lost at sea.

A year after the accident, the Safety Board was uncertain that the cargo door would be located and recovered from the Pacific Ocean. The Safety Board decided to proceed with a final report based on the available evidence without the benefit of an actual examination of the door mechanism. The original report was adopted by the Safety Board on April 16, 1990, as NTSB/AAR-90/01.

Subsequently, on July 22, 1990, a search and recovery operation was begun by the U.S. Navy with the cost shared by the Safety Board, the Federal Aviation Administration, Boeing Aircraft Company, and United Airlines. The search and recovery effort was supported by Navy radar data on the separated cargo door, underwater sonar equipment, and a manned submersible vehicle. The effort was successful, and the cargo door was recovered in two pieces from the ocean floor at a depth of 14,200 feet on September 26 and October 1, 1990.

Before the recovery of the cargo door, the Safety Board believed that the door locking mechanisms had sustained damage in service prior to the accident flight to the extent that the door could have been closed and appeared to have been locked, when in fact the door was not fully latched. This belief was expressed in the report and was supported by the evidence available at the time. However, upon examination of the door, the damage to the locking mechanism did not support this hypothesis. Rather, the evidence indicated that the latch cams had been back-driven from the closed position into a nearly open position after the door had been closed and locked. The latch cams had been driven into the lock sectors that deformed so that they failed to prevent the back-driving.

Thus, as a result of the recovery and examination of the cargo door, the Safety Board's original analysis and probable cause have been modified. This report incorporates these changes and supersedes **NTSB/AAR-90/01** .

The issues in this investigation centered around the design and certification of the B-747 cargo doors, the operation and maintenance to assure the continuing airworthiness of the doors, cabin safety, and emergency response.

The National Transportation Safety Board determines that the probable cause of this accident was the sudden opening of the forward lower lobe cargo door in flight and the subsequent explosive decompression. The door opening was attributed to a faulty switch or wiring in the door control system which permitted electrical actuation of the door latches toward the unlatched position after initial door closure and before takeoff. Contributing to the cause of the accident was a deficiency in the design of the cargo door locking mechanisms, which made them susceptible to deformation, allowing the door to become unlatched after being properly latched and locked. Also contributing to the accident was a lack of timely corrective actions by Boeing and the FAA following a 1987 cargo door opening incident on a Pan Am B-747.

As a result of this investigation, the Safety Board issued safety recommendations concerning cargo doors and other **nonplug** doors on pressurized transport category airplanes, cabin safety, and emergency response.

NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C. 20594

AIRCRAFT ACCIDENT REPORT

EXPLOSIVE DECOMPRESSION--
LOSS OF CARGO DOOR IN FLIGHT
UNITED AIRLINES FLIGHT 811
BOEING 747-122, N4713U
HONOLULU, HAWAII
FEBRUARY 24, 1989

1. FACTUAL INFORMATION

1.1 History of the Flight

On February 24, 1989, United Airlines (UAL) flight 811, a Boeing 747-122 (B-747), N47 13U, was being operated as a regularly scheduled flight from Los Angeles, California (LAX) to Sydney, Australia (SYD), with intermediate stops in Honolulu, Hawaii (HNL) and Auckland, New Zealand (AKL).

The flightcrew assigned to the LAX/HNL route segment reported no difficulty during their flight.

A flightcrew change occurred when flight 811 arrived at HNL. The oncoming captain stated that he and his crew reported to UAL operations 1 hour and 15 minutes prior to the flight's scheduled departure time from HNL. The crew had completed a 34-hour layover (rest period) in HNL.

The captain reviewed the flight plan, the weather, pertinent NOTAMs, and maintenance records, and signed the Instrument Flight Rules (IFR) clearance before boarding the airplane.

Flight 811 departed HNL gate 10 at 0133 Honolulu Standard Time (HST), 3 minutes after the scheduled departure time, with 3 flight crewmembers, 15 cabin crewmembers, and 337 passengers. The flightcrew attributed the short delay to cabin crew problems with arming the 5L cabin door emergency exit slide and the normal securing of the 2L door after a somewhat extended passenger boarding process. The second officer stated that all cabin and cargo door warning lights were out prior to the airplane's departure from the gate. He said that he dimmed the annunciator panel lights at his station while the airplane was departing the gate area.

The captain was at the controls when the flight was cleared for takeoff on HNL runway 8R at 0152:49 HST. The auxiliary power unit (APU), which was used during the takeoff, was shutdown shortly after making the initial power reduction to climb thrust.

The flightcrew reported the airplane's operation to be normal during the takeoff and during the initial and intermediate segments of the climb. The flightcrew observed en route thunderstorms both visually and on the airplane's weather radar, so they requested and received clearance for a deviation to the left of course from the HNL Combined Center Radar Approach Control (CERAP). The captain elected to leave the passenger seat belt sign "on."

The flightcrew stated that the first indication of a problem occurred while the airplane was climbing between 22,000 and 23,000 feet at an indicated airspeed (IAS) of 300 knots. They heard a sound, described as a "thump," which shook the airplane. They said that this sound was followed immediately by a "tremendous explosion." The airplane had experienced an explosive decompression. They said that they donned their respective oxygen masks but found no oxygen available. The airplane cabin altitude horn sounded and the flightcrew believed the passenger oxygen masks had deployed automatically.

The captain immediately initiated an emergency descent, turned 180° to the left to avoid a thunderstorm, and proceeded toward HNL. The first officer informed CERAP that the airplane was in an emergency descent and appeared to have lost power in the No. 3 engine. The appropriate 7700 emergency code was placed in the airplane's radar beacon transponder and an emergency was declared with CERAP at approximately 0220 HST. The No. 3 engine was shut down shortly after commencing the descent because of heavy vibration, no N1 compressor indication, low exhaust gas temperature (EGT), and low engine pressure ratio (EPR).

The second officer then left the cockpit to inspect the cabin area and returned to inform the captain that a large portion of the forward right side of the cabin fuselage was missing. The captain subsequently shut down the No. 4 engine because of high EGT and no N1 compressor indication, accompanied by visible flashes of fire. The flightcrew initiated fuel dumping during the descent to reduce the airplane landing weight.

The airplane was cleared for an approach to HNL runway 8L. The final approach was flown at 190 to 200 knots with the No. 1 and No. 2 engines only. During flap extension, the flightcrew observed an indication of asymmetrical flaps as the flap position approached 5°. The flightcrew decided to extend inboard trailing edge flaps to 10° for the landing. The right outboard leading edge flaps did not extend during the flap lowering sequence. The airplane touched down on the runway, approximately 1,000 feet from the approach end, and came to a stop about 7,000 feet later. The captain applied idle reverse on the Nos. 1 and No. 2 engines and employed moderate to heavy braking to stop the airplane. At 0234 (HST), HNL tower was notified by the flightcrew that the airplane was stopped and an emergency evacuation had commenced on the runway.

After the accident, UAL ramp service personnel, who had been involved with the cargo loading and unloading of flight 811 before takeoff from HNL, stated that they had opened and closed the forward cargo door electrically. They said that they had observed no damage to the cargo door. The ramp service personnel said that they had verified that the forward cargo door was flush with the fuselage of the airplane, that the master door latch handle was stowed, and that the pressure relief doors were flush with the exterior skin of the cargo door.

The dispatch mechanic stated that, in accordance with UAL procedures, he had performed a "circle check" prior to the airplane's departure from the HNL gate. This check included verification that the cargo doors were flush with the fuselage of the airplane, that the master latch lock handles were stowed, and that the pressure relief doors were flush or within 1/2 inch of the cargo door's exterior skin. He said a flashlight was used during this inspection.

The second officer stated that, in accordance with UAL Standard Operating Procedures (SOP) he had performed an operational check of the door warning annunciator lights as part of his portion of the cockpit preparation. The second officer also stated that he used a flashlight while performing an exterior inspection, again in accordance with UAL procedures. The exterior inspection was conducted while ramp service personnel were performing cargo loading operations and the cargo doors were open. He stated that he had observed no abnormalities or damage.

1.2 Injuries to Persons

Injuries	Flightcrew	Cabincrew	Passengers	Others	Total

*Lost in flight. An extensive air and sea search for the passengers was unsuccessful.

1.3 Damage to the Airplane

The primary damage to the airplane consisted of a hole on the right side in the area of the forward lower lobe cargo door, approximately 10 by 15 feet large. The cargo door fuselage cutout lower sill and side frames were intact but the door was missing (see figures 1 and 2). An area of fuselage skin measuring about 13 feet lengthwise by 15 feet vertically, and extending from the upper sill of the forward cargo door to the upper deck window belt, had separated from the airplane at a location above the cargo door extending to the upper deck windows. The floor beams adjacent to and inboard of the cargo door area had been fractured and buckled downward.

Examination of all structure around the area of primary damage disclosed no evidence of preexisting cracks or corrosion. All fractures were typical of fresh overstress breaks.

Debris had damaged portions of the right wing, the right horizontal stabilizer, the vertical stabilizer and engines Nos. 3 and 4. No damage was noted on the left side of the airplane, including engines Nos. 1 and 2.

The right wing had sustained impact damage along the leading edge between the No. 3 engine pylon and the No. 17 variable camber leading edge flap. Slight impact damage to the No. 18 leading edge flap was noted.

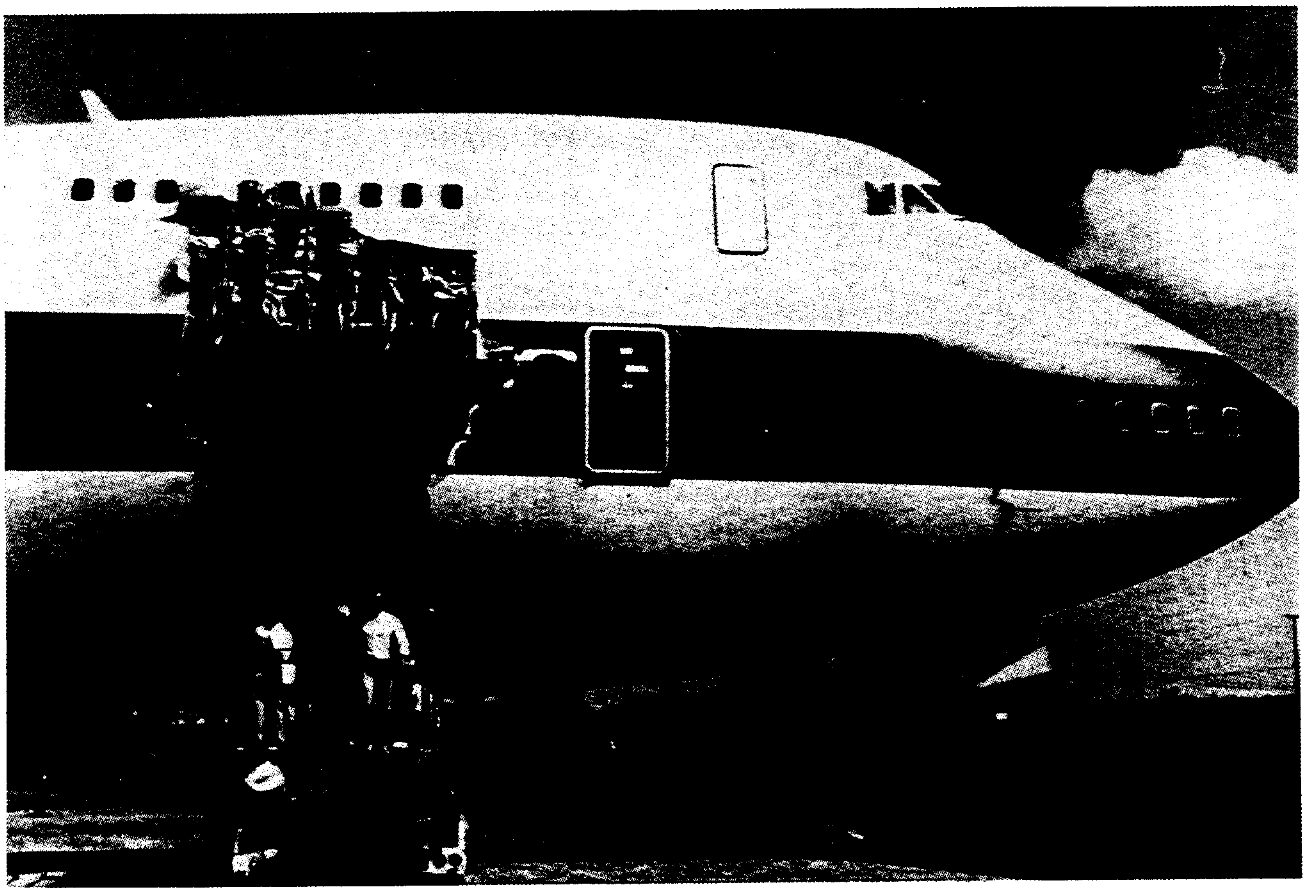

Figure 1 .--Overall view of forward cargo door area
on the right side of the aircraft.

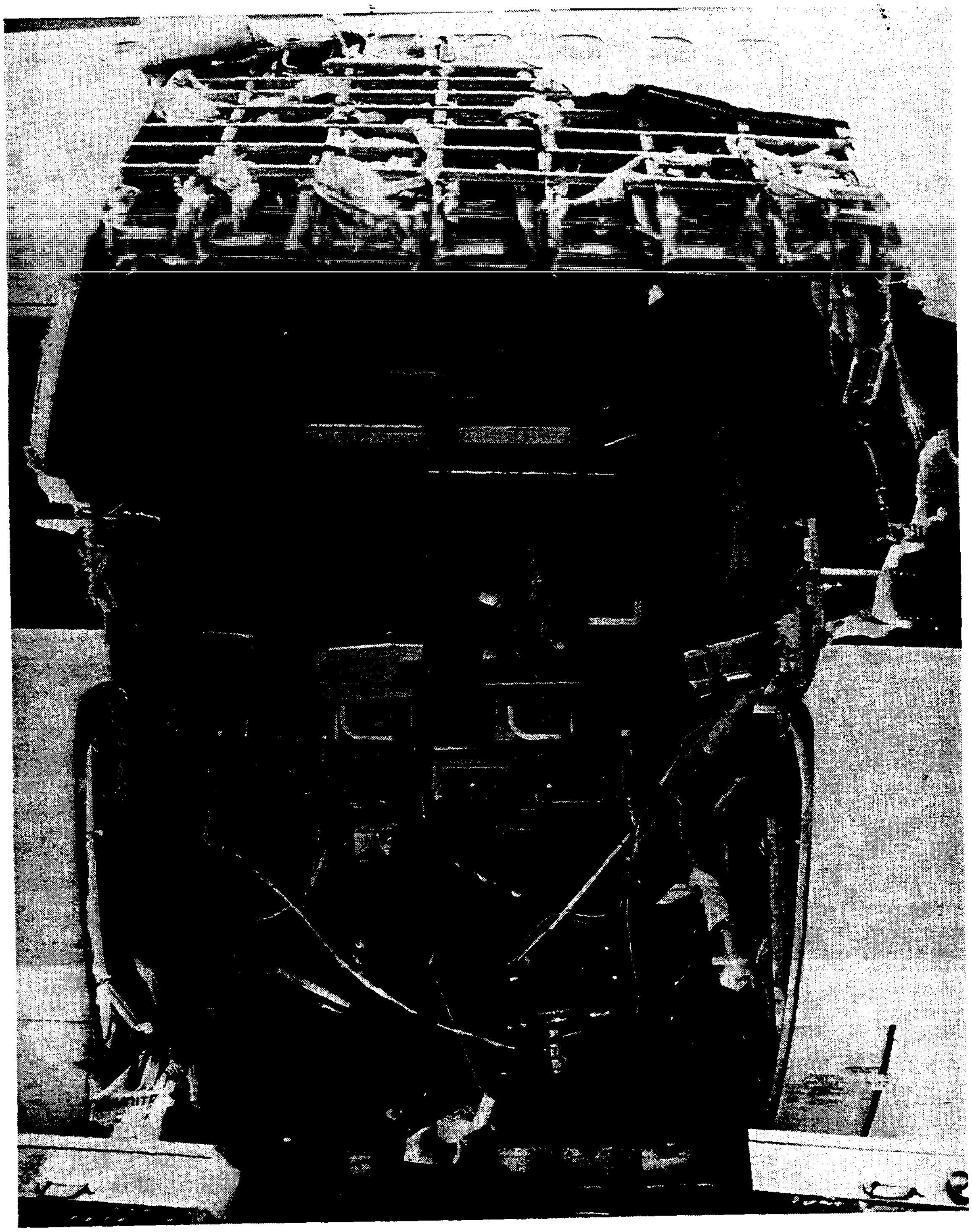

Figure 2.--Close-up view of hole and surrounding structure damage.

There was a break and scuff in the wing leading edge aft of engine No. 4 and a scuff in the wing leading edge outboard of engine No. 4. There was a large indentation (to a depth of nearly 8 inches) in the area just above the outboard landing light, and the landing light covers were broken. There was a small puncture in the upper surface of the No. 14 kmeger flap and impact damage to the wing leading edge just aft of the No. 14 krueger flap. There was a gash on the upper wing surface aft of the No. 14 krueger flap and leading edge, as well as punctures to the wing leading edge aft of the number 16 krueger flap. The under wing surface aft of the krueger flaps also sustained impact damage.

The right wing also had sustained damage at the wing-to-body fairing and two flap track canoe fairings.[1] Wing-to-body fairing damage was limited to surface scraping forward of and below the wing. The outboard surface of the No. 6 flap track canoe fairing revealed a slightly more significant gouge mark. The most severe damage was evident on the inboard surface of the No. 8 flap track canoe fairing, where three separate punctured areas were observed. The trailing edge flaps were not damaged.

The leading edge of the right horizontal stabilizer had several dents. The most severe dents, located 8 to 10 feet from the stabilizer root, were approximately 3 inches wide and 1 inch deep. No punctures were found. The vertical stabilizer had multiple small and elongated indentations with a maximum depth of 1/2 inch near the right base of the leading edge. A small gouge and two small scrapes were noted at midspan of the upper rudder.

A piece of cargo container was found lodged between the No. 3 engine pylon (inboard) and the wing underside. The piece of metal had severed the pneumatic duct for the leading edge flaps. Various nicks and punctures were evident on the inboard side of the No. 3 engine pylon. The No. 4 engine pylon had a small puncture near the leading edge of the wing.

The external surfaces of the No. 3 engine inlet cowl assembly exhibited foreign object damage including small tears, scuffs and a large outwardly directed hole. The entire circumference of all the acoustic (sound attenuator) panels installed on the inlet section of the cowl had been punctured, tom, or dented. None of the No. 3 engine cases were penetrated by objects, nor was there evidence of fire damage to any visible engine components and accessories. The

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[1]The flap track canoe fairings are numbered 1 through 8, from left outboard to right outboard.

leading edges of all fan blade airfoils on the No. 3 engine exhibited extensive foreign object damage.

External damage to the No. 4 engine inlet and core cowls was confined to the inboard side of the inlet cowl assembly. The damage consisted of one major scuff mark, four lesser scuff marks and one crescent- shaped cut. The sound attenuator panels that were installed in the inlet area of the inlet cowl assembly had not been penetrated. The No. 4 engine fan blade airfoils had sustained both soft and hard object damage from foreign objects.

The cargo door separation resulted in the loss of fuselage shell structure above the cargo door, along with main cabin floor structure below seats 8GH through 12GH (see figure 3). The missing floor area extended inboard from the interior of the right side fuselage wall to the inboard seat track of seats 8GH through 12GH.

The supply and fill lines from the flightcrew oxygen bottle, and the supply line for the passenger oxygen system had been broken below the cabin floor inboard of the missing cargo door.

The two cabin pressurization out-flow valves, located on the underside of the fuselage, aft of the rear cargo compartment, were found fully open. The two over-pressure relief valves located on the forward left side of the airplane were found in the normal closed position. These valves were removed and bench tested. (See section 1.16.3, Pressurization System.) The majority of the cabin floor-to-cargo compartment blowout panels were found activated. The blowout panels are designed to relieve excess pressure differential following an explosive decompression to prevent catastrophic damage to the cabin floor structures.

The estimated damage to the airplane was $14,000,000, based on UAL's costs to repair it.

1.4 Other Damage

No other property damage resulted from this accident.

Figure 3.--Forward view of Cabin Zone B.
Note missing seats 8GH through 12GH.

1.5 Personnel Information

The crew consisted of 3 flight crewmembers (the captain, the first officer, and the second officer) and 15 cabin crewmembers. (See appendix B.)

1.6 Aircraft Information

1.6.1 General

, On February 24, 1989, the United Airlines B-747 fleet consisted of 31 airplanes, including: 2 B-747-222B, 11 B-747-SP, 5 B-747-123, and 13 B-747-122 series airplanes. N4713U was equipped with four Pratt & Whitney model JT9D engines.

The accident airplane, serial No. 19875, registered in the United States as N4713U, was manufactured as a Boeing 747-122 transport category airplane by the Boeing Commercial Airplane Company (Boeing), Seattle, Washington, a Division of the Boeing Company. N4713U, the 89th B-747 built by Boeing, was manufactured in accordance with Federal Aviation Administration (FAA) type certificate No. A20WE, as approved on December 30, 1969. The airplane was certificated in accordance with the provisions of 14 CFR Part 25, effective February 1, 1965.

The maximum calculated takeoff weight for flight 811 was 706,000 pounds. The flight plan data showed an actual takeoff weight of 697,900 pounds. The center of gravity (CG) for takeoff was computed at 20.4 percent mean aerodynamic chord (MAC). The forward and aft CG limits were 12 and 29.7 percent MAC, respectively.

At the time of the accident, N47 13U had accumulated 58,8 15 total flight hours and 15,028 flight cycles. N4713U had not been involved in any previous accident. Records indicated that the airplane had been inspected and maintained in accordance with the General Maintenance Program as defined in UAL Operations Specifications and in accordance with the FAA approved Aircraft and Powerplants Reliability Program. The records indicated that all required inspection and maintenance actions had been completed within specified time limits and all applicable airworthiness directives (AD) had been accomplished or were in the process of being accomplished, with the exception of AD 88-12-04, which was applicable to the B-747 lower lobe cargo door, and which had only been complied with partially. (See section 1.6.8 for explanation).

1.6.2 Cargo Door Description and Operation

Both the forward and aft lower cargo doors are similar in appearance and operation. They are located on the lower right side of the fuselage and are outward-opening. The door opening is approximately 110 inches wide by 99 inches high, as measured along the fuselage.

Electrical power for operation of the cargo door switches and actuators is supplied from the ground handling bus, which is powered by either external power or the APU. See figure 17 for a diagram of the cargo door electrical circuitry. The engine generators cannot provide power to the ground handling bus. APU generator electrical power to the ground handling bus is interrupted when an engine generator is brought on line after engine start. The APU generator "field" switch can be reengaged by the flightcrew, if necessary on the ground, to power the ground handling bus. The air/ground safety relay automatically disconnects the APU generator from the ground handling bus, if it is energized, when the airplane becomes airborne and the air/ground relay senses that the airplane is off the ground.

The cargo door and its associated hardware are designed to carry circumferential (hoop) loads arising from pressurization of the airplane. These loads are transmitted from the piano hinge at the top of the door, through the door itself, and into the eight latches located along the bottom of the door. The eight latches consist of eight latch pins attached to the lower door sill and eight latch cams attached to the bottom of the door. The cargo door also has two midspan latches located along the fore and aft sides of the door. These midspan latches primarily serve to keep the sides of the door aligned with the fuselage. There are also four door stops which limit inward movement of the door. There are two pull-in hooks located on the fore and aft lower portion of the door, with pull-in hook pins on the sides of the door frame. (See figure 4 for cargo door components).

The cargo doors on the B-747 have a master latch lock handle installed on the exterior of the door. The handle is opened and closed manually. The master latch lock handle simultaneously controls the operation of the latch lock sectors, which act as locks for the latch cams, and the two pressure relief doors located on the door. Figure 5 depicts a lock sector and latch cam in an unlocked and locked condition.

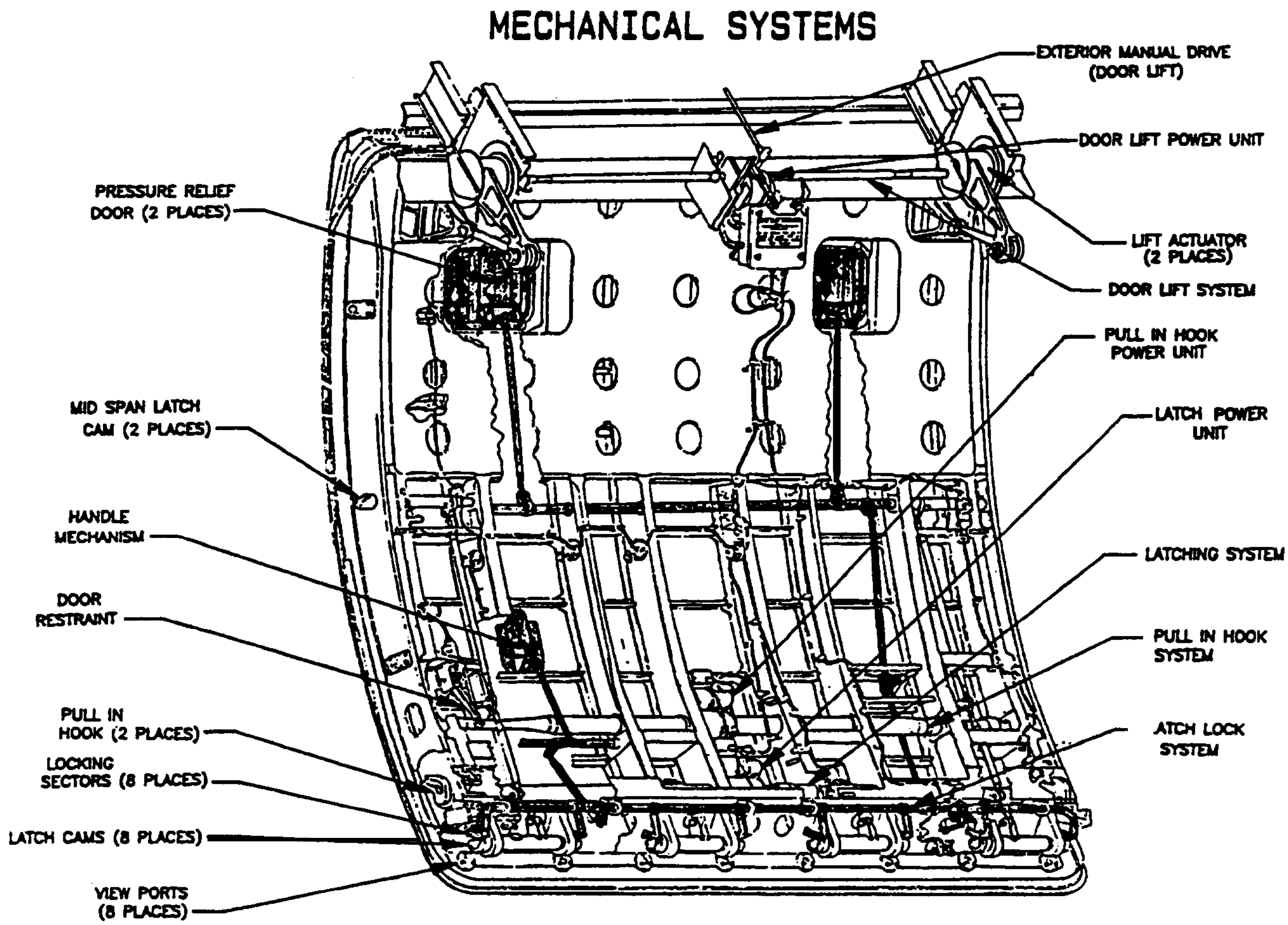

Figure 4.--Boeing 747 lower lobe forward cargo door.

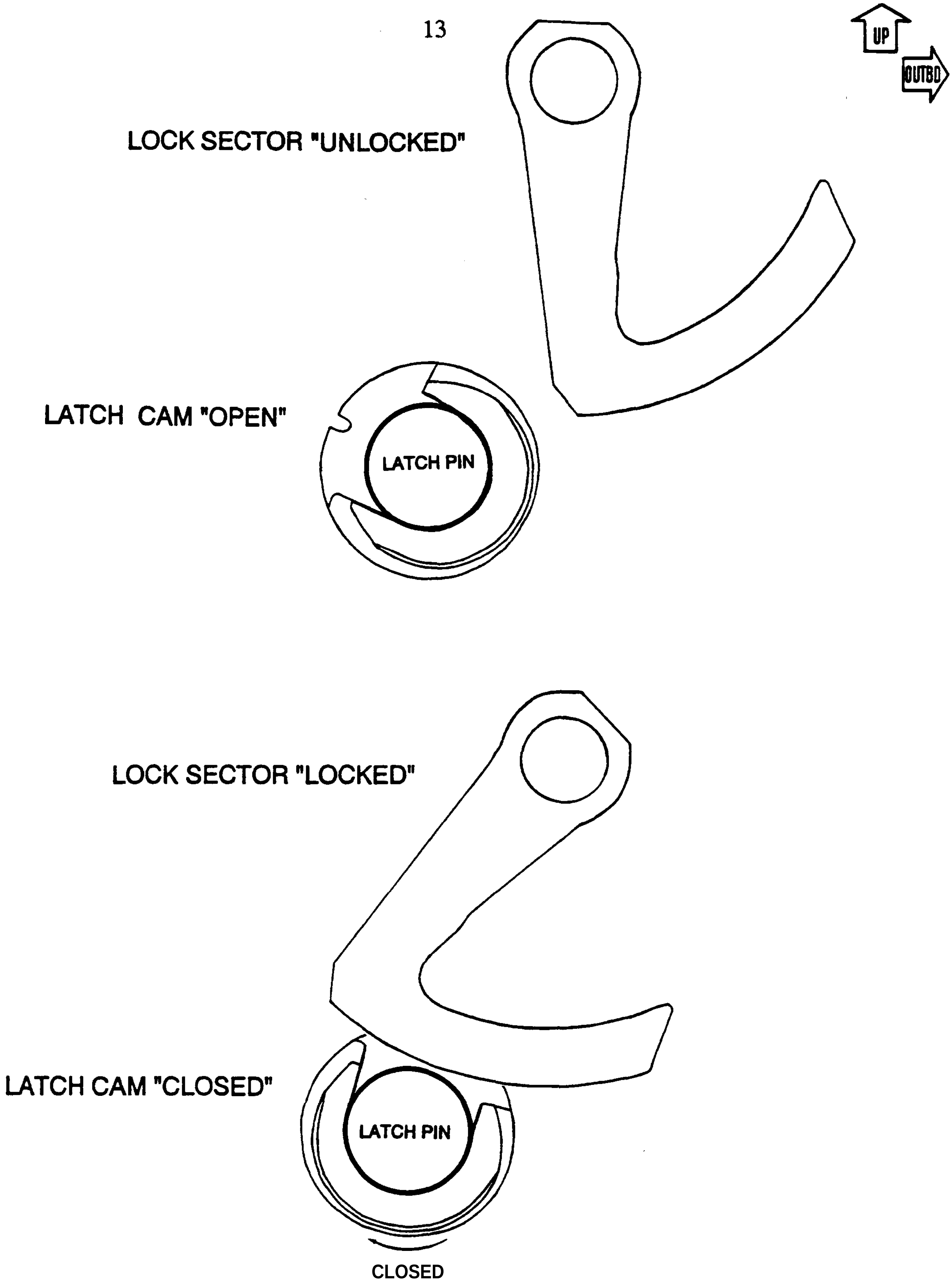

Figure 5.--Cargo door latch cam and lock sector in unlocked and locked positions.

The door has three electrical actuators for opening/closing and latching of the door. One actuator (main actuator) moves the door from the fully open position to the near closed position, and vice versa. A second actuator (pull-in hook actuator) moves the pull-in hooks closed or open, and the third actuator (latch actuator) rotates the latch cams from the unlatched position to the latched position, and vice versa. The latch actuator has an internal clutch, which slips to limit the torque output of the actuator.

Normally, the cargo doors are operated electrically by means of a switch located on the exterior of the fuselage, just forward of the door opening. The switch controls the opening and closing and the latching of the door. If at any time the switch is released, the switch will return to a neutral position, power is removed from all actuators, and movement of the actuators ceases.

In order to close the cargo door, the door switch is held to the "closed" position, energizing the closing actuator, and the door moves toward the closed position. After the door has reached the near closed position, the hook position switch transfers the electrical control power to the pull- in hook actuator, and the cargo door is brought to the closed position by the pull-in hooks. When the pull-in hooks reach their fully closed position, the hook-closed switch transfers electrical power to the latch actuator. The latch actuator rotates the eight latch cams, mounted on the lower portion of the door, around the eight latch pins, attached to the lower door sill. At the same time, the two midspan latch cams, located on the sides of the door rotate around the two midspan latch pins located on the sides of the door frame. When the eight latch cams and the two mid-span cams reach their fully closed position, electrical power is removed from the latch actuator by the latch-closed switch. This completes the electrically powered portion of the door closing operation. The door can also be operated in the same manner electrically by a switch located inside the cargo compartment adjacent to the door.

The final securing operation is the movement of lock sectors across the latch cams. These are manually moved in place across the open mouth of each of the eight lower cams through mechanical linkages to the master latch lock handle. The position of the lock sectors is indicated indirectly by noting visually the closed position of the two pressure relief doors located on the upper section of each cargo door. The pressure relief doors are designed to relieve any residual pressure differential before the cargo doors are opened after landing, and to prevent pressurization of the airplane should the airplane depart with the cargo doors not properly secured. The pressure relief doors are mechanically linked to the movement of the lock sectors. This final procedure also actuates the master latch lock switch, removing electrical control power from the opening and closing control circuits, and also extinguishes the cockpit cargo door warning light through a switch located on one of the pressure relief doors. Opening the cargo door is accomplished by reversing the above procedure.

The B-747 cargo door has eight (8) view ports located beneath the latch cams for direct viewing of the position of the cams by means of alignment stripes. Procedures for using these view ports for verifying the position of the cams were not in place or required by Boeing, the FAA, or UAL (see 1.17.5 for additional information).

Closing the door manually is accomplished through the same sequence of actions without electrical power. The door actuator mechanisms are manually driven to a closed and latched position by the use of a one-half inch socket driver. The door can also be opened manually with the use of the socket driver. There are separate socket drives for the door raising/lowering mechanism, the pull-in hooks, and the latches.

Operating procedures for the normal electrical operation of the forward and aft cargo doors are outlined in the UAL Maintenance Manual (MM). Authorization for deferral of maintenance on the door power system is contained in the UAL B-747 Minimum Equipment List (MEL). In addition, operating procedures for dispatching aircraft with an inoperative door electrical power system (manual operation) are specified in the operator's MEL.

The UAL MM differs from Boeing's recommended MM. UAL had modified Boeing printed material or replaced pages with their own methods and procedures for conducting maintenance functions. The modifications to the manufacturer's MM were accepted by the FAA through "approval" by the FAA Principal Maintenance Inspector (PMI). Electrical cargo door open/close operations in the UAL and Boeing MM's are approximately the same, except the final "Caution" statement differs in methods to ensure that the latch cams are closed:

United Airlines Maintenance Manual

CAUTION DO NOT FORCE HANDLE. LATCH CAMS NOT FULLY CLOSED COULD CAUSE HANDLE MECHANISM SHEAR RIVET TO SHEAR.

<u>Boeing Airnlane Comnanv Maintenance Manual</u>

<u>CAUTION</u> DO NOT FORCE HANDLE. IF RESISTANCE IS FELT, CHECK LATCH ALIGNMENT STRIPES THROUGH VIEWING PORTS IN DOOR. LATCH CAMS NOT FULLY CLOSED COULD CAUSE HANDLE MECHANISM SHEAR RIVET TO SHEAR.

The following step in Boeing's MM does not appear in the UAL MM: "Check that the Cargo Door Warning Light on flight engineer panel goes out." The UAL flightcrew checklist includes a check of the warning light as part of the cockpit procedures for dispatch.

Prior to the issuance of AD-88-12-04 (see 1.6.8), UAL ramp service personnel only operated the cargo doors electrically. Manual operation was accomplished only by maintenance personnel. AD-88-12-04 required the additional procedure of recycling the master latch lock handle following manual operation of the latch actuator.

1.6.3 UAL Boeing 747 Special Procedures--Doors

The Safety Board's investigation revealed that UAL had published a "special maintenance procedure" in the UAL MEL for manual operation of the cargo door. The Maintenance Manual Special Procedures, 5-8-2-52, dated January 1988, were incorporated into UAL's MEL for use by maintenance controllers and work foremen in issuing instructions or procedures to mechanics. The procedure allowed the use of a special 1/2-inch socket drive wrench as the primary tool for use in manually opening or closing the cargo door. The document further authorized, as an alternate tool, an air-driven torque-limiting screwdriver. UAL procedures required approval by San Francisco Line Maintenance and the station maintenance coordinator before an air-driven screwdriver could be used to operate the doors of a B-747 airplane with an inoperative cargo door power system.

At the Safety Board's public hearing, the FAA PMI and the FAA B-747 maintenance inspector for UAL testified that prior to the accident they were unaware of an FAA authorization for UAL's use of an air-driven torque-limiting screwdriver on B-747 cargo doors. However, the FAA's approval for the use of the tool was noted in the MEL section of the airline's maintenance manual. The original approval had occurred before the current inspectors assumed their respective positions. Both testified that they had not reviewed UAL's B-747 MEL because they assumed that the previous inspectors had reviewed it.

According to UAL, the calibration/adjustment for the torque- limited air-driven screwdrivers was tested every six months. Safety Board investigators found no records for the calibration/adjustment of the power tools used to manually open and close UAL B-747 cargo doors.

The Safety Board received statements from UAL supervisory maintenance personnel at all UAL stations and contract facilities for B-747 operations indicating that air-driven screwdrivers had not been used by maintenance personnel to open or close the forward cargo door on N47 13U in the months prior to the accident.

1.6.4 UAL Maintenance Program

Airplanes operated by UAL are maintained under an FAA-approved continuous airworthiness maintenance program, as required by 14 CFR Part 121, Subpart L. The requirements of the UAL maintenance program are detailed in their Operations Specifications, dated November 21, 1988. Generally, UAL has an overall in-house capability to perform virtually all of the maintenance required on its own airframes and powerplants. All of the required major airframe and powerplant maintenance for N4713U had been performed at the UAL maintenance facility in San Francisco, California.

UAL's maintenance and inspection program is scheduled either at specific flight hour or calendar intervals. These maintenance and inspection programs are designated as: Service No. 1, Service No. 2, or A, B, C, MPV, and D Checks.

The work scope of Service Checks consists of a general inspection of the airplane and engines, including servicing of consumable fluids, oxygen, and tire pressures. The Service No. 1 check involves an inspection at each maintenance facility where the airplane lands. The Service No. 2 check is performed at a maintenance facility where the airplane is scheduled for at least 12 hours of ground time. The maximum time interval between Service No. 2 Checks is not to exceed 65 flight hours.

The “A” Check is performed at intervals not to exceed 350 flight hours. This check includes an extended inspection of the cockpit, cabin, cargo compartments, landing gear, tires, and brakes. It does not include a detailed inspection of the cargo doors.

The Phase Check ("B" Check) is scheduled on a calendar basis, not to exceed 13 1 days. The scope of the "B" Check contains items of inspection such as interior safety equipment and functional verification of various aircraft systems and components. It does not include a detailed inspection of the cargo doors.

The "C" Check is heavy maintenance oriented and is scheduled on a calendar basis, every 13 months. The "C" Check work scope is substantial and includes:

- structural inspection items;
- corrosion repair;
- prevention and inspection of critical flight control systems; **and,**
- a detailed inspection of the cargo doors.

The Mid-Period Visit (MPV) Check is a heavy maintenance inspection that is scheduled at intervals not to exceed 5 years. Items requiring scheduled overhaul are contained in the check as well as inspections of the airplane structure and interior.

The D Check, completes the routine scheduled B-747 maintenance plan and is scheduled at intervals not to exceed 9 years. The work scope is very similar to the MPV Check and consists of heavy maintenance to the airplane structure, landing gear, interior, and airplane systems, including the cargo doors.

1.6.5 Maintenance Records Review

A review of the airplane's history indicated that the forward and aft cargo doors were the original doors and neither had been removed for repair or replaced for cause. There was no record of major repair to either door or adjacent airplane structure.

The forward cargo door's forward mid-span latch pin had been removed because of gouging of the pin surface, during the last "C" check on

November 28, 1988. According to the available maintenance documents, including the most recent "D" check, a full cargo door rigging check had not been accomplished. UAL maintenance personnel indicated that no rigging of the forward or aft cargo doors was required during the following checks:

1. "D" check accomplished April 1984;

2. "C" checks accomplished November 11, 1987, and November 28, 1988; and,

3. "B" checks accomplished March 21, 1988 and July 27, 1988;

The records prior to the "D" check in 1984 and the "C" check accomplished in November 1987 were not required to be retained. This procedure complies with FAR 121.380.

The logbook of N4713U was reviewed and all numbered pages were in sequential order with none missing. The airplane had been released for flight by UAL, HNL Maintenance, in accordance with UAL procedures. The Los Angeles to HNL segment of flight 811, on February 23, 1989, generated four logbook discrepancy entries. All items were cleared by HNL maintenance and none were related to the cargo door. No new deferred items were generated and no current deferred items were corrected. The Maintenance Release document for flight 8 11 indicated that all deferred items were in accordance with the UAL Minimum Equipment List (MEL) and none referenced the forward cargo door.

UAL stores its maintenance information in an “electronic logbook,” entitled Aircraft Maintenance Information System (AMIS). This system tracks on a daily and worldwide basis the flightcrew defect reports, all nonroutine maintenance defects, and maintenance corrective actions for the UAL airplane fleet. The system follows an Airline Transport Association (ATA) chapter format. According to UAL, the AMIS information is used as part of UAL's FAA approved maintenance reliability program affording the capability to assess trends at any given time.

A complete history of N4713U was reviewed for the following ATA Chapters:

Chapter-00-Miscellaneous

No significant items associated with the cargo door systems.

Chapter-21-Air Conditioning and Pressurization

An entry, dated August 19, 1988, indicated "Auto and Standby pressure controllers were erratic." UAL maintenance cleared this item as "Checked per Maintenance Manual Chapter (MM) 21-31-O.

Chapter-31-Instruments (Not related to any specific system)

No significant items associated with the cargo door systems.

Chapter-52-Doors (Cargo door section only)

During the period September 7, 1988, through November 1, 1988, a series of five discrepancies on the forward cargo door's electrical opening and closing system were noted. Ground handling personnel were required to operate the door by the manual system. On November 1, 1988, UAL maintenance corrective action for this discrepancy was signed off as, "replaced power unit [lift mechanism] per Maintenance Manual Chapter 52-34-02.

An expanded AMIS history of the N4713U forward cargo door system was prepared beginning December 1, 1988, and continuing until the date of the accident. The history tracked the airplane by each flight and station transited.

During the period December 5, 1988, through December 23, 1988, eight defect reports regarding the opening and closing of the forward cargo door were entered into the system. The reported defects involved problems with the cargo door not always operating with the normal electrical system. Appendix E contains the details of the writeups and corrective actions.

During the period December 23, 1988, through February 23, 1989, two forward cargo door discrepancies were noted on N4713U. On January 3, 1989, the discrepancy was, "Manual lock seals broken." The corrective action was signed off as, "recycled [door] per placard on door and documented. No door problems." On January 15, 1989, the discrepancy was, "cargo door seal, lower aft comer is tom and loose from retainer." The corrective action was "repaired seal." There were no further recorded discrepancies.

On February 23, 1989, a written discrepancy noted " Aft cargo door damaged aft lower comer." The corrective action listed, 'Interim repair per (EVA) **LM-8-433.** Accomplish permanent repair within 60 flight hours."

Chapter-53-Structures(Fuselage)

During the period March 1988, through February 24, 1989, one defect was noted for each of the forward and aft cargo doors on **N4713U.**

Forward Cargo Door.--On September 6, 1988, the discrepancy was, " Approximately six inches of forward cargo door jamb damaged center of lower side sealing surface." The corrective action was, "Installed doubler and sealed area. "

Aft Cargo Door.--On April 22, 1988, the discrepancy was, " Aft cargo door rear sill latch does not spring up to lock." The corrective action was, " Replaced latch."

1.6.6 Service Diffkuity Report Information

A review was made of the Service Difficulty Reports (SDRs) for ATA Chapter 52 for all UAL Boeing 747 airplanes. Thirty-nine SDRs were recorded over the period January 31, 1983, through March 21, 1989. The following summarizes data concerning the forward and **aft** cargo doors:

- **6** cases of corrosion;
- 13 cases of cracking;
- 9 cases of door open (false) indications;
- 8 cases where cabin did not pressurize;
- 2 cases of cabin pressure loss; and
- 1 case of dent caused by ground equipment.

None of the noted SDR cases were recorded for **N4713U.**

1.6.7 Service Letters and Service Bulletins

Boeing issues information to its customers via Service Letters (SL's) and Service Bulletins (SB's) to inform operators of reported and anticipated difficulties with various airplane models. Twelve SL's provided guidance for maintenance or information applicable to the B-747 cargo doors. Twenty-nine SB's provided guidance for maintenance or information applicable to the B-747 cargo door.

SB-747-52-2097, "Pressure Relief Door Shroud Installation--Lower Lobe and Side Cargo Doors," was issued on June 27, 1975. Revision 1 to SB-747-52-2097 was issued November 14, 1975. In general, the SB recommended the installation of shrouds on the inboard sides of the cargo door pressure relief door openings. The purpose of the shrouds was to prevent the possibility of the pressure relief doors being rotated (blown) to the closed position during the pressurization cycle. This condition could only occur if the master latch lock handle had been left open and the flightcrew failed to note the cargo door open warning before takeoff.

UAL records for N4713U indicated that SB-747-52-2097 had been complied with and the shrouds had been installed on the forward and aft cargo doors. However, examination of the aft cargo door on N47 13U revealed that the shrouds were not in place. UAL could not find records to verify if the shrouds had been installed or if they had been removed from either door.

1.6.8 Airworthiness Directives

There had been 141 Airworthiness Directives (ADs) issued that were applicable to the accident airplane. Two ADs were pertinent to the cargo door. AD 79-17-02-R2 ("Inspection of Fore and Aft Lower Cargo Door Sill Latch Support Fittings,") required an inspection every 1,700 flight hours. The second, AD 88-12-04 ("To Insure That Inadvertent Opening Of The Lower Cargo Door Will Not Occur In Flight,") issued on May 13, 1988, required an initial one time inspection of the cargo door latch locking mechanisms within 30 days of issuance of the AD, and certain repetitive inspections until terminating action for the AD was taken.

The circumstances of a Pan American World Airways (Pan Am), Boeing 747-122 cargo door opening in flight (see 1.17.1 for details) led to the issuance of Boeing Alert Service Bulletins (ASB) 52A2206 on April 8, 1987, and 52A2209 on August 27, 1987, entitled, "Doors - Cargo Doors Lower Lobe Forward and Aft Cargo Doors, Latch Locking System Tests, Operation and Modification." Tests and investigation revealed that latch lock sectors would, in some instances, not restrain the latch cams from being driven open manually or electrically. Movement of the latch cams without first moving the lock sectors to the stowed [unlocked] position would cause bending, gouging, and breaking of the sectors. The FAA issued AD-88-12-04 to make the provisions of SB's 52A2206 and 52A2209 mandatory.

The terminating action for AD 88-12-04 called for installing steel doublers to add strength to the lock sectors to prevent the latch cams from being able to be driven to the open position manually or electrically with the sectors in the locked position. AD 88-12-04 also required that, if the door could not be operated normally (electrically), a trained and qualified mechanic was to open and close the door manually, rather than ramp service personnel. Further, the AD required an inspection of the lock sectors for damage once a cargo door was restored to electrical operation after any malfunction had required manual operation of the door. The amount of time allowed for completing the terminating action portion of AD 88-12-04 was either 18 months or 24 months, from the issue date of the AD, depending on the Boeing 747 model series. Terminating action for the AD had not been accomplished on N4713U prior to the accident, nor was it required since, for this airplane, the deadline for compliance with the terminating action was January 1990. According to UAL, N4713U was scheduled for completion of the terminating action in April 1989, when the airplane was scheduled for other heavy maintenance.

During the Safety Board's investigation it was determined that a clerical error was made by UAL personnel, while attempting to expedite the processing of an advanced copy of a Notice of Proposed Rulemaking (NPRM 87-NM-148-AD), preceding AD 88-12-04. The error involved the omission of one line of text during the typing of the document. Because of that error, the portion of the text of the NPRM (and the final text of the AD) was left out of UAL's maintenance procedures. The omitted text required an inspection of the B-747 cargo door lock sectors every time a cargo door was restored to normal (electrical) operation after manual operation was required.

The UAL maintenance internal auditing system, including quality assurance personnel, did not detect the omission until after the accident. UAL personnel stated that, for unknown reasons, no one within the maintenance or quality assurance programs had reviewed the final AD language for comparison with the UAL maintenance procedure.

A review by Safety Board investigators of forms used by UAL to verify compliance with applicable FAA AD's issued indicated that all of the applicable mandatory ADs were satisfied within their specified time limits. The list provided by UAL to the FAA as part of the FAA's oversight responsibilities showed compliance with AD-88-12-04, with the exception of the terminating action.

Section 1.17.3 contains information relevant to the B-747 cargo door corrective actions taken since the accident.

1.7 Meteorological Information

The accident occurred in night visual meteorological conditions. No adverse weather was experienced, although the flight did have to deviate around thunderstorms during the descent.

1.8 Aids to Navigation

There were no navigational problems.

1.9 Communications

There were no radio communication diffkulties between flight 811 and air traffic control (ATC). Members of the flightcrew did not have any difficulty in verbally communicating with each other, however, attempts to communicate with the cabin crewmembers by interphone were unsuccessful following the explosive decompression.

1.10 Aerodrome Information

After the explosive decompression, the airplane returned to HNL, a 14 CFR Part 139 certificated airport on the island of Oahu, Hawaii. The airport is located about 4 miles west of Honolulu, Hawaii.

HNL is a "joint use" airport that is used by the State of Hawaii, the U.S. Air Force, general aviation, commercial, air carrier, air taxi, and military aircraft. Aircraft Rescue and Fire Fighting (ARFF) services are provided by State and Hickam Air Force Base ARFF units. Prior to the emergency landing at Honolulu, flight 8 11 requested that all available fescue and medical equipment to be on hand when they landed. When the crash alarm was broadcast, all civilian and military fire units responded and were in position in l-minute at pre-designated stations at runway 8 left.

The Safety Board's investigation revealed that there was no direct radio communications between the State Airport vehicles and Hickam ARFF vehicles. Because there were no direct radio communications, the Chief of the airport's units had to drive his vehicle to the vehicle of the Chief of the Hickam units to coordinate the positioning of ARF'F units prior to the landing of United 811.

The Hickam vehicles are painted olive drab camouflage. During the response, the Chief of the State ARFF vehicles observed a near collision between a State and a Hickam vehicle. He attributed this to the camouflaged Hickam vehicle not being visually conspicuous in spite of the fact that each of the vehicles had a red rotating beacon operating. The response took place on a moonless night and in light rain.

1.11 Flight Recorders

The airplane was equipped with a Sundstrand model 573 digital type Flight Data Recorder (DFDR) and a Sundstrand model AV557-B Cockpit Voice Recorder (CVR).

Examination of the data plotted from the DFDR indicated that the flight was normal from liftoff to the accident. The recorder operated normally during the period. However, the decompression event caused a data loss of approximately 2 1/2 seconds. When the data resumed being recorded, all values appeared valid with the exception of the pitch and roll parameters. Lateral acceleration showed a sharp increase immediately following the decompression. Vertical acceleration showed a sharp, rapid change just after the decompression and a slight increase as the airplane began its descent.

The CVR revealed normal communication before the decompression. At 0209:09:2 HST, a loud bang could be heard on the CVR. The loud bang was about 1.5 seconds after a "thump" was heard on the CVR for which one of the flightcrew made a comment. The electrical power to the CVR was lost for approximately 21.4 seconds following the loud bang. The CVR returned to normal operation at 0209:29 HST, and cockpit conversation continued to be recorded in a normal manner.

1.12 Wreckage and Impact Information

An extensive air and surface search of the ocean conducted immediately following the accident failed to locate the portions of the airplane lost during the explosive decompression. However, the Safety Board, as well as other parties to the investigation, pursued several avenues to search for and recover the cargo door.

Navy radar near Honolulu tracked debris that fell from the airplane when the cargo door was lost. Refinement of the radar data led to a probable "splashdown" point in the ocean. Further assistance from the Navy regarding the ocean currents and drift information led to a probable location of the cargo door and associated debris on the ocean floor.

The undersea search operation was begun on July 22, 1990, using the *Orion,* a state-of-the-art Navy side-scanning sonar "fish." Searching in the area selected by analysis of radar data and undersea currents, the *Orion* located a debris field on its first pass over the 14,200-foot-deep ocean floor. The second pass located a significant sonar target, which later analysis indicated was probably the cargo door. Since the *Orion* is only capable of searching, the debris field was marked with transponders for use during the subsequent recovery phase.

On September 14, 1990, the recovery ship *Laney Chouest* sailed from Pearl Harbor with the manned, deep-sea submersible *Sea Cliff*. Safety Board, FAA, Boeing, and UAL engineering staff assisted the recovery team aboard the *Laney Chouest*. After four dives in the area previously identified as the debris field, only pieces of cargo container and other small debris from the airplane had been recovered. (It appears that the significant target identified by the *Orion* was a piece of cargo container rather than the cargo door.) On the following dive, however, the lower portion of the cargo door was located and recovered. The fuselage structure above the cargo door was located and raised to the surface on the sixth dive, but heavy seas prevented its recovery. The upper portion of the door was recovered during the *Sea Cliff's* seventh dive on October 1, 1990. Afterward, it was decided that no further effort could be justified to recover the fuselage structure above the cargo door, and the recovery mission was terminated.

Following recovery of the cargo door, each piece was sprayed with a corrosion inhibitor. The ship promptly returned to Pearl Harbor, and the retrieved door portions were removed and examined before being shipped to Seattle, Washington, for detailed examinations under the supervision of Safety Board staff.

Visual examinations on the recovery ship and in Pearl Harbor confirmed that the cargo door look sectors were in the locked position and that the latch cams were in the nearly open position. Figure 6 depicts the position of the lock sectors and cams as recovered from the ocean. There was no evidence of progressive fractures in the door structure.

The cost for the search mission was $193,000, and the cost for the recovery mission was $250,000. These costs were shared by the Safety Board, the FAA, UAL, and Boeing. Section 1.16 contains information on the examination of the recovered wreckage.

1.13 Medical and Pathological Information

Appendix D contains a list of injuries.

1.14 Fire

There was no fire in the cabin or fuselage. The fires in engines No. 3 and 4 were extinguished after the engines were shut down.

1.15 Survival Aspects

The fatal injuries were the result of the explosive nature of the decompression, which swept nine of the passengers from the airplane.

At 0210, the FAA notified the U.S. Coast Guard that a United Airlines, Inc., B-747, with a possible bomb on board, had experienced an explosion and was returning to HNL. The Coast Guard Cutter, *Cape Corwin*, departed Maui at 0248 to search the area for debris and the missing passengers. Ultimately, 4 shore commands, 13 surface/air units, and approximately 1,000 persons took part in the combined search and rescue (SAR) operation. The search was terminated at 1200 on February 26, 1989, without recovery of any passenger bodies.

The flight attendants had approximately 20 minutes to prepare the cabin and the passengers for an imminent ocean ditching, and subsequently, for an emergency evacuation. During the 20 minutes they attended to injured flight attendants and passengers, attached the face masks to their emergency oxygen bottles, helped each other don life preservers, helped numerous passengers don life preservers, held up safety cards and life vests to call attention to these items for passengers to use, briefed "helper" passengers to assist in the evacuation, cleared

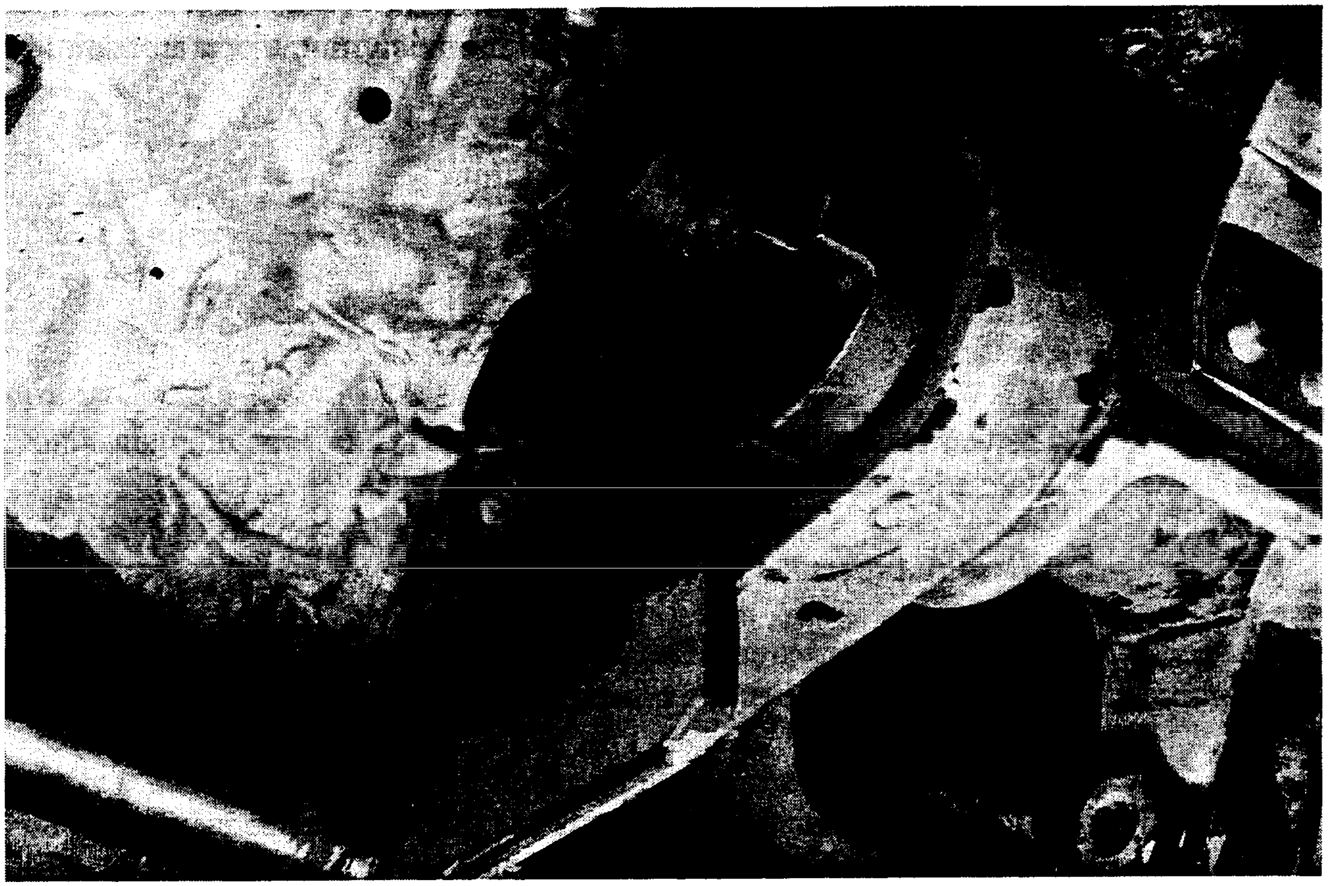

Figure 6.--Recovered lock sectors and cams.

debris away from the exit doors and aisles, closed the doors of the storage compartment above doors 2 left and 2 right, prepared the cabin for an emergency evacuation, and told the passengers to brace for impact.

Several problems were experienced by the flight attendants and the passengers following the decompression, while preparing for a possible ditching, and preparing for the emergency evacuation. These problems included difficulties encountered by flight attendants in connecting face masks to their portable oxygen bottles, the lack of a sufficient number of megaphones, limited visibility from a flight attendant seat, overhead storage compartment doors opening, and donning and fastening life preservers.

Federal Aviation Regulation 14 CFR 25.1447 (c)(4) requires that "portable oxygen equipment must be immediately available for each cabin attendant." Those portable oxygen bottles on N4713U, which were readily available, were not immediately usable because the masks were not attached to the regulators. The flight attendants reported difficulties in attaching the masks to the regulators.

The aft purser ran back to the flight attendant jumpseat at door 5-left for a portable oxygen bottle. However, she found no bottle at this location (none was installed). She then ran back to the 4-left jumpseat, by which time she was "light headed." After the aft purser reached jumpseat 4-left, flight attendant No. 14, who was already sitting there, placed an oxygen mask on her face. The aft purser further stated, "considering the fact that in this case there was no other available source of oxygen, you can't imagine how horrible I felt going back there needing oxygen but finding no oxygen bottle at 5-left. It was terrifying."

A portable emergency oxygen bottle was not required to be stowed at the flight attendant seat at exit 5-right; however, one was stowed in the right coat closet behind the flight attendant seat. In addition, the left side closet and rest rooms were physically separated from the right side closet and rest rooms. This arrangement requires a flight attendant, who was seated at exit 5-left to walk around to the right side of the cabin to obtain the oxygen bottle.

Communication between the flight attendants and passengers was very difficult because of the high ambient noise level in' the cabin after the decompression, even though the public address (PA) system was operational. Flight attendants were located at each of the 10 exit doors, yet there were only two megaphones required to be on the airplane; one located at door l-left and another located a 4-left.

The flight attendants, who were responsible for each of these two doors, used the megaphones to broadcast commands to passengers in their immediate areas and to other flight attendants in preparation for the landing and subsequent evacuation. The other 13 flight attendants (including the one deadheading flight attendant) had to shout, use hand signals, and show passengers how to prepare for the evacuation by holding up passenger safety cards, so passengers could review the information and also know how to put on their life preservers.

As soon as the decompression occurred, the flight attendant in the upper deck business class section went to her jumpseat and donned her oxygen mask, life preserver, and restraint system. While she waited for instructions, and because of intense cabin noise she had to communicate with passengers by holding up a safety card and a life preserver. Passengers sitting in the front rows, in turn, showed safety cards and life preservers to other passengers seated behind them. Eventually everyone understood that they were to read the safety card and put on their preservers. However, the 5 foot 3 1/2 inch flight attendant stated that her jumpseat was so low that she could not directly observe the passengers in the 4th row (last).

A two door overhead stowage compartment that had formerly stored a life raft was located above each exit door. These compartments contained blankets and passenger carry-on luggage. At doors 2-left and 2-right the doors of each compartment had opened downward and blocked each exit. Also the contents of the compartments fell to the floor at the exits. The doors had to be closed before the evacuation because they partially blocked the exit.

The chief purser was not able to tighten the life preserver's two straps around her waist and needed the deadheading flight attendant to tighten them for her. Several flight attendants and passengers had difficulties connecting the two straps around their waists. One flight attendant helped about 36 passengers don their preservers.

Safety Board investigators and United Airlines personnel examined several life preservers from each of the types of preservers produced by five manufacturers. The strap of one manufacturer's preserver was very difficult to tighten around the waist while another from the same manufacturer was easy to tighten. The two vests had different strap material and strap adjustment fittings. Also, the straps are very difficult, if not impossible, to tighten when they are pulled at an acute angle from the wearer's body, i.e. from about 45 to 70 degrees. Holding the hands and straps closer to the waist facilitates easier adjustment of the straps.

1.16 Tests and Research

1.16.1 Cargo Door Hardware Examinations

1.16.1.1 Before Recovery of the Door

The following forward cargo door closing and latching components were returned to the Safety Board's Materials Laboratory for analysis after they were documented in place on the airplane:

- Two pull-in hook pins, one from the lower end of the forward side of the door body cutout forward frame, and one from the lower end of the aft side of the body cutout aft frame, with housings;

- Two mid-span pins, one from the forward side of the door body cutout forward frame, and one from the aft side of the door body cutout aft frame.

All components were initially examined while installed on the airplane. All eight forward cargo door latch pins, with housings, were removed for further laboratory examination. Also, for comparison, one of the latch pins, with housing, from the aft cargo door was also removed. For orientation purposes, the eight lower latch pin assemblies are referred to by number, with the No. 1 latch pin being the most forward on the lower door sill, and the No. 8 pin being the most aft. When referencing a circumferential location on the latch pins or mid-span pins, a clock position was used. The clock code was oriented looking forward with 12 o'clock being straight up and 9 o'clock being directly inboard.

Based on the orientation of the latching mechanisms, the fully unlatched latching cams would first contact the latch pins from about the 1: 15 o'clock position to the 7: 15 position as the door was closed. As the cams are being latched around the pins, they would rotate approximately 80°, making contact with the pins from about the 4:15 position to the 10:15 position (See figure 7).

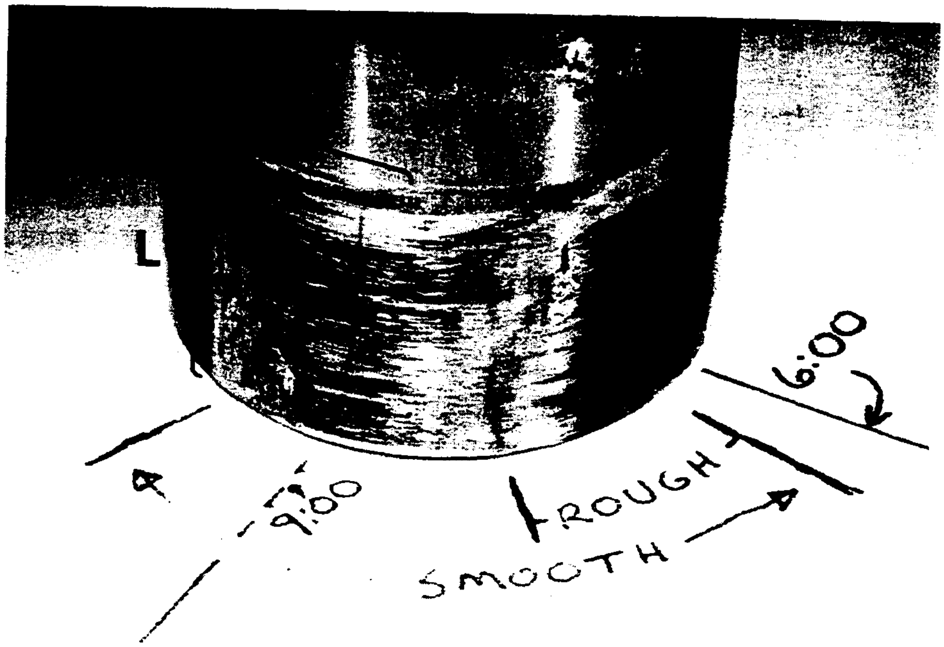

Figure 7.--Latch pin number 6. Note the rough and smooth areas and the steps indicating the contact area with the latch cam.

Detailed examination of the exposed surface of the pins (the portion of the pins extending from the housings) revealed various types of wear and damage. In general, all of the forward door cargo latch pins had smooth wear over the entire portion of the pin area contacted by the cams during normal closing and opening of the door. The pins also had distinct roughened (smeared) areas between the 6:15 and the 7:30 positions (See figure-8). The roughened areas had evidence of "heat tinting" and transfer of cam material to the surface of the pins. On pins 1 and 8 the roughened areas extended past the pin bottom to the 5:00 position. The 7:30 position approximately corresponds to the area on the pin where the lower surface of the cam would be relative to the pin when the latch cams are in the unlatched or nearly unlatched position.

The forward pull-in hook pin was not significantly bent, but the structure to which it was attached was deformed outward, so the hook pin was deflected significantly outward. Three of the four bolts holding the aft pull-in hook pin had sheared, so the hook pin was also deflected outward. Both hook pin ends were damaged, but neither pin wassignificantly deformed along its length. There was significant heat tinting on the damaged area of the forward hook pin. Boeing engineering calculations determined that the pull-in hook pins would fail at a 3.5 psi differential cabin pressure with the latch cams unlatched.

The forward mid-span latch pin was relatively undamaged. The aft mid-span latch pin had definite areas of damage. Both pins had wear areas where the cams would contact the pins during latching.

1.16.1.2 After Recovery of the Door

The documentation of the recovered cargo door was divided into four areas: 1) door structure, 2) master latch lock system, 3) latch system, and 4) hook system. A description of the recovered door follows.

1. Door Structure:

The cargo door had fractured longitudinally near the mid-span lap joint near stringer 34R, just beneath the mid-span torque tubes. Except for an area of missing skin between frames 2 and 3 and a portion of frame webs where the upper latch lock torque tube had tom out, the frames and skin of the upper door

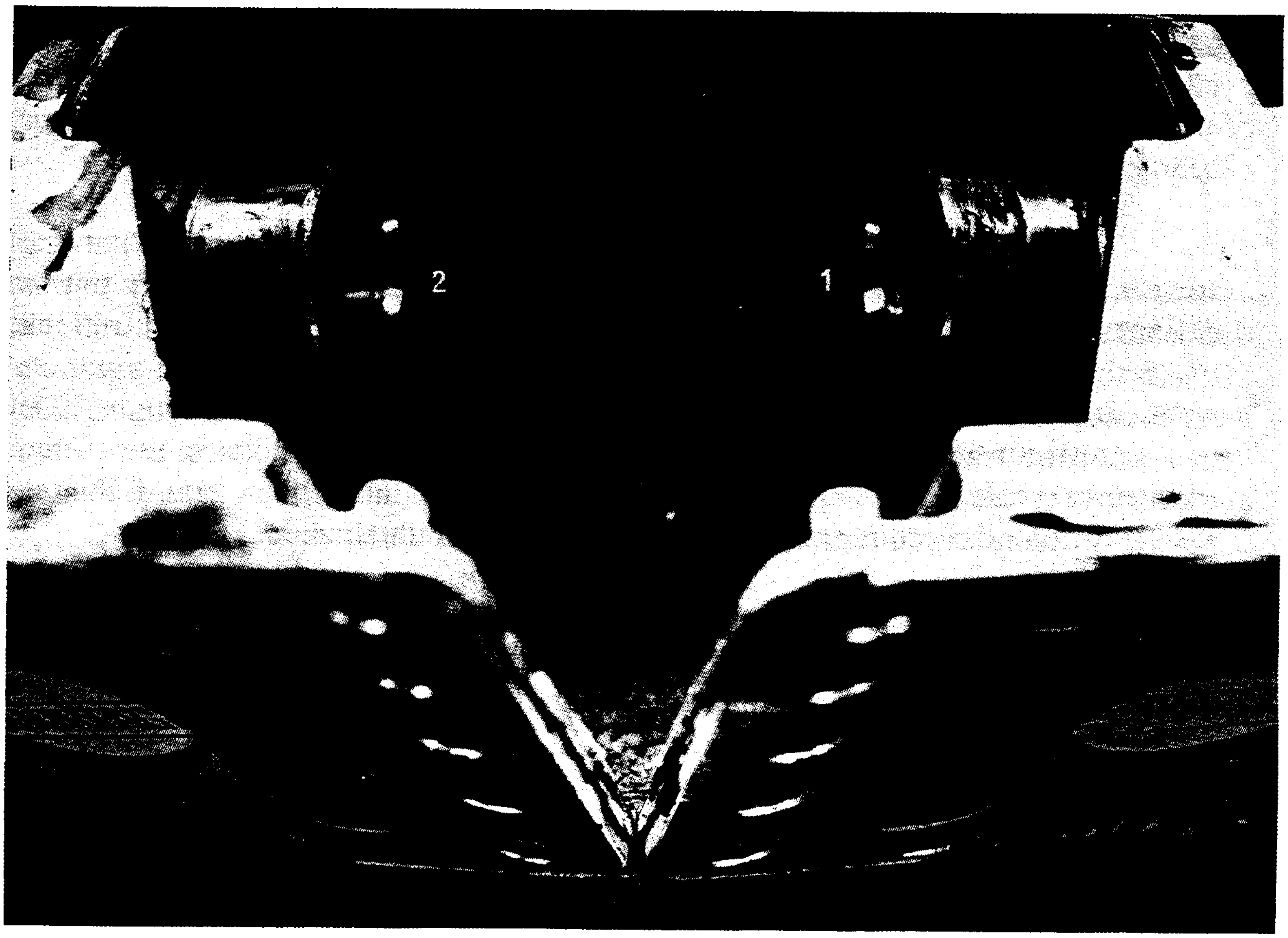

Figure 8.--Lower latch pin and housing assemblies
Nos. 1 and 2 looking up and slightly outboard.

piece mated to the lower door piece.[2] Several areas of the upper door skin along the longitudinal fracture were bent back. In addition, a large area of lower door skin between frame 6 and the aft door edge had peeled downward from the fracture line. The two door pieces are shown together in Figures 9 and 10. Examinations of the fracture surfaces of the skin and frames revealed no evidence of pre-existing cracks. All fractures were typical of overstress separation.

Seven of the eight lock sector slots in the lower beam showed evidence of contact and scraping by the lock sectors. Only the No. 1 lock sector slot was undamaged, although the bracket forward and above the No. 1 slot did appear to have been damaged by contact from the lock sector (slots numbered l-8, forward-aft). The direction of the scraping on the slots could not be determined conclusively.

The decal covering the latch actuator manual drive port was found broken circumferentially around the edge of the port cover, which was loose and rotated from its normal position (See figure 11). There was an impression in the decal similar to a Phillips-head screw slot in line with the center of the retainer screw securing the cover. There was also a 0.06-inch-long linear slit from 10 to 4 o'clock approximately centered over the retainer screw head (See figures 12 and 13). There was no rotational tearing and no loss of decal material in the area covering the screw head location. During examinations of the door at Boeing, it was noted that the retainer bracket on the inside of the latch actuator manual drive port cover was bowed outward; the port cover was not deformed. The retainer bracket on the inside of the hook actuator manual drive port cover was similarly bowed outward, and the port cover was bowed outward.

The hinge that attaches the cargo door to the fuselage is comprised of several hinge sections--those attached along the upper edge of the cargo door and those along the fuselage just above the cargo door cutout--interconnected with hinge pins. The hinge pins and all hinge sections from N4713U's forward cargo door were intact; all hinge sections rotated relatively easily. All attach bolts from the hinge sections on the door remained attached; conversely, no bolts remained attached to the hinge sections on the fuselage. Several areas on the hinge sections, such as the fuselage hinge sections, showed evidence of contact from the door during overtravel (See figure 14). In addition, the fuselage forward hinge sections

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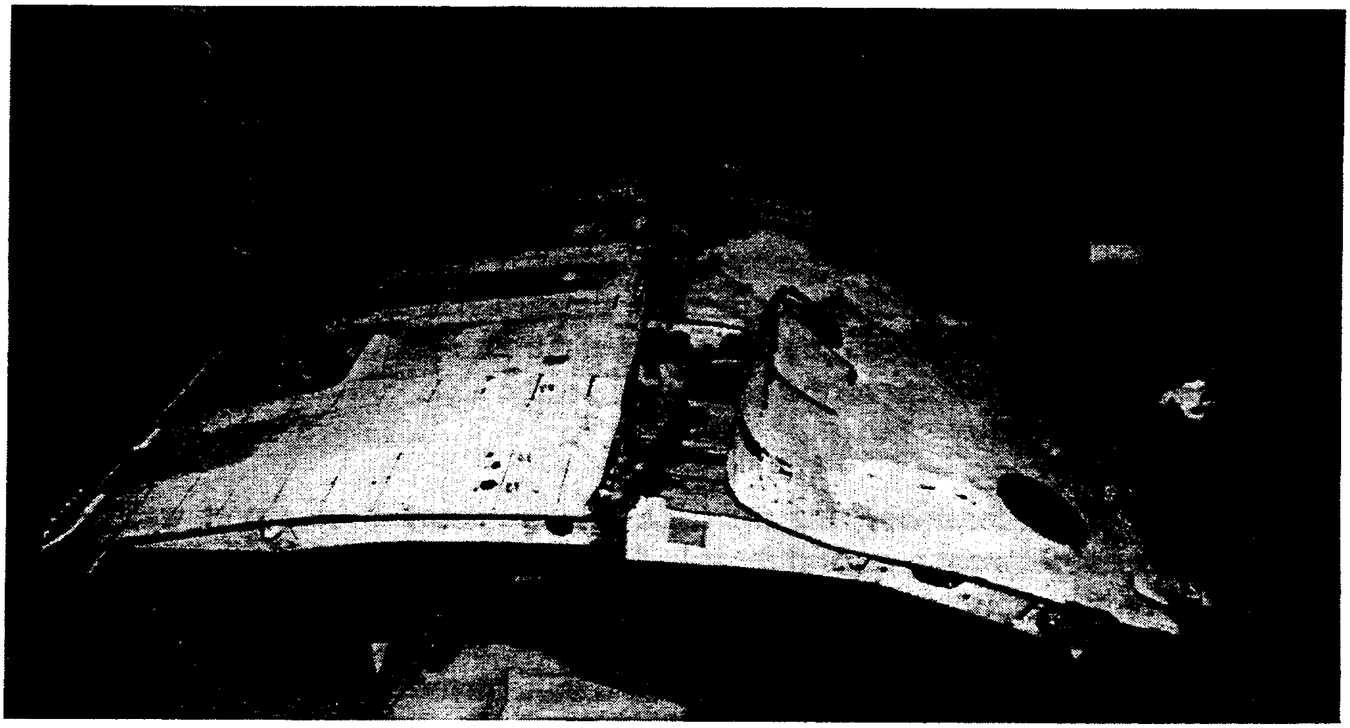
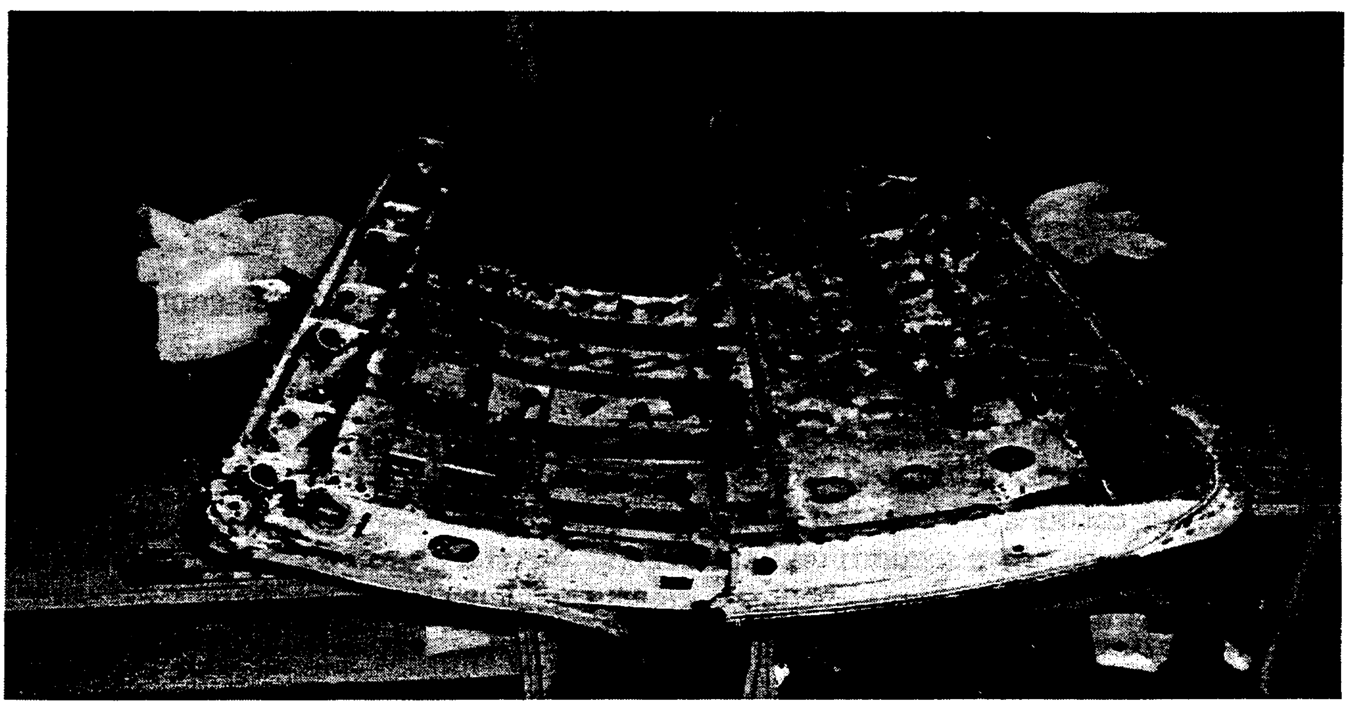
[2]For ease in reference, the following numbering was used to relate forward cargo door frames to fuselage body stations (BS): frame 1--BS 567.10, frame 2--BS 580.95, frame 3--BS 596.75, frame 4--BS 608.15, frame 5--BS 623.96, frame 6--BS 636.02, frame 7--BS 651.50, frame 8--BS 662.90.





Figures 9 and lO.--Exterior [top photo] and interior bottom photo]
views of cargo doors after removal of pull-in hooks,
latch cams, lock sectors, and actuators.

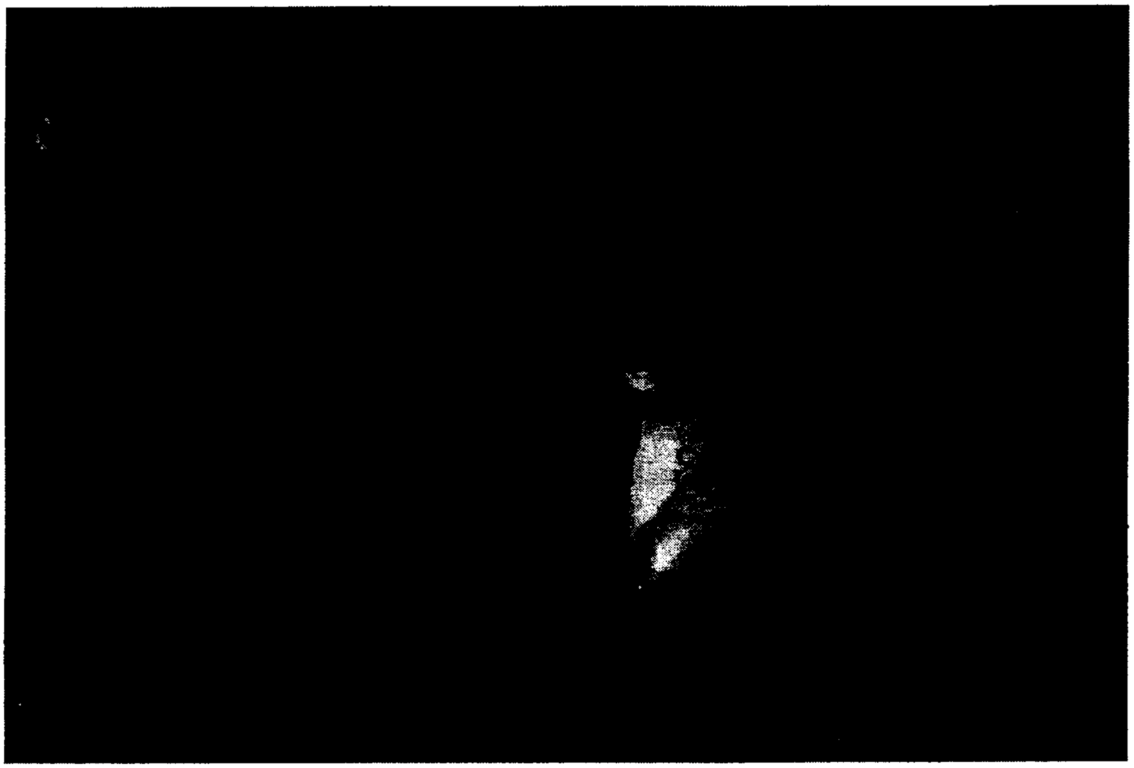


Figure 1 1.--Decal over latch actuator manual drive port.

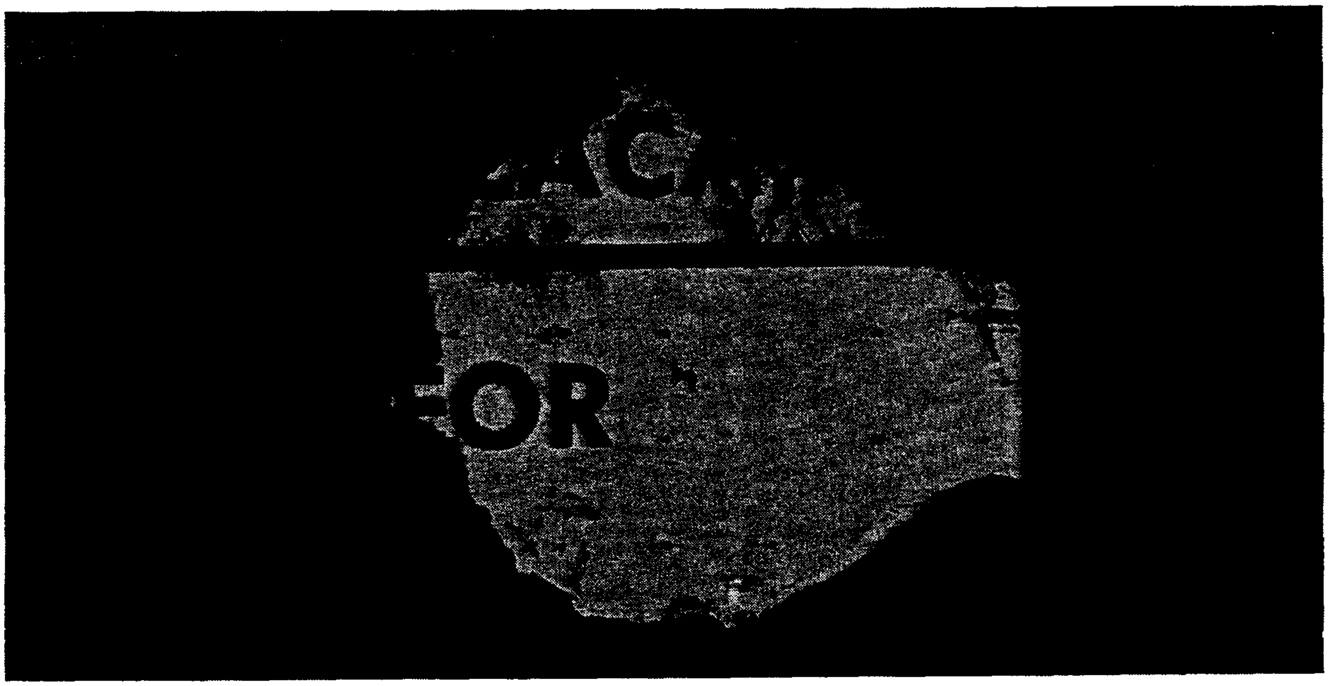


Figure 12.--Decal over latch actuator manual drive port
(2X Magnification).

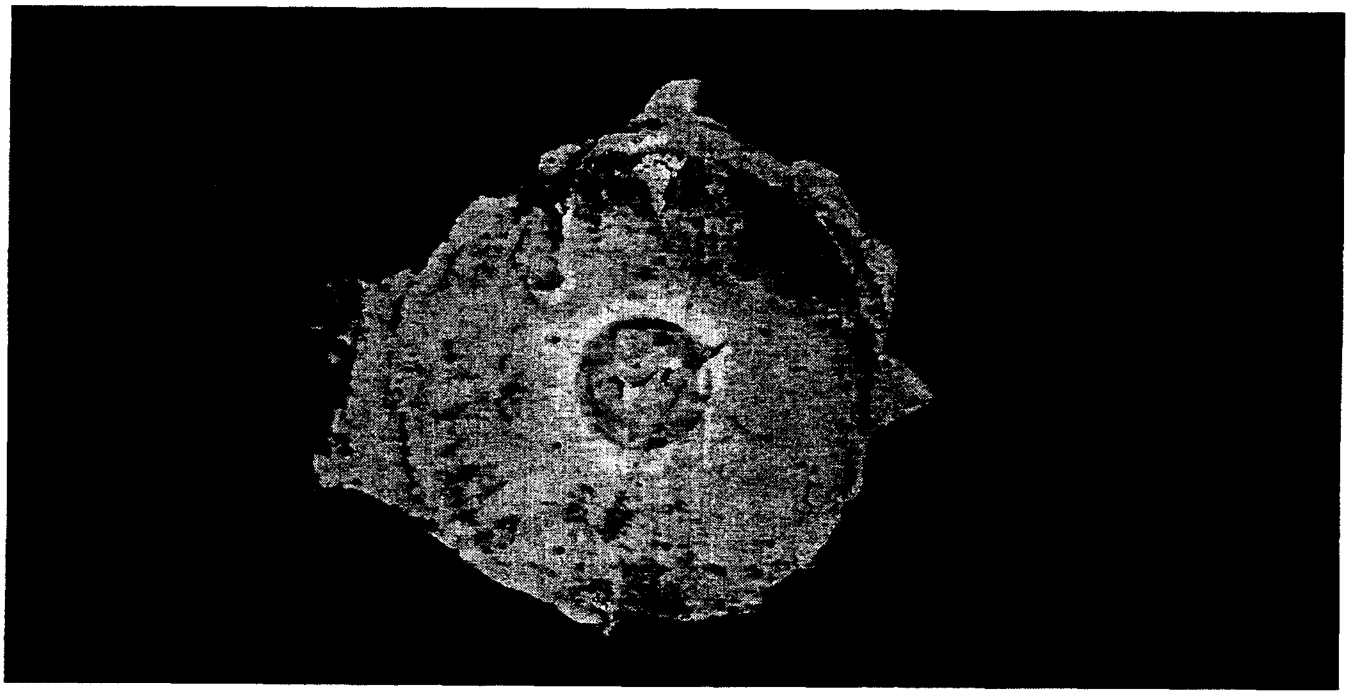


Figure **13.--Underside** of decal piece (2X Magnification).

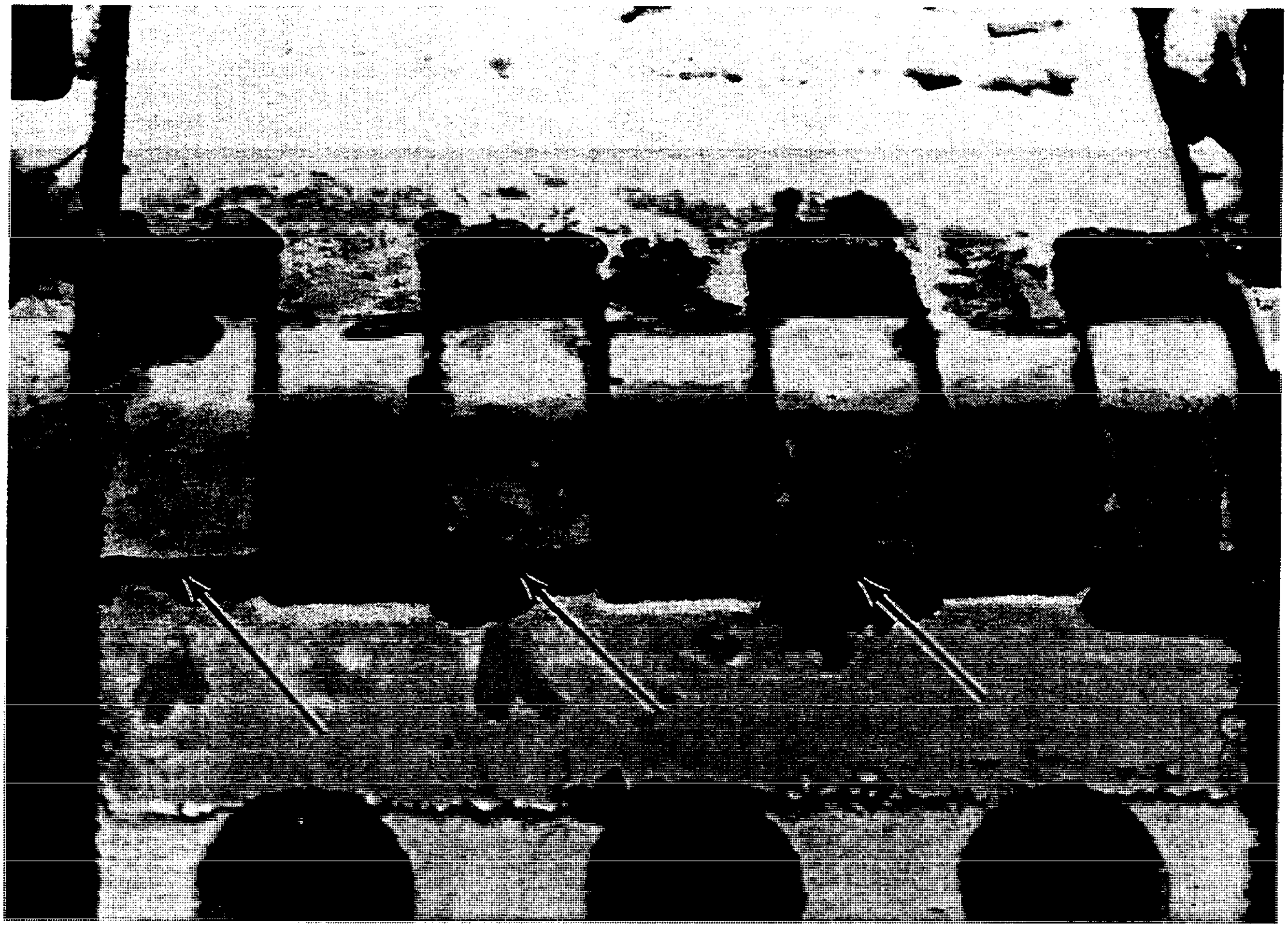


Figure 14.--Close-up view of cargo door hinge section.
Arrows show impressions caused by contact with opposite hinge section.

were slightly bent. The upper flange of the door, to which the door hinges are attached, was not deformed. The forward cargo door can rotate open 143 degrees before the hinge would deform, permitting the door to contact the fuselage above.

Examination of the outer skin contour of the upper door piece revealed that it had been crushed inward. There were also many areas on the outer skin where blue and red paint transfer marks could be seen. These marks were generally forward of the aft pressure-relief door, and the blue marks were located above the red marks. The UAL paint pattern incorporates red and blue stripes along the fuselage above the cargo door. Figure 15 is a plot of the documented paint marks on the upper door piece.

There was no evidence of the pressure relief door shrouds found on the forward door, however, most of the inner door lining to which the shrouds attach was missing.

2. Master Latch Lock System:

All eight lock sectors were found in the locked position--actually past the fully locked position. They had been pulled through the lock sector slots in the lower beam of the cargo door. (When they are fully locked, the lock sectors should be recessed in the lower beam approximately 3/8 inch). All lock sectors had deflected off the high shoulder of the latch cams due to interference with the partially unlatched cams. Prior to disassembly of the components, the interference between the cams and the lock sectors was removed by rotating the cams to the latched position.

Examination of the lock sectors disclosed that the bottom of the lower arm of each lock sector was gouged. For seven of the eight lock sectors, the distance from the main gouge area to the location of the interference between the latch cam and the lock sector was approximately 0.75 inch. (The No. 2 lock sector was corroded and had fractured at the location of the large gouge common to the other seven lock sectors. Consequently, it was not in contact with the No. 2 latch cam when the door was retrieved).

The master latch lock handle housing and trigger were found relatively flush with the door outer skin. The top of the handle was recessed approximately 0.50 inch inward from flush, and the bottom of the handle was protruding approximately 0.40 inch outward from flush (See figure 16). This

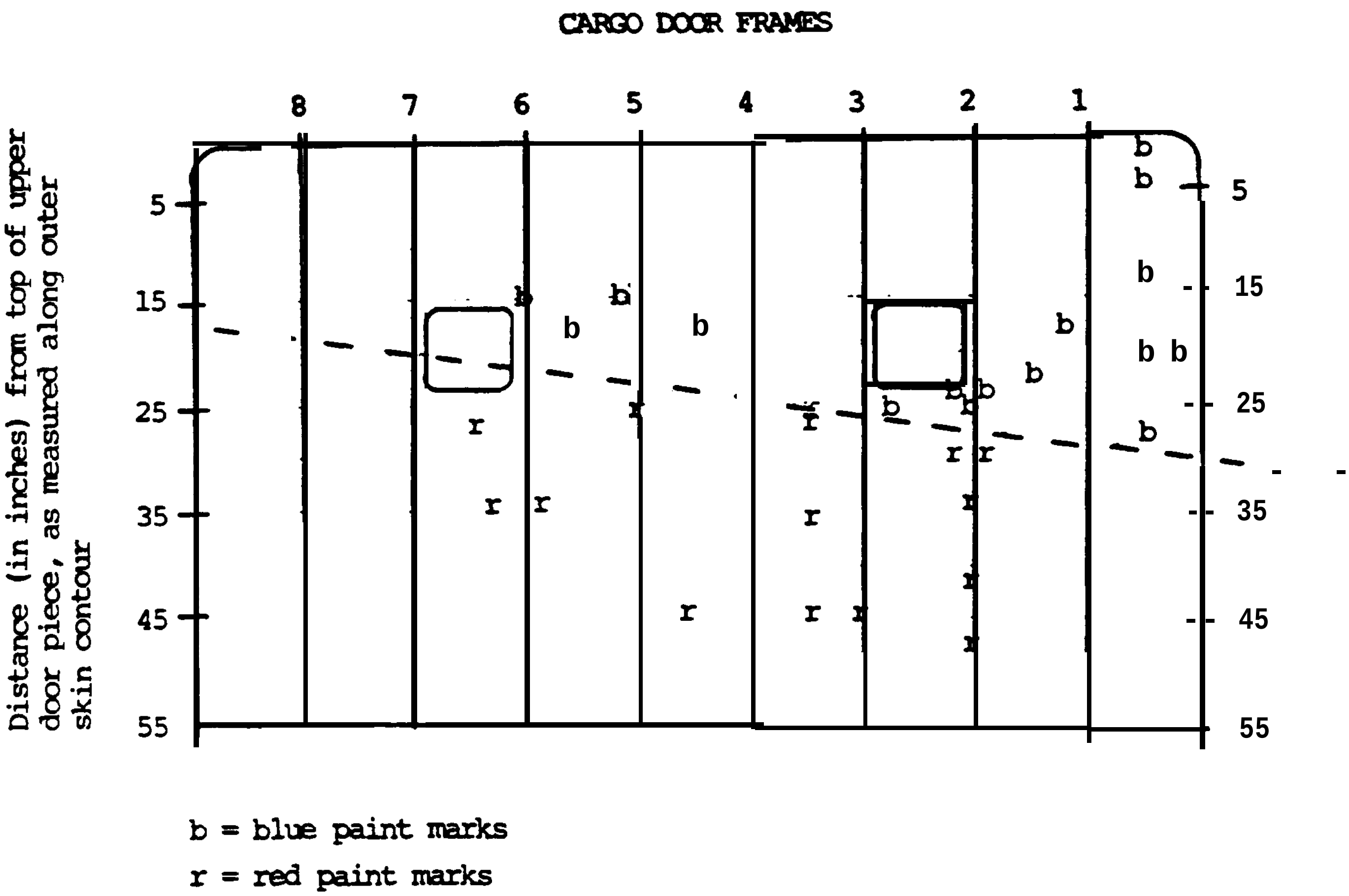


Figure 15.--Documented paint marks on outer skin of upper door piece. Dashed line is approximately 8 degrees from horizontal.

Figure 16.--Position of master latch lock handle.

position of the handle indicates that the lock sectors were in a position past fully locked. The fuse pin was found in three pieces but was heavily corroded. The handle housing was undamaged.

Two of the **three** connecting rods between the master latch lock handle and the lock sector torque tube **were** bowed slightly, but they were otherwise intact. No deformation was observed on any section of the lock sector torque tube, although one of the six bearings assembled on the torque tube had been damaged. The No. 3 bearing inner race and its torque tube locator sleeve were displaced forward approximately 0.20 inch from the bearing housing centerline. The outer race was broken and pushed forward out of the housing.

The lower two connecting rods between the lock sector torque tube and the torque tube below the pressure-relief doors were undamaged; however, the upper connecting rod had separated at the upper, tapered end. The torque tube below the pressure-relief doors were missing, and the pressure-relief door connecting rods had separated at the lower, tapered end. The remaining portion of each rod was undamaged, but the forward pressure-relief door was jammed open into the cutout.

3. Latch System:

All eight lower latch cams were found in a nearly unlatched position, and all of them **were** binding against the lock sectors except the No. 2 cam (lock sector No. 2 had broken). Latch cams l-6 were approximately 62 degrees from the fully latched position, and cams 7 and 8 were approximately 70 degrees from fully latched. Full rotation of the latch cams is 80 degrees.

Several of the lower latch cams contained compression and smearing damage on the lower lip of the latch cam cavity (“lower” relative to an open cam). This damage is consistent with the forceful movement of the cams across the latch pins.

The four rods between the latch actuator torque tube and the four bellcranks containing the latch cams were attached and undamaged. No section of the latch actuator torque tube was damaged, and the bearings/supports along the tube were intact. The latch actuator was removed and later disassembled. No anomalies were found.

4. Pull-in Hook System:

The forward and aft pull-in hooks were found near the closed position. Both of them exhibited wear patterns consistent with contact with the pull-in hook pins during door operation. For both the forward and aft hooks, the inboard edge of the pull-in hook channel contained compression and smearing damage consistent with a forceful movement of the hooks over the pins while the hooks were in the closed or nearly closed position.

1.16.2 Forward Cargo Door Electrical Component Examinations

1.16.2.1 Before Recovery of the Door

Several electrical components associated with the operation of the forward cargo door were examined on the airplane and were then removed for further testing. These components included the No. 2 ground handling power bus relay, the air/ground safety relay, the No. 1 auxiliary power circuit breaker, and the outside and inside door control switches. All of these components were tested for both single faults and intermittent failures. The test results showed that all of the switches/relays were functional, although a loose wire connection was found on the outside door control switch. This loose wire connection showed evidence of overheated insulation on the two terminal lugs that attach to terminal No. 5, and there was evidence of a bum (arc point) on the top of the screw head for terminal No. 5. Terminal No. 5 is associated with power for the door "close" cycle, and not the door "open" cycle.

An electrical continuity check was performed on the cockpit cargo door warning light system components that remained with the airplane. This check confirmed the integrity of the circuit from the door area to the cockpit. The examination of the two bulbs that comprise the forward cargo door warning light revealed that one bulb was inoperative. The other bulb, which is in parallel with the inoperative bulb, was found operative. The illumination of the display legend, which reads "FWD CARGO DR" on the flight engineer's panel, was discernible with one bulb inoperative. A functional check of the circuit, which allows the cockpit warning lights to be dimmed during night operations, was also performed. The check consisted of removing the card containing this circuit and installing it in another B-747. The test was satisfactory in that the dim/bright circuit functioned properly.

1.16.2.2 After Recovery of the Door

Switches--General

The cargo door was recovered with all of its position sensing switches installed in their proper locations. The electrical junction box was found attached to the door but damaged. The switches recovered and examined were: S2 Master Latch Lock; S3 Door Warning; S4 Latch Close; S5 Hook Position; S6 Fwd Mid-Span Latch Open; S7 Door Close; S8 Hook Close; and S9 Aft Mid-Span Latch Open. Figure 17 provides a diagram of the cargo door's electrical circuitry.

Five of the eight position-sensing switches installed on the door had evidence of external damage to the switch housing. The damage on four switches (S2,S3,S4,S8) consisted of primarily compression dimpling on the housing. The S5 switch exhibited mechanical impact damage on the switch housing and mounting bracket. The striker assembly for switch S8 was loose (2 of 3 rivet fasteners sheared). The electrical wiring recovered with the door exhibited signs of tensile separation from overload at all failure points examined.

Each switch was photographed and its installed position was documented. Electrical continuity readings were taken with an ohmmeter across the poles of each switch at the first point of wire separation as found on the door. After the readings were recorded, all switches were removed from the door so that photographs and x-rays of each switch could be taken. Electrical continuity readings were retaken.

Disassembly of each switch consisted of: (1) drilling two holes in the switch housing to release trapped water from the switch (2) cutting a small window in the switch housing to examine the internal basic switches (3) removing the housing, (4) removing the internal bracket, and (5) removing basic switch covers.

During the drilling step, water was released from every switch when the holes were drilled in the switch housing. The water was filtered into a glass container. The quantity was not measured but appeared to be less than 5 mL. The residue from the filtered water trapped on the filter media had a blue-green color.

After the switch housing was removed, an ohmmeter was connected across the l-2 poles of the switches that would not transfer electrical continuity (S2,S3,S4,S6,S7) when actuated. The rivets were then drilled out of the internal bracket. After the last of the two rivets were drilled out, the switch contacts

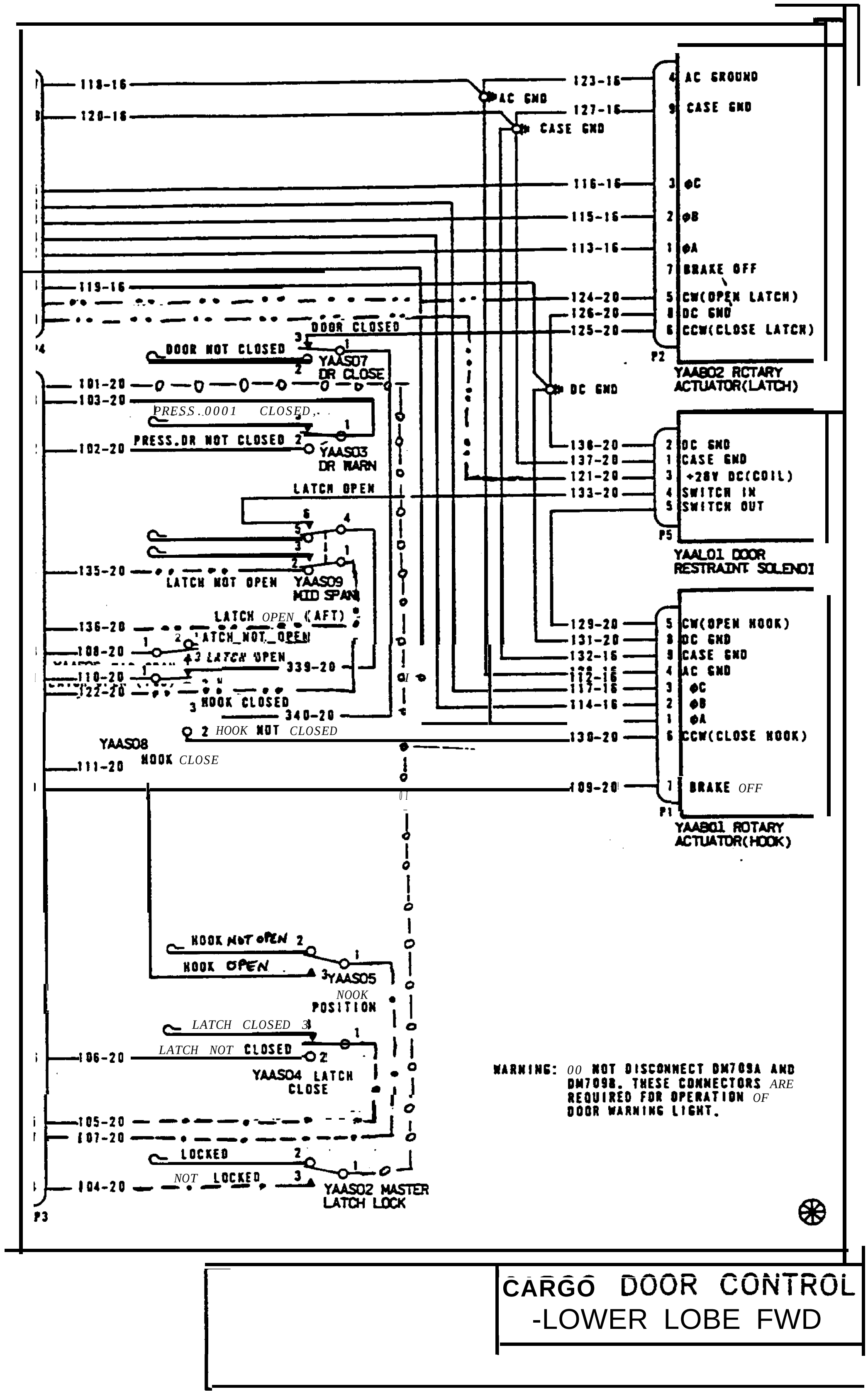


Figure 17.--Diagram of cargo door electrical circuitry.

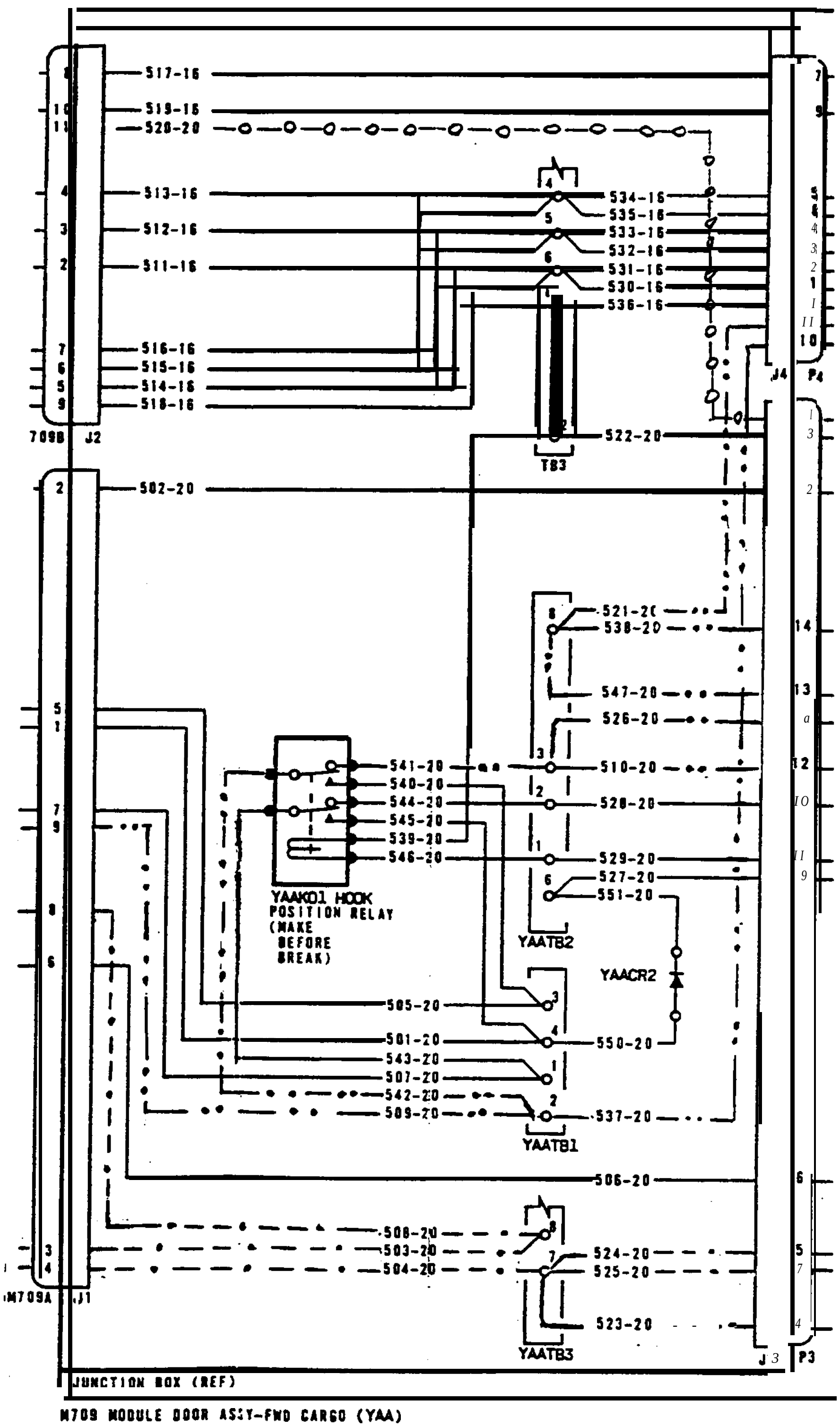
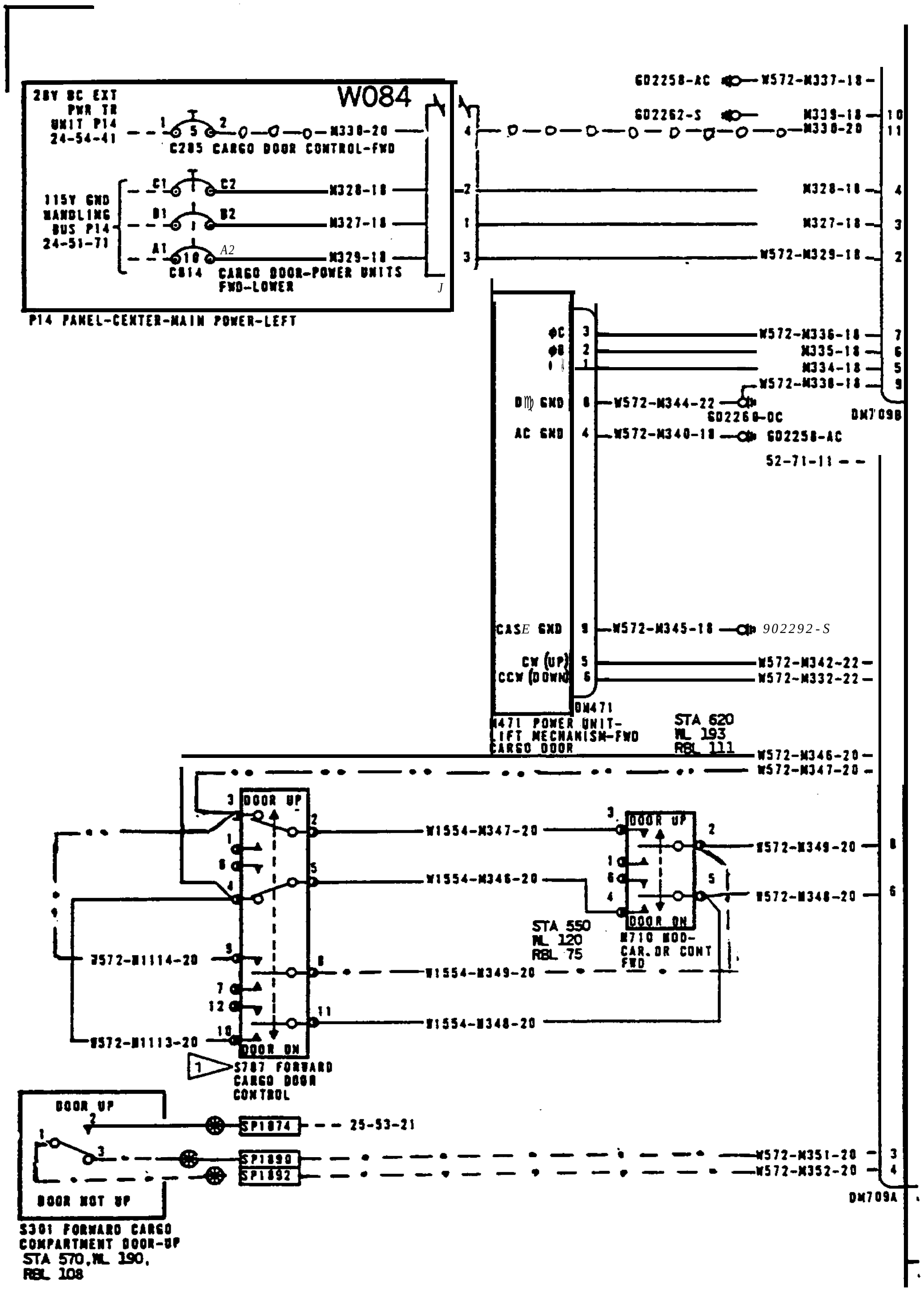


Figure 17a.--Diagram of cargo door electrical circuitry.



NOTES:

1 WHERE 2 WIRES ARE COMMON TO A PIN OR TERMINAL THESE WIRES SHOULD BE CRIMPED TOGETHER INTO ONE TERMINAL LUG.

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Figure 17b.--Diagram of cargo door electrical circuitry.

transferred to the other pole on S2, S3, and S4. On S6, the used[3] basic switch was held closed by its plunger. S7 transferred after the switch housing and water inside were removed.

During removal of the basic switch covers, a trend was noted in the discoloration of some of the basic switches. The used switch had a reddish-brown coloration. The unused switch was not discolored.

Each switch was found to be wired correctly to its poles and through its contacts within the basic switches. All contacts operated with light finger pressure after removal of the basic switch covers. There was no evidence of pitting, excessive corrosion, or heat distress in the contacts of any of the switches. The following sections detail pertinent observations concerning each switch.

The S2 master latch lock is given particular significance because of its function to protect against inadvertent door operation and is thus described in more detail. It is a single-pole double-throw (SPDT) switch used to sense the unlocked position of the door lock sectors. The switch is mounted in the aft lower comer of the door. A bracket attached to the No. 7 lock sector depresses the switch when the door lock sectors are rotated to their unlocked position. When the bracket attached to the lock sector contacts the switch plunger and depresses it, the circuit path through the switch is closed and 28VDC electrical control power to the door is established. When the force on the plunger is relaxed, the circuit is opened and 28VDC electrical control circuit is removed.

The wires leading to the S2 switch had been cut by the team after the recovery in an attempt to test continuity through the switch. The door recovery team reported that it found continuity through the l-3 contacts but not through the l-2 contacts. The switch plunger was actuated by the recovery team. The recovery team noted that the switch did not transfer continuity during these tests. The operation of the switch plunger would normally transfer continuity. Subsequent detailed examination of the S2 switch confirmed the findings of the recovery team.

The area around the upper face of the internal bracket was bent toward the basic switches and had evidence of corrosion residue. The bracket was found broken. The switch contacts transferred from the l-3 actuated position to the l-2 nonactuated position when the bracket was removed. Scanning electron

---

[3]The "used" switch is the switch through which electricity passes; the "unused" switch does not have electricity pass through it.

microscope examination of the fracture surfaces revealed evidence of overload and corrosion.

The external switch housing was dented. The final examination performed on the switch consisted of removing the plastic covers on the basic switches. Prior to removal of the basic switch covers, it was noted that the cover to the used basic switch was cracked. The contacts functioned normally when exercised by light finger pressure.

Microscopic examination revealed a black discoloration near one of the lower contact posts of the used basic switch. Energy dispersive spectrometric examination of the residue disclosed the presence of gold, iron, magnesium, sodium, and chlorine. No mechanical or electrical anomalies were detected with the basic switch contacts.

Additional testing was performed by Boeing on switches of a similar design to those used on the accident airplane's cargo door. The testing was conducted to identify conditions that would result from salt water immersion at a pressure depth of 14,200 feet for 18 months. The testing verified that external damage to the switch housing occurred at pressure depths of 7,000 feet and greater. Switch seal leakage and subsequent internal corrosion was also noted. None of the testing performed by Boeing duplicated internal switch damage that caused basic switch contact closure or internal damage to the switch support bracket.

Wiring:

The electrical wiring recovered with the cargo door was documented in place before being removed for further tests. About 40 percent or 112 feet of wire from the original length of approximately 274 feet was recovered and examined. Of this amount, about 46 feet of wire installed in the aircraft forward of the cargo door was not examined. Most of the wires leading from the door to the fuselage were not recovered. There was no visible external evidence of burning, arcing, or heat distress in any of the wires removed. Several areas of wire insulation damage were found.

Thirty five wires were identified that could provide a possible short circuit path that could drive the latch actuator open with or without failures of other door electrical components if the ground handling bus was energized. The wires were schematically coded by function. Wires coded **(-..-..-)** were denoted for wiring that provides open command logic to the latch actuator. Wires coded

(--.--.--.) were denoted for additional wiring enabled by an activated (failed) S2 switch. Wires coded (-0-o-o-o) were denoted for wiring providing 28VDC power from the C285 circuit.

Potential short circuit paths were identified for the cargo door that could provide 28VDC to the latch actuator control circuit relay. These potential short circuit paths can cause the latch actuator to drive the latches toward their open position if 115VAC power is available to the latch actuator motor. The potential short circuit paths include two bare wires shorting against each other, bare wire-to-metal structure-to-bare wire contact, wire to conductive fluid (such as water) to wire, or a combination of the aforementioned.

Conductive contact of (-0-o-o-o) or (--.--.--) coded wire with (-..-..-) coded wire could potentially result in providing a 28VDC circuit path to the latch actuator open circuit. Direct wire-to-wire paths are coded in Figure 17 as defined above. The two-wire short circuit paths are identified as wire pairs consisting of wire 101-20 shorting with any of the following wires; 108-20, 121-20, 122-20, 124-20, 135-20, or 136-20.

If the S2 master latch lock switch fails in the "Not Locked" position, there are additional wire pairs that provide short circuit paths. These are coded in Figure 17 as (--.--.--) to (-..-..-..) wire pairs.

Short Circuit Wire Damage Simulation Tests:

Tests were conducted by Boeing and United to simulate typical examples of bare wire short circuiting to determine the extent of visible wire damage that would be expected in the 28VDC cargo door control circuit.

United performed tests on BMS 13-42 wire, the wire type used in the B-747 cargo door control circuit. Visible electrical short circuit damage on bare BMS 13-42 wire surfaces was difficult to create at 28VDC. Surface damage was considered visible when detected by microscopic examination at 15X magnification. United testing simulated the relay coil resistance variations that would be found during typical in-service conditions. A current of 1.0 A at 28VDC created visible surface damage on momentary bare wire-to-bare wire contact. Multiple contacts at 1.0 A provided a more positive indication. A single momentary contact between two bare BMS 13-42 wires with 0.160 A at 28VDC did not create visible surface damage. Contact between a BMS 13-42 bare wire and Alclad 2024-T3 metal (airplane and cargo door structure) with 0.160A at 28VDC did not create visible surface damage.

Boeing performed wire tests on BMS 13-48 20 gauge wire. The test setup used the MS27418-2B door latch actuator control relay in parallel with the 60B003 1 l-2 door restraint solenoid, the actual electrical loads used in the B-747 cargo door latch actuator control circuit. A single momentary contact of a bare 28VDC power wire, with a bare wire connecting to the relay of the solenoid, showed small pithead area developed at the point of wire contact that was visible without magnification. ′

Wire Examination Procedure:

All of the recovered wires were examined in the Safety Boards Materials Laboratory on a mylar sheet to simulate their installed positions. Labels were used to identify the coded wires using the manufacturer's original wire identification numbers imprinted on each wire's insulation. Wire pairs for direct electrical short circuiting were located in two common wire bundles installed on the cargo door. One common wire bundle was associated with the P3 plug connector, the'other with the P4 plug junction box. The wire bundles were examined visually for areas of obvious insulation damage. Each individual wire was also examined with a stereo-microscope. Representative wire damage features were photographed.

Wire Damage Found:

Seven wires numbered 101-20, 102-20, 105-20, 107-20, 108-20, 122-20, and 135-20 had visible damage located near a 3.8 inch position as measured from the P3 plug pin tips. This common position on the wire corresponds to a 360-degree loop in the wire bundle, which is located immediately below the junction box. Figures 18 and 19 show typical wire damage. Wire 122-20 had an open insulation area approximately 0.25 inch long. The other four wires had flattened 'insulation damage areas.

In the P4 plug connector wire bundle, three wires displayed insulation damage. Wires 113-20, 121-20, and 124-20 had transverse insulation nicks, which exposed bare conductors. All three had insulation nicks 3 inches from the P4 plug pin tips; wires 121-20 and 124-20 had additional insulation nicks 34 inches from the plug pin tips. The two P4 insulation damage locations corresponded to wire bundle clamp positions.

Figure 18.--Wires (from top to bottom) 101, 122, 104, 107, 110, 108, 105 at 3.8 inches from pin end (4X Magnification).

Figure 19.--Wire 122 at 3.8 inches from pin end (4X Magnification).

1.16.3 Pressurization System

The pressure relief valves located on the left side of the fuselage in the forward cargo compartment were removed from the airplane and subjected to bench tests at the UAL maintenance facility in San Francisco, California. No significant anomalies were discovered and both valves performed within specified tolerances.

1.16.4 General Inspection of Other UAL Airplanes

During the on-scene phase of the investigation, the Safety Board investigators examined six other B-747 airplanes while they were on the ground at HNL (four UAL airplanes and two operated by other carriers) to observe routine cargo door operations and to assess the condition of latching components. Generally, the door operations were normal. During the examination of latch pins on these airplanes, it was noted that most had a smooth wear ridge at the 9:00 position (looking forward) or were -undamaged. All wear areas on the pins were smooth.

During electrical operation- of the aft cargo door on one of the other UAL B-747 airplanes (N4718U), the pull-in hooks did not pull the door fully closed and the latch cams completed the closure. During operation of the latch cams, the bottom of the door moved, first circumferentially downward and then inboard. This additional movement was approximately 1/4 inch. A definite "thunking" noise was discernible as the door moved to its closed position at the end of cam rotation. On one occasion, the door would not open under electrical power. The door was 'kicked" by a UAL mechanic, power was reapplied, and the door opened properly. Examination of the door by UAL mechanics, disclosed that the riveted plate holding the aft pull-in hook switch striker was loose.

All eight lower latch pins for the forward cargo door on N4718U exhibited a smooth ridge near the 9:00 position. Pins No. 1 and 2 also showed a smooth ridge at the 6:30 position with a smooth wear area between the 6:30 and 9:00 position. The forward and aft midspan cams of both forward and aft cargo doors had a heavy gouge mark corresponding to the end of the midspan latch pin.

N4718U was subsequently removed from service for repair of the aft cargo door latching mechanisms.

1.17 Additional Information

1.17.1 Previous Cargo Door Incident

On March 10, 1987, a Pan American Airways B-747-122, N740PA, operating as flight 125 from London to New York, experienced an incident involving the forward cargo door. According to Pan Am and Boeing officials who investigated this incident, the flightcrew experienced pressurization problems as the airplane was climbing through about 20,000 feet. The crew began a descent and the pressurization problem ceased about 15,000 feet. The crew began to climb again, but about 20,000 feet, the cabin altitude began to rise rapidly again. The flight returned to London.

When the airplane was examined on the ground, the forward cargo door was found open about 1 1/2 inches along the bottom with the latch cams unlatched and the master latch lock handle closed. The cockpit cargo door warning light was off.

According to the persons who examined the airplane, the cargo door had been closed manually and the manual master latch lock handle was stowed, in turn closing the pressure relief doors and extinguishing the cockpit cargo door warning light. Subsequent investigation on N740PA revealed that the latch lock sectors had been damaged and would not restrain the latch cams from being driven open electrically or manually. It was concluded by Boeing and Pan Am that the ground service person who closed the cargo door apparently had back-driven (opened) the latches manually after the door had been closed and locked. The damage to the sectors, and the absence of other mechanical or electrical failures supported this conclusion.

Further testing of the door components from N740PA and attempts to recreate the events that led to the door opening in flight revealed that the lock sectors, even in their damaged condition, prevented the master latch lock handle from being stowed, until the latch cams had been rotated to within 20 turns (using the manual 1/2 inch socket drive) of being fully closed. A full cycle, from closed to open, is about 95 turns with the manual drive system.

1.17.2 FAA Surveillance of UAL Maintenance

The Denver, Colorado, FAA Flight Standards District Office (FSDO) holds the operating certificate for United Airlines, Inc. The FAA FSDO in San

Francisco, California, has the primary surveillance and oversight responsibility for UAL maintenance.

The FAA's PMI has the responsibility to oversee an airline's compliance with Federal Regulations with respect to maintenance, preventive maintenance, and alteration programs. The PMI determines the need for, and then establishes work programs for, surveillance and inspection of the airline to assure adherence to the applicable regulations. A portion of the PMIs position description reads as follows:

Provides guidance to the assigned air carrier in the development of required maintenance manuals and recordkeeping systems. Reviews and determines adequacy of manuals associated with the air carrier's maintenance programs and revisions thereto. Assures that manuals and revisions comply with regulatory requirements, prescribe safe practices, and furnish clear and specific instructions governing maintenance programs. Approves operations specifications and amendments thereto.

Determines if overhaul and inspection time limitations warrant revision.

Determines if the air carrier's training program meets the requirements of the FARs, is compatible with the maintenance program, is properly organized and effectively conducted, and results in trained and competent personnel.

Directs the inspection and surveillance of the air carrier's continuous airworthiness maintenance program. Monitors all phases of the air carrier's maintenance operation, including the following: maintenance, engineering, quality control, production control, training, and reliability programs.

At the Safety Board's public hearing on this accident, the PMI for United Airlines at the time of the flight 811 accident stated that he was trained as an FAA air carrier inspector and had been assigned to United Airlines since November 25, 1985. In addition to attending the normal FAA indoctrination course, he had received training in accident investigation, compliance enforcement, nondestructive testing, enforcement, and composite materials. To qualify for the position of PMI, he had completed a 3-week management training course at Lawton, Oklahoma. This was supplemented by a 2-week course on management training systems.

According to the PMI, FAA surveillance of UAL B-747 maintenance activities was organized around the daily work schedule of the FAA air safety inspector, specifically assigned to the UAL B-747 fleet by the PMI. The schedule for surveillance is normally prepared a year in advance by the FAA computerized Work Planning Management System (WPMS). Each FAA inspector is assigned specific responsibilities in the surveillance and monitoring of the airplane fleet to which he is assigned.

The PMI stated that assigned inspectors conducted surveillance of the UAL airplanes while they were in light or heavy maintenance and when they were released to service or in the process of preparing for a flight. Postflight surveillance was also performed. He said, as a routine, the inspectors visually inspected the airplanes and reviewed the airplane log records either during en route checks, while in flight, or upon termination of various flights. He said that inspectors conduct spot ramp inspections; however, they do not routinely observe ramp service operations as part of the surveillance program.

He said that FAA inspectors are not required to inspect the airplanes, but merely are to observe ramp service activities. Deficiencies or malfunctions were to be noted. The assigned inspector or the PMI would then report these observations to the UAL quality assurance liaison person or directly to UAL management.

The PMI stated that the FAA had conducted five special surveillance inspections of UAL in the previous 3 years and 5 months. The last special inspection, an MEL Survey Inspection, was completed in 1988. That inspection primarily addressed how many deferred maintenance items were being carried or deferred on each aircraft during a specified time period.

The PMI stated that his office does not approve the method by which the carrier complies with an AD, unless specified in the AD. However, a scheduled surveillance method was in place to review the carrier's AD compliance process and the ADs applicable to certain fleets. Each assigned inspector had a schedule for performing this oversight in his work program. The PMI or his staff review a monthly report from the carrier listing ADs applicable to a particular fleet and their compliance. The FAA's surveillance of the carrier's AD compliance process involved a review of this list, not actual shop visits to verify compliance.

The inspector assigned to the UAL B-747 fleet stated that approximately 30 percent of his time was spent on actual ramp maintenance surveillance. Other activities included: en route inspections, station inspections, meetings, classes and administrative paper work. Spot ramp inspections were scheduled as a normal routine, as well as by mandate in a particular AD.

The PMI stated that foreign contract maintenance bases were inspected once a year at a minimum. The PMI had the prerogative to use geographical surveillance inspectors (inspectors from other FAA offices), or inspectors from his office more familiar with UAL maintenance procedures to conduct inspections or investigations.

The PMI and the B-747 maintenance inspector assigned to UAL testified that, prior to this accident, they were not aware of any problems involving the operation of B-747 cargo doors, including the problems reported with N4713U during December 1988. The PMI testified that he could always use more inspectors to "conduct more in-depth surveillance and monitor UAL's fleet more adequately."

The extensive documentation of maintenance performed on UAL B-747 airplanes was forwarded to the PMI's official library by US mail. The data were ultimately channeled to the B-747 maintenance inspector. The PMI and maintenance inspector testified that the voluminous paperwork and work schedules precluded their monitoring the information to determine trends on problem areas.

1.17.3 Corrective Actions

On March 31, 1989, the FAA issued telegraphic (AD) ADT 89-05-54. This AD superseded AD 88-12-04 and required certain procedures to be accomplished when operating the cargo doors. These included: confidence checks of the door mechanical and electrical systems, inspections of the door locking mechanisms, and repairs if necessary. The AD also accelerated the schedule for terminating action to place steel doublers on the latch lock sectors, and it reinstituted the procedures for using the eight view ports to verify the position of the latch cams, after the door is latched and locked.

The FAA, in conjunction with the Air Transport Association, the manufacturers, and other interested parties, are collectively working to address the human factor issues in the readability and understandability of ADs and SBs by line maintenance personnel. They are also reviewing the entire range of design, maintenance, and operation of outward opening doors to develop advisory information for pertinent parties.

FAA representatives stated at the Safety Boards public hearing that the FAA is increasing their operations and airworthiness inspector staffmg by approximately 1,000 new hires in the next 3 fiscal years.

The **PMI** for UAL at the time of the accident stated at the Safety Boards public hearing that, as a **result** of the accident, "we have intensified our surveillance on the cargo door activities to the point where the assigned inspectors and inspectors who are not assigned to that particular fleet, **747s,** are doing night surveillance, early morning surveillance, and we have intensified our surveillance on the cargo door in watching the operation of the cargo door to comply with the Airworthiness Directive."

On August 23, 1989, the Safety Board issued three safety recommendations (A-89-92 through -94) to the FAA. The recommendations urged the FAA to:

> Issue an Airworthiness Directive (AD) to require that the manual drive units and electrical actuators for Boeing 747 cargo doors have torque limiting devices to ensure that the lock sectors, modified per **AD-88-12-04,** cannot be overridden during mechanical or electrical operation of the latch cams.
>
> Issue an Airworthiness Directive (AD) for non-plug cargo doors on all transport category airplanes requiring the installation of positive indicators to ground personnel and flightcrews confirming the actual position of both the latch cams and locks, independently.
>
> Require that fail-safe design considerations for non-plug cargo doors on present and future transport category airplanes account for conceivable human errors in addition to electrical and mechanical malfunctions.

Section 4.0 contains the -FAA's response to the recommendations and the status of the **followup** actions.

On October 12, 1989, the FAA issued NPRM **89-NM-148-AD,** which proposed the amendment of ADT-89-05-54. The proposed revisions would require modification of the warning systems for the forward and aft cargo door, and the main deck cargo door, if installed. The modifications would provide visual warnings to flightcrew and ground crew when the doors are not fully closed, the latch cams are not rotated to the closed position, or the lock sectors are not in the locked position. Further, the source for the waming signal would monitor the position of the latch cams. Public comments for the NPRM were due by December 27, 1989.

Boeing has completed tests that have verified the integrity of the upgraded latch lock sectors to prove that the latch cams cannot be back-driven through the lock sectors mechanically or electrically. Boeing also has been conducting tests on the B-747 cargo door to evaluate the effects of unrepaired damage and abuse on the latch/lock system. The tests, which determined the allowable damage limits on the latch lock system and mechanism support structures, were completed in March 1990. Additionally, Boeing conducted tests to evaluate any unlatching tendencies under cabin pressure loads. These tests were completed in November 1990 and included the measurement of loads in the latch system as the latch cams are rotated incrementally from the fully latched position to the unlatched position under pressurization loads.

The first series of tests included electrical backdriving of the latch cams into the lock sectors (both steel and steel reinforced were tested) with a modified latch actuator (the maximum output torque of the modified latch actuator was roughly twice that of a normal, torque-limiting latch actuator.) During these tests, the maximum cam rotation was 22.2 degrees against steel reinforced lock sectors and 18.8 degrees against the all-steel lock sectors.

During the second set of tests, which measured the effects of internal pressure loads on partially unlatched cams, it was discovered that pressurization did not create any significant loads in the latch mechanism with the door fully closed and the latch cams positioned up to 45 degrees from the fully latched position.

Both series of tests show that if the latch cams were somehow electrically backdriven by a latch actuator that had no torque-limiting ability, the steel or steel-reinforced lock sectors would limit the amount of cam rotation such that the partially unlatched cams would still prevent pressure loads from forcing the door open.

1.17.4 Boeing 747 Cargo Door Certification

Title 14 CFR 25.783, Amendment 25-15, effective October 24, 1967, was the original certification basis for Boeing 747 cargo doors. Specifically, Part 25.783 (e) and (f) applied to doors for which the initial opening movement is outward (non-plug type doors). Those rules specified that:

> (e) There must be a provision for direct visual inspection of the locking mechanism by crewmembers to determine whether external doors, for which the initial opening movement is outward (including passenger, crew, service, and cargo doors), are fully locked. In addition, there must be a visual means to signal to appropriate crewmembers when normally used external doors are closed and fully locked.
>
> (f) Cargo and service doors not suitable for use as an exit in an emergency need only meet paragraph (e) of this section and be safeguarded against opening in flight as a result of mechanical failure.

Amendment 25-23, effective May 8, 1970, added the following text to paragraph (f): ". ..or failure of a single structural element." Amendment 25-23 did not apply to the initial certification basis for the B-747.

Amendment 25-54, effective October 14, 1980, expanded Part 25.783 (e), (f), and (g) to read:

> (e) There must be a provision for direct visual inspection of the locking mechanism to determine if external doors, for which the initial opening movement is not inward (including passenger, crew, service and cargo doors), are fully closed and locked. The provision must be discernible under operational lighting conditions by appropriate crewmembers using a flashlight or equivalent lighting source. In addition, there must be a visual warning means to signal the appropriate flight crewmembers if any external door is not fully closed and locked. The means must be designed such that any failure or combination of failures that would result in an erroneous closed and locked

indication is improbable for doors for which the initial opening movement is not inward.

(f) External doors must have provisions to prevent the initiation of pressurization of the airplane to an unsafe level if the door is not fully closed and locked. In addition, it must be shown by safety analysis that inadvertent opening is extremely improbable.

(g) Cargo and service doors not suitable for use as an exit in an emergency need only meet paragraph (e) of this section and be safeguarded against opening in flight as a result of mechanical failure or failure of a single structural element.

At the Safety Board's public hearing, the FAA and the Boeing representatives acknowledged that during certification of the Boeing 747 the loss of a lower lobe cargo door was not considered to be an "acceptable event." Therefore, redundant mechanical devices and operational procedures were incorporated to protect against loss of the door in flight. Initial FAA certification approval of the Boeing cargo door design and operation included the installation and use of eight view ports on the door for ground personnel to observe the alignment of paint stripes on the latch cams with arrows on the latch pin support fitting, thereby complying with the requirements of 14 CFR 25.783(e), which require a ". . . provision for direct visual inspection of the door locking mechanism . . .," to determine if the door is closed and locked.

In correspondence dated November 24, 1969, and May 15, 1970, Boeing requested that the FAA approve the use of a visual inspection of the pressure relief doors of the cargo doors as an alternate method for determining the locked condition of the door. This design also provided a visual indication to the flightcrew via the cargo door warning light on the flight engineer's warning light annunciator panel. Boeing's request stated that this means of compliance ". . . provides a simpler check whereby only the pressure relief doors need to be checked . . .," by the ground crew, in lieu of actually observing the latch cams and alignment stripes through the eight view ports. Boeing also provided a Failure Analysis to support its request. The conclusion of the Failure Analysis reads: "Any failure, mechanical or electrical, within the latching system which results in open latches will always be indicated by open pressure relief doors." The FAA approved their alternate method on June 8, 1970. Subsequently, the procedures for maintaining the view ports and the alignment stripes in a serviceable condition, which had been included in the UAL MM were removed. Also, the provision for observing the alignment stripes as part of the door closing procedure were not required for B-747 airline operators.

At the Safety Board's public hearing, a Boeing witness, in answer to a question relative to Boeing's possible consideration of modifications or design changes to the B-747 cargo door indication system to install a position switch directly on the latch cams, stated, "We are looking into the best possible designs that would provide indication on the cams and door closed, both exterior to the aircraft and in the flight deck. We are going to look into that.... However, we want to achieve the required indication in the most reliable method and we have not yet determined what that will be, or any changes (that) are necessary, or would make it more reliable than the way the system operates currently."

1.17.5 Advisory Circular AC 25.783-l

Advisory Circular (AC) 25.783-l was issued December 10, 1986, on the subject, "Fuselage Doors, Hatches, and Exits." AC 25.783-l set forth the acceptable means of compliance with the provisions of Part 25 of the FAR's dealing with the certification of fuselage doors. Specifically, it provides for an acceptable method for showing compliance with the provisions of Part 25.783, Amendment 25-54.

Neither the provisions of Part 25.783, Amendment 25-54, nor the guidelines of AC 25.783-l were part of the certification basis of the Boeing 747.

1.17.6 Uncommanded Cargo Door Opening--UAL B-747, JFK Airport

On June 13, 1991, UAL maintenance personnel were unable to electrically open the aft cargo door on a Boeing 747-222B, N152UA, at JFK Airport, Jamaica, New York. The airplane was one of two used exclusively on nonstop flights between Narita, Japan, and JFK. This particular airplane had accumulated 19,053 hours and 1,547 cycles at the time of the occurrence.

The airplane was being prepared for flight at the UAL maintenance hangar when an inspection of the circuit breaker panel revealed that the C-288 (aft cargo door) circuit breaker had popped. The circuit breaker, located in the electrical equipment bay just forward of the forward cargo compartment, was reset, and it popped again a few seconds later. A decision was made to defer further work until the airplane was repositioned at the gate for the flight. The airplane was then taxied to the gate, and work on the door resumed.

The aft cargo door was cranked open manually, the C-288 circuit breaker was reset, and it stayed in place. The door was then closed electrically and cycled a couple of times without incident. With the door closed, one of the two “cannon plug” (multiple pin) connectors was removed from the J-4 junction box located on the upper portion of the interior of the door. The wiring bundle from the junction box to the fuselage was then manipulated while readings were taken on the cannon plug pins using a volt/ohmmeter. Fluctuations in electrical resistance were noted. When the plug was reattached to the J-4 junction box, the door began to open with no activation of the electrical door open switches. The C-288 circuit breaker was pulled, and the door operation ceased. When the circuit breaker was reset, the door continued to the full open position, and the lift actuator motor continued to run for several seconds until the circuit breaker was again pulled. At this time, a flexible conduit, which covered a portion of the wiring bundle, was slid along the bundle toward the J-4 junction box, revealing several wires with insulation breaches and damage.

UAL personnel notified the Safety Board of the occurrence, and the airplane was examined at JFK by representatives of the Safety Board, United Airlines, and Boeing. After the wires in the damaged area were electrically isolated, electrical operation of the door was normal when the door was unlocked. When the door was locked (master latch lock handle closed), activation of the door control switches had no effect on the door. This indicated that the S2 master latch lock switch was operating as expected (removing power from the door when it was locked). After the on-site examinations, the wiring bundle was cut from the airplane and taken to the Safety Board’s materials laboratory for further examination.

The wiring bundle with the damaged wires contained all electric control wires (28 volt DC) and power wires (115 volt AC) that pass between the fuselage and the aft cargo door. From the forward side of the J-4 junction box, the bundle progresses in the forward direction, just above the forward pressure relief door, then upward, following the forward lift actuator arms. The bundle then enters an empty space between two floor beams, where the bundle has an approximate 180-degree bend when the door is closed. From this location, the wiring bundle progresses inboard, through a fore-to-aft intercostal between two floor beams. The wiring bundle then splits, with wires going in several directions.

The bundle is covered by the flexible conduit approximately from the lower end of the lift actuator arms to the fore-to-aft intercostal between the floor beams.

The conduit covering the wiring bundle is intended to prevent the wire bundle from being damaged during opening and closing of the door and during cargo handling operations. The conduit is a sealed flexible interconnector consisting of a convoluted helical brass innercore covered by a bronze braid. The innercore is soldered at every other convolute, and should be capable of withstanding pressures exceeding 1,000 pounds per square inch (psi). Boeing has indicated that the conduit is an evolutionary improvement and that it has been installed on all B-747 airplanes produced since 1981 (from line number 489 on). Airplane N152UA was delivered in April 1987.

Airplanes produced prior to 198 1, including N4713U, used a bungee retraction system, to retract the cargo door wire bundle. Guidelines for the replacement of the bungee system with the flexible conduit were covered in Boeing Service Bulletin 747-752-2170, dated August 1981. The service bulletin was prompted by reports that the wire bundle bungee retraction system had not retracted the wire bundle sufficiently to prevent trapping the bundle between the cargo door and the door frame. UAL did not perform the retrofit on N4713U, which was line number 89, nor was the company required to do so.

Examination of the wires in the damaged area on the wiring bundle revealed that four of the wires were similar in appearance, with insulation breaches that progressed through to the underlying conductor. Adjacent to the breach on these four wires, the insulation was blackened, as if it had been burned. Another wire contained an extensive breach but no evidence of burned insulation. The damaged area was located on the bundle at a position approximately corresponding to a conduit support bracket and attached standoff pin on the upper arm of the forward lift actuator mechanism. This support bracket was found bent in the forward direction. In addition, mechanical damage was noted on adjacent components in this area.

A second damaged area was noted on the wiring bundle at a position approximately corresponding to the conduit swivel clamp at the elbow between the two arms of the forward lift actuator mechanism. Wires in this area were missing portions of their exterior coating, but no breaches to the underlying conductors were noted.

The exterior braid on the conduit contained minor rub marks and was slightly kinked at a position corresponding to the area on the wires with breached insulation. Additional examinations revealed that the innercore of the conduit contained multiple circumferential cracks in the areas corresponding to the damage areas on the wires. The cracks were in the convoluted innercore directly adjacent to the inside diameter of the conduit.

The lock sectors, latch cams, and latch pins from the aft cargo door were examined on the incident airplane and were generally in excellent condition. There was no evidence to suggest that the cams had ever been electrically (or manually) driven into or through the lock sectors.

Boeing also informed the Safety Board that, in May of 1991, a B-747 operated by Quantas was found to have chafing of the wires in the wire bundle to the aft cargo door. This airplane also had a flexible conduit protecting the wires, and the chafing was located approximately at the standoff pin on the bracket at the upper arm of the forward lift actuator.

The Safety Board determined that the chafing of the wires on the airplane involved in the JFK occurrence was caused by, or was greatly accelerated by, the circumferential cracks in the conduit and that the cracks in the conduit were caused either by repeated flexing of the conduit as the cargo door opens and shuts or by unusual stresses on the conduit generated concurrently with damage to the conduit guide bracket and attached standoff pin on the upper end of the forward lift actuator upper arm.

A portion of the wire bundle for the forward cargo door on many B-747 airplanes is also covered by a flexible conduit that is very similar to the conduit for the aft cargo door. However, there are substantial differences between the orientation of the flexible conduits for the two doors, and the Safety Board has not become aware of problems associated with the flexible conduit for the forward door.

Nevertheless, because of the concerns about the chafed wires and possible electrical short circuits, on August 28, 1991, the Safety Board recommended that the FAA:

Issue an Airworthiness Directive applicable to all Boeing 747 airplanes with a flexible conduit protecting the wiring bundle between the fuselage and aft cargo door to require an expedited inspection of:

(1) the wiring bundle in the area normally covered by the conduit for the presence of damaged insulation (using either an electrical test method or visual examination);

(2) the conduit support bracket and attached standoff pin on the upper arm of the forward lift actuator mechanism;

(3) the flexible conduit for the presence of cracking in the convoluted innercore.

Wires with damaged insulation should be repaired before further service. Damage to the flexible conduit, conduit support bracket and standoff pin should result in an immediate replacement of the conduit as well as the damaged parts. The inspection should be repeated at an appropriate cyclic interval. (Class II, Priority Action) (A-91 -83)

Evaluate the design, installation, and operation of the forward cargo door flexible conduits on Boeing 747 airplanes so equipped and issue, if warranted, an Airworthiness Directive for inspection and repair of the flexible conduit and underlying wiring bundle, similar to the provisions recommended in A-91 -83. (Class II, Priority Action) (A-91 -84)

The FAA responded to these safety recommendations on November 1, 1991, stating that it agreed with the intent of the recommendations and that the issuance of an NPRM was being considered to address the issues in the safety recommendations. The Safety Board replied on November 27, 1991, classifying each of the recommendations as "Open--Acceptable Response," pending the completion of the rulemaking process. Since that exchange of correspondence, the FAA has published an NPRM which is now being reviewed by the Safety Board. Safety Recommendations A-91-83 and -84 will continue to be classified as "Open--Acceptable Response" until an acceptable final rule is published.

2. ANALYSIS

2.1 General

This analysis is based on the facts gathered during the initial investigation phase, without the benefit of the evidence from the cargo door, updated to include the findings from the subsequent examinations of the door after it was recovered.

The flightcrew and flight attendants were trained and qualified in accordance with the applicable Federal regulations and UAL standards and requirements. There were no air traffic control or weather factors related to the cause of this accident.

The airplane had been properly maintained, with the exception of certain requirements pertaining to the cargo doors. Those discrepancies will be discussed in detail in this analysis.

The evidence examined by the Safety Board during its investigation revealed conclusively that this accident was precipitated by the sudden loss of the forward lower lobe cargo door, which led to an explosive decompression. There was no evidence of preexisting metal fatigue or corrosion in the structure surrounding the cargo door. All breaks were the result of overload at the time of the loss of the door. There was no evidence of a bomb or similar device that caused an explosion on the airplane.

The explosive decompression of the cabin when the cargo door separated caused the nine fatalities. The floor structure and seats where the nine fatally injured passengers had been seated were subjected to the destructive forces of the decompression and the passengers were lost through the hole in the fuselage. Their remains were not recovered. Most of the injuries sustained by the survivors were caused by the events associated with the decompression, such as baro-trauma to ears, and cuts and abrasions from the flying debris in the cabin. Other injuries were incurred during the emergency evacuation.

The loss of power to the Nos. 3 and 4 engines was caused by foreign object damage when debris were ejected from the cargo compartment and cabin during the explosive decompression. The debris also caused damage to the right wing leading edge flap pneumatic ducting, and other areas along the right side and empennage of the airplane.

During the approach to HNL, all of the leading edge flaps had extended, except the outboard sections 22 through 26 on the right wing. The reason that they failed to extend probably was the damage to the pneumatic duct caused by the ejected debris. The pneumatic pressure probably was too low to actuate the most outboard flaps to the extended position.

The failure of the flightcrew and passenger oxygen systems was caused by structural deformation and damage to the supply lines in the area adjacent to the cargo door and failed fuselage structure.

The Safety Board's analysis of this accident concentrated on the reasons for the loss of the cargo door and the events that led to its loss in flight. The analysis included an evaluation of the design, certification, and approval processes for the B-747 cargo doors, and the operational, maintenance, and inspection processes for the doors. Also, the analysis included an evaluation of the historical events that had occurred over the past months and years that eventually led to this accident.

2.2 Loss of the Cargo Door

The calculated pressure differential at the time of the loss was about 6.5 psi, which would have exerted a load on a properly closed and locked door that was substantial, but well within design limits.

There was no evidence of a structural problem with the cargo door that could have caused it to fail from metal fatigue or corrosion. Although the cargo door was recovered in two pieces on the floor of the ocean, there was no evidence of a preseparation structural failure of the door. All fractures and damage found on the door were determined to be the result of the sudden opening of the door rather than the cause. The evidence showed that the door was intact when it flew open violently and that its integrity was compromised when it struck the upper fuselage structure and most likely when it struck the water. The fracture in the cargo door occurred just below the midspan latch cams. Paint marks on the outer surface of the door that matched upper fuselage structure paint pattern, damage to the latch pins, pull-in hooks and hook pins, as well as damage to the floor structure near the upper door hinge area were consistent evidence that the door was intact when it flew open.

The evidence was also conclusive that the failure of the door did not result from the failure of the structure surrounding the door. The damage to the cabin floor beam structure, adjacent to the cargo door hinge area, showed that decompression loads in the cabin broke the beams downward when pressure was released from the cargo compartment. The fuselage skin above the door was tom away during the decompression as the door separated violently from the airplane. Unfortunately, the upper skin structure was not recovered from the sea.

There are no reasonable means by which the door could open in flight with the cams properly closed and locked. If the lock sectors were in proper condition, and were properly situated over the closed latch cams, the lock sectors had sufficient strength to prevent the cams from vibrating to the open position during ground operation and flight. Thus, the only ways in which the cargo door could open while in flight involve the placement of the cams in a partially latched or unlatched position. Either the latching mechanisms were forced open electrically through the lock sectors after the door was secured, or the door was not properly latched and locked before departure. Then the door opened when the pressurization loads reached a point at which the latches could not hold.

2.3 Partially Closed Door

Examination of the eight latch pins that had been removed from the lower sill of the forward cargo door revealed smooth wear patterns where the latch cams had normally rotated around the pins. These wear patterns indicate that interference had existed during normal operation between the cams and the pins over an extended period of time. All eight pins also had roughened areas from approximately the 6:15 position to the 7:30 position (clock references are as looking forward, 9:00 being directly inboard). The 7:30 position corresponds closely to the area where the lower surface of the cam first contacts the pin as the door reaches the nearly closed position, before the cams are rotated to the latched position.

The hoop stresses generated by pressurization of the airplane create a bearing load against the cam/pin contacting points. Even if the cams are in the unlatched position, and the airplane is pressurized, this bearing load could act as a frictional latch between the cams and the pins and would tend to keep the door in the closed position.

Transferred cam material and heat tinting of the pin surface was found to extend from the point where the cam-to-pin interface at the near fully open position of the latch cams (7:30 position) to a position corresponding to the bottom of the pin (6:15 position). This evidence was found on the roughened areas on all of the pins. The heat tinting and metal transfer are indicative of the high stress and rapid movement of the cam across the pin when the door separation occurred. Therefore, the location of this evidence indicates the probable location of the cams just before, and at the time of, separation of the door. The Safety Board concludes that these markings and their location on the pins resulted from a very fast, high bearing stress, separation of the cams across the pins, when the cams were in or very close to the unlatched position. Further, examination of the recovered cargo door confirmed that the latch cams were in a nearly unlatched position at the time the separation occurred. The lock sectors were found in the locked position jammed against the cams. Therefore, the cargo door latch cams had been closed, the master latch lock handle had been closed, and the lock sectors had moved to the locked position. Subsequently, the cams had been back-driven to the near-open position, deforming the lock sectors.

The pull-in hooks and pull-in hook pins would also counteract the pressurization loads in the outward direction, providing that the latch cams were not engaged on the latch pins and carrying the pressurization loads. However, Boeing studies showed that the pull-in hooks would fail at a pressure differential of about 3.5 psi, assuming that the cams are in the unlatched position and that there is no bearing load on the pins. Therefore, based on the probable pressure differential of about 6.5 psi just before the door separated, it is concluded that forces other than the pull-in hooks/pins were holding the door closed. Since the flightcrew and passengers reported no pressurization difficulties until the explosive decompression, it is reasonable to conclude that the door was being held closed by the bearing stresses of the cam-to-pin interfaces as well as by the pull-in hooks.

The Safety Board believes that the approximate 1.5 to 2.0 seconds between the first sound (a thump) and the second very loud noise recorded on the CVR at the time of the door separation was probably the time difference between the initial failure of the latches at the bottom of the door, and the subsequent separation of the door, explosive decompression, and destruction of the cabin floor and fuselage structure. The door did not fail and separate instantaneously; rather, it first opened at the bottom and then flew open violently. As the door separated, it tore away the hinge and surrounding structure as the pressure in the cabin forced the floor beams downward in the area of the door to equalize with the loss of pressure in the cargo compartment.

Three possible theories to explain why the latch cams could have been in a partially latched condition during flight are examined: (1) they were never closed fully before the door was "locked" before takeoff. (2) they were back-driven manually after the door had been fully latched and locked or (3) they were back-driven electrically after the door had been fully latched and locked.

2.4 Incomplete Latching of the Door During Closure

The Safety Board considered the possibility that the master latch lock handle had not been closed before the airplane departed the gate, and the possibility that the shrouds recommended by SB-747-52-2097 for the cargo door pressure relief doors were not installed on the forward door. If this were the case, it is possible that this condition allowed the pressure relief doors to be rotated closed when the airplane pressurized.

The Safety Board believes that these events were very unlikely based on the statements of the ramp personnel, line maintenance personnel, and the flightcrew. The ramp and maintenance personnel would have to have missed seeing the master latch lock handle in the unstowed position and the pressure relief doors open before departure. Also, the flightcrew would have to have missed seeing the cockpit cargo door warning light indication.

The examination of the recovered forward cargo door did not provide confirmation that the pressure relief door shrouds were actually installed on the forward door, although UAL records showed that they had been installed on both cargo doors of N4713U, in accordance with SB-747-52-2097. However, the shrouds were found not to be installed on the aft door, contrary to UAL records, and therefore may not have been installed on the forward door. Without the shrouds, the pressure relief doors could have rotated shut during the pressurization cycle. Because the closure of the pressure relief doors would back-drive the lock sectors, this scenario would presume previous damage to the sectors, which would permit the sectors to move over the unlatched cams.

Before recovery of the cargo door, the Safety Board believed that the lock sectors might have been damaged some time prior to the accident flight to the extent that they could have been moved to the locked position even though the latching cams were not fully closed.

During closure of the door, the latch actuator may not be able to rotate the cams to the fully closed position because of excessive binding forces between the latch cams and pins. This could occur if the cargo door is misaligned (out of rig) or if the pull-in hooks do not pull the door in far enough to properly engage the cams around the pins. There is sufficient evidence of wear on the pins and from the previous discrepancies with the door to indicate that the door was misaligned and not properly rigged.

The smooth wear areas found on the pins from N4713U are signs of heavy contact (interference) between the cams and pins during numerous past closings and openings of the door. This wear, other evidence from the door, and the maintenance history of the door, suggest strongly that the door was out of rig during the weeks and months before the accident.

The wear pattern damage to the pull-in hook pins also showed interference during the normal ground operations prior to the accident. This is further evidence of an out-of-rig door. It is also possible that the excessive binding force acting over a period of time precipitated a failure of the latch actuator. Regardless of the reason(s), the conditions of the latch pins and pull-in hook pins showed prolonged out-of-rig operation.

Most of the previous discrepancies with the forward cargo door on N4713U during December 1988 involved problems with closing the door electrically. These problems always occurred when the airplane was fully or nearly fully loaded, just before departure. The trouble-shooting and corrective actions by UAL maintenance, which on some occasions only involved cycling the door and finding it functional, were performed when the airplane was not fully loaded, during overnight maintenance inspections. The flexing of the fuselage with a full load of fuel, cargo, and passengers could have caused distortion of the door frame and resulted in misalignment between the cams and pins. In this case, the pull-in hooks may not have pulled the door fully in before the cam actuator attempted to latch the door. The wear evidence on the latch pins from N47 13U suggests that this event had been occurring before the accident.

Safety Board investigators also witnessed this event during inspection and operation of the aft door on another UAL B-747, N4718U, in HNL. It was noted that the door on N4718U was not being pulled in fully by the pull-in hooks, so the latch cams completed the closing cycle with significant interference and "thunking" sounds. In fact, the out-of-rig door on N4718U failed to operate electrically at one point during its examination.

By design, any attempt to close the master latch lock handle and move undamaged lock sectors into place would not be successful unless the cams were rotated to near the fully latched position. This condition was substantiated by Boeing tests. Even with severely damaged lock sectors, as found on the Pan Am B-747, if the cams were more than 20 turns from the fully closed position on the Pan Am airplane, the master latch lock handle could not be stowed. Examination of the recovered N47 13U door indicated that the door lock sectors were generally intact and jammed against the cams that had been back-driven into the lock sectors. Consequently, if the latch cams had been in the nearly unlatched position as found on the recovered door at the time the cargo handler attempted to move the master latch lock handle, the interference between the cams and the lock sectors would have prevented the master latch lock handle from moving to the closed position. Furthermore, this interference would have prevented the closure of the pressure relief doors as the airplane pressurized, irrespective of the possible absence of the pressure relief door shrouds. This conclusion is supported by extensive testing of the latch/lock mechanisms following the recovery of the door.

Therefore, based upon the examination of the lock sectors and the tests that were conducted, the Safety Board concludes that the latches were fully closed and that the locking handle was placed in the stowed position after the cargo was loaded.

2.5 Manual Unlatching of the Door Following Closure

It is possible that the cams could have been manually back-driven (about 95 turns) after the. door had been secured; however, the UAL ramp personnel involved with dispatching the flight stated that the door was operated electrically. Furthermore, it seems unlikely that the ramp personnel would have driven the manual latch actuator 95 turns toward the open position **after** the door was fully latched.

The placard/seal located over the latch actuator manual drive on the recovered door was found with damage that initially suggested it had been previously compromised. If this were the case, it would indicate that someone may have used the manual drive to operate the door latches on an earlier flight or possibly immediately before the accident flight. However, the Safety Board believes that an insertion of a screw driver and rotation of the plate retaining screw would have caused rotational tearing around the circumference of the screw head. There was no such tear. Rather, the damage to the placard/seal was more consistent with that which would occur from impact and underwater pressure forces. Therefore, the evidence strongly suggests that manual operation of the latch actuator by ground service personnel after the door was properly closed is unlikely.

2.6 Electrical Unlatching of the Door Following Closure

2.6.1 Conditions or Malfunctions Required to Support Hypothesis

It was determined in 1987, after the Pan Am incident, that the locking sectors for B-747's, including those installed on N4713U, could be overcome by the force of the latch cam actuator, electrically or mechanically. If the latch cam actuator had been energized for some reason with the originally designed unstrengthened lock sectors installed, the latch actuator motor was capable of driving the latch cams open through properly positioned lock sectors, whether they were damaged or undamaged. Therefore, the locking sectors installed as original equipment for B-747's, and those installed on N4713U, would not perform the locking function as intended by the design. They would not "lock" the latches in place as implied by the name "lock sectors."

The investigation has shown that there are several conditions that must be met before the latch actuator will electrically drive the latch cams to the unlatched position on the B-747 after the door has been properly closed and locked. First, the ground handling power bus must be energized by having external power connected, or the APU must be operating and the APU generator field switch in the cockpit must be set to power the bus via the No. 2 ground handling power relay. Second, the air/ground relay must be in the "airplane on the ground" position. These two conditions are normally present when the airplane is on the ground before engine startup. Third, there must be a signal to the door open position in one of the two door open/close switches. Fourth, the S2 master latch lock switch, which cuts off power to the door actuators when the handle is stowed, must sense "not locked."

Therefore, it would take several independent conditions and some failures to provide for electrical power to be available to drive the door open electrically once it is closed and locked. The number of conditions and combinations depend upon the phase of operation of the airplane.

While the airplane was on the ground, before engine startup, with the master latch lock handle stowed, the external power connected (or with the APU running), and the ground handling bus powered, an "open" signal to the cargo door latch actuator would have occurred if any of the following combinations of conditions had been met: (1) a malfunction of the S2 master latch lock switch and the placement by someone of one of the door control switches to the "open" position; (2) a malfunction of the S2 master latch lock switch and certain short circuits; or (3) a two-wire short circuit path consisting of wire 101-20 shorting with any of the following wires: 108-20, 121-20, 122-20, 124-20, 135-20, or 136-20.

While the airplane was on the ground, after engine startup, and with the cargo door master latch lock handle stowed and the APU running, an "open" signal to the door latch actuator would have occurred if the following conditions had been met: (1) an energized ground handling bus resulting from the flightcrew reenergizing the APU generator field or failure of the No. 2 ground handling power relay; (2) a malfunction of the S2 master latch lock switch; (3) a malfunction of either of the door open/close switches or the placement of the switch in the "open" position by someone. An "open" signal would have also occurred had certain wire short circuits been present with condition (1) alone, or with conditions (1) and (2).

Regardless of the cause, electrical power to the latch actuator would have had to persist for the time necessary to rotate the cams to the nearly open position. If the electrical power had been applied for a longer time, the latch cams could have opened fully and caused the pull-in hooks to rotate open, a situation that would have prevented the airplane from pressurizing after takeoff. However, it is also possible that the latch actuator stalled before they opened fully because of the forces of the interference between the lock sectors and the cams as they were back-driven.

After takeoff, electrical operation of the door latch actuator would have required: (1) the APU to be running; (2) malfunction of the air/ground relay, (3) malfunction of the No. 2 ground handling power relay; and (4) malfunction of the S2 master latch lock switch and one of the cargo door open/close switches or a short circuit of the aforementioned wire pairs. Although the flightcrew could conceivably energize the ground handling bus from the APU by actuating the APU generator "field" switch, there was no evidence that they did so.

Thus, regardless of the phase of operation, either a wiring short circuit or a failure of the S2 master latch lock switch combined with some other anomaly or action would be required to cause the latches to move toward the open position. Before the recovery of the door, the Safety Board was able to examine two of the electrical relays and the door open/close switches from N4713U that would have to have failed to allow electrical operation of the cargo door in flight, with the APU running. These were the No. 2 ground handling power relay, the air/ground relay, and the internal and external door open/close switches. The examination of the relays and switches revealed no evidence of a single fault or conditions that might have caused an intermittent failure mode. The arcing noted on the No. 5 terminal of the outside door control switch was on the door "close" circuit and could not have been related to a short to the open mode. Further, because the flightcrew did not note a cargo door warning light, and the fact that the airplane was able to be pressurized, confirms that the master latch lock handle was in the closed position before takeoff. This position would actuate the master latch lock switch to disconnect power to the door opening actuators.

According to the flightcrew testimony and the pilots' comments recorded on the CVR during the flight, the APU was shut down shortly after takeoff and remained in that condition. Engine generators cannot power the ground handling bus from which the cargo door actuating mechanisms are powered. Once the APU was shut down, there was no power available to any of the cargo door electrical components. Therefore, an electrical actuation of the latch cam actuator at the time of the door loss was not possible.

The Safety Board believes that there is another reason why the opening of the door could not have been caused by electrical actuation shortly before the explosive decompression. Because the door carries the structural loads (hoop stresses) through its hinge and latches, the latch cams would be heavily loaded against the latch pins when the airplane was pressurized to the 6.5 psi differential pressure that was calculated to have been present at the time of the decompression. In that case, the torque limiter within the actuator would probably slip well before the actuator could achieve the torque necessary to drive the cams open against the frictional lock produced by the high bearing stresses resulting from pressurization.

2.6.2 Electrical Switches and Wiring Examinations--Recovered Door

All cargo door position sensing switches (S2 through S9) were found installed in their proper position. The cargo door recovery team found the S2 master latch lock switch in the "not-locked" position immediately after the door was aboard the recovery ship. This position would be consistent with the master latch lock handle being open. Further tests of the S2 switch revealed damage that probably resulted from the pressures under the sea. The only notable exception was a broken internal bracket that may have affected the operation of the switch prior to the accident. Other similar switches did not exhibit this failure. It is therefore possible that the S2 master latch lock switch failed prior to the accident, allowing more possibilities for electrical short circuits to power the latch actuator. Nevertheless, despite extensive testing, it could not be determined whether the S2 switch was functional before the accident.

The examination of 35 wires that remained with the recovered cargo door revealed several areas of damaged insulation that could have permitted an electrical short circuit to power the latch actuator. However, no evidence was noted of arcing that was indicative of short circuits. Furthermore, a significant number of the wires that had the potential for allowing for short circuits to power the latch actuator were not recovered. Testing conducted by Boeing and by UAL was inconclusive regarding whether a short circuit would have left detectable evidence of arcing. Therefore, the Safety Board was unable to determine whether the latch actuator was inadvertently powered by a short circuit in the cargo door wires.

The incident involving a UAL Boeing 747 at JFK Airport on June 13, 1991, confirmed that electrical short circuits in the cargo door wiring could cause the door to open. In this case, the short circuits were in the fuselage-to-cargo door wiring bundle where the bundle was covered by a flexible conduit. Although N47 13U did not have a flexible conduit installed at the forward door position, its wiring was routed over the top of the door hinge where exposure to damage could occur. That portion of the wiring from N4713U was not recovered from the sea. The wires located at the door hinge area are more susceptible to in-service damage from movement during the open/close cycle, as compared with the wires mounted on the door that are normally static.

Following the incident at JFK, UAL directed that the circuit breaker that terminates power to the cargo doors be pulled after the door is closed and before departure of every B-747 flight. UAL obtained approval for this practice from the FAA and requested Boeing and the FAA to make such a practice part of the approved manual for the airplane. Neither Boeing nor the FAA acted on UAL's request.

Nevertheless, the Safety Board believes that the FAA should initiate rulemaking to include design considerations for nonplug transport category aircraft cargo doors that would deactivate the electrical circuitry to the door actuators after the doors are closed and locked. The catastrophic nature of the loss of a cargo door dictates the need to provide additional redundancies and fail-safe features in the door mechanisms to supplement the hardware safety features.

2.6.3 Possibility of Electrical Malfunction

Due to the lack of physical evidence, the Safety Board was unable to conclude that an electrical short caused the cargo door actuator to move the latch cams to the nearly open position, allowing the door to separate when the cabin pressure exceeded the load-carrying capability of the door latches. Neither could this possibility be eliminated. A momentary actuation of the door open switch by someone on the ground in the presence of a faulty S2 switch could also have caused the latches to open through the closed lock sectors. However, no evidence has been found that someone actuated the switch after the door was initially closed and locked.

The Safety Board concludes that it was not possible for the cargo door to have opened electrically at the time of the loss of the door. There was no power to the ground handling bus to power the actuator, even if there had been an electrical short. Further, the Safety Board concludes that it is highly improbable that an electrical short could have caused the latches to open after the airplane was airborne. Although the ground handling bus could conceivably have been powered, failures of other components that were tested as functional would also have been necessary.

The Safety Board believes that the electrical operation of the latch actuators from the fully closed and locked position most likely occurred before the engines were started when the ground handling bus was powered. The precise source of the electrical actuation could not be determined. Once the engines were started, the possibility of an electrical short decreases significantly because the ground handling bus is disengaged from the APU when the engines start. There was no evidence that the flightcrew reengaged the ground handling bus.

Because the preaccident condition of the S2 master latch lock switch could not be determined, it could also not be determined whether its proper functioning would have prevented the accident. The Safety Board did not determine whether damaged cargo door wires or a malfunctioning S2 switch could have been found by UAL maintenance had they been more aggressive in trouble-shooting the cargo door problem in the weeks prior to the accident.

2.7 Design, Certification, and Continuing Airworthiness Issues

The Safety Board's analysis of this accident went beyond the conclusions about how the door failed. The Safety Board also examined the initial design and certification of the B-747 cargo door, and the continuing airworthiness system that should have prevented this accident, to identify the breakdowns in this system that led to the accident. As is the case with most aviation accidents, there are many factors that led up to the actual failure of the door on flight 8 11.

The Safety Board found that there were multiple opportunities during the design, certification, operation, and maintenance of the forward cargo door for N4713U for persons to have taken actions that could have precluded the accident involving flight 811. The circumstances that led to this accident exemplify the need for human factors considerations in the promulgation of regulations, the application of regulatory policies, the design of airplane systems, and the quality of airline operational and maintenance practices.

The first opportunity to prevent this accident occurred during the design and certification of the B-747 cargo door mechanical systems, when the design was chosen and approved, which allowed for the overriding of the lock sectors by either mechanical or electrical actuation. It is apparent that the original design was not tested sufficiently to verify that the locking sectors in fact “locked” the latch cams in the closed position. This shortcoming should have become apparent during the initial certification testing and approval process. Later, it should have become apparent when Boeing applied for, and the FAA granted, an alternative method of compliance with the certification regulations (25.783 [e]) that permitted the elimination of operational practices that included a visual verification of the cargo door latch positions via view ports in the doors.

The failure mode analysis performed by Boeing, and the FAA’s acceptance of its content in granting the exemption, probably were based on the assumption that the lock sectors would always prevent the master latch lock handle from being in a stowed position when the latch cams were not fully closed. This assumption was not valid, as evidenced by the fmdings in 1987 following the Pan Am incident that the lock sectors could not prevent the latch cams from being driven from the fully latched position with the master latch lock handle stowed, while a false indication was provided to the flightcrew that the cargo door was properly latched and locked. At the time that Boeing sought approval of the alternative compliance, Boeing and the FAA should have reviewed the design and required testing of the door latch/lock mechanisms to verify their integrity. Thus, the procedure for direct viewing of the latches via the view ports before the airplane could be dispatched should not have been eliminated without adequate verification that the lock sectors were totally effective.

The next opportunity for the FAA and Boeing to have reexamined the original assumptions and conclusions about the B-747 cargo door design and certification was after the findings of the Turkish Airline DC-10 accident in 1974 near Paris, France. The concerns for the DC-10 cargo door latch/lock mechanisms and the human and mechanical failures, singularly and in combination, that led to that accident, should have prompted a review of the B-747 cargo door's continuing airworthiness. In the Turkish Airlines case, a single failure by a ramp service agent, who closed the door, in combination with a poorly designed latch/lock system, led to a catastrophic accident. The revisions to the DC-10 cargo door mechanisms mandated after that accident apparently were not examined and carried over to the design of the B-747 cargo doors.

Specifically, the mechanical retrofit of more positive locking mechanisms on the DC-10 cargo door to preclude an erroneous locked indication to the flightcrew, and the incorporation of redundant sensors to show the position of the latches/locks, were not required to be retrofitted at that time for the B-747. Of similar concern is the fact that the cargo doors for the L-101 1 required redundant latch/lock indication sensors at initial certification, during the approximate same time frame the DC-10 and B-747 were certificated.

More recently, when Boeing and the FAA learned about the circumstances of the Pan Am cargo door opening incident in March 1987, more timely and positive corrective actions should have been taken. The Safety Board believes that the findings of that incident investigation should have called into question the assumptions and conclusions about the original design and certification of the B-747 cargo door, especially the alternative method for verifying that the door was latched and locked that was sought by Boeing and was granted by the FAA. Since a B-747 cargo door opening in flight was considered to be an "unacceptable event", once a door did come open in flight, the FAA and Boeing should have acted much quicker to prevent another failure.

It took nearly 16 months from the date of the Pan Am Incident (March 10, 1987) until the FAA issued AD-88-12-04 (July 1, 1988). And then, the AD allowed 18 or 24 months, depending on the model B-747, from the date of its issuance for compliance with the terminating actions of the AD. The fact that Boeing had issued an Alert SB as a result of the Pan Am incident is an indication of the apparent urgency with which Boeing treated this issue. Alert SB's are issued for "safety of flight" reasons, while regular SB's deal with "reliability" and not necessarily safety of flight items. Despite this, the terminating action, issued as revision 3 to the Alert SB, on August 27, 1987, was not mandated by the FAA for 11 months.

The Safety Board found no evidence that the FAA or Boeing reassessed the original design and certification conclusions regarding the safety of the B-747 cargo door during this period. Several opportunities for preventive action were also missed by UAL during this period. First, UAL delayed the completion of the terminating actions of Alert SB 52A2206 (Rev 3 and AD-88 12-04. In fact, there was no evidence that UAL had intended to comply with the terminating action of the Alert SB, until it was mandated by the FAA.

It is understandable that an airline would not take its aircraft out of service to incorporate revisions that do not appear to be safety critical. Although by definition an Alert SB is safety related, there was no implication from Boeing's and FAA's actions regarding this matter that urgency was required. The airlines rely on the airframe manufacturers and- the FAA to evaluate the need for urgent airworthiness actions that might take airplanes out of revenue service. In this case, UAL had scheduled completion of its B-747 fleet modifications in accordance with the terminating actions for AD-88-12-04 before the final allowable date; however, the schedule was based on other heavy maintenance schedules to prevent unnecessary down-time of its airplanes.

UAL personnel stated after the UAL 811 accident that its personnel did not fully appreciate the importance, or safety implications, of the terminating actions, or they would have incorporated the improvements much earlier. The usual difficulties in setting short suspense dates for performing terminating actions in AD's, such as parts availability, did not seem to exist in this case, because the parts were not complex components and probably could have been fabricated fairly quickly in-house by most airlines.

Human performance certainly contributed to UAL's failure to incorporate an important inspection step into its maintenance program as mandated by AD-88-12-04. When UAL obtained an advance draft copy of the forthcoming NPRM that eventually led to the AD; the airline began preparing its work orders to implement the forthcoming the AD requirements into its B-747 fleet (30 airplanes at the time). UAL developed its maintenance work sheets from the text of the draft NPRM, which was virtually identical to the text of the final rule. As a result of a clerical error, one of the important inspection steps required by the AD was omitted.

Apparently, UAL maintenance personnel never compared the work sheets they received with the actual requirements of the AD, or if they did, the omission was not detected. FAA inspectors responsible for oversight of UAL's maintenance program also did not detect this error because normal surveillance of AD compliance merely involved verifying the correctness of UAL's paperwork that listed the applicable AD's and compliance dates. The inspectors did not actually verify UAL's compliance action by shop visits, or by comparison of work sheets with AD provisions. These omissions by the UAL maintenance and quality assurance personnel, and the limitations of the FAA surveillance procedures were probably significant in setting the stage for the events that led to the actual cause of the door separation from N47 13U.

Another matter of concern is the quality of UAL's trend analysis program. There was no indication that the repeated discrepancies with the forward cargo door on N4713U "raised a flag" within the UAL maintenance department. A quality assurance or trend analysis program should have detected an adverse trend and should have prompted efforts to resolve the repeated problems. If it had, any faults in the door electrical system or damage to mechanical components might have been detected.

In summary, the Safety Board concludes that there were several opportunities wherein Boeing, the FAA, and UAL could have taken action during the initial design and certification of the B-747 cargo door, as well as during the operation and maintenance of the cargo door installed on N4713U, to ensure the continuing airworthiness of the cargo door. The Safety Board further concludes that these deficiencies and oversights contributed to the cause of this accident.

2.8 Survival Aspects

The Hickam ARFF units and the airport's ARFF units operated on separate radio networks and thus they could not communicate directly on-scene by radio. This situation required them to communicate by voice. Although the two ARFF services had a common radio frequency (as per the Airport Emergency Plan), procedures for its use had not yet been developed. The Safety Board believes that such communication procedures should be expeditiously developed.

The use of camouflage paint schemes on military ARFF vehicles may be appropriate for military purposes; however, the Safety Board believes that camouflage is not appropriate for ARFF vehicles that are operated at a joint- use airport. It is obvious that these vehicles must be conspicuous to be seen by other responding vehicles and by persons who are involved in the accident, such as airport and airline personnel, crew and passengers, and off-airport firefighting and rescue vehicles.

The National Fire Protection Association Standards recommend for primary firefighting, rapid intervention and combined agent vehicles, that, "Paint finish shall be selected for maximum visibility and shall be resistant to damage from firefighting agents."[4] Furthermore, Federal Aviation Regulation 14 CFR 139.319 (f) (2) requires emergency vehicles, "Be painted or marked in colors to enhance contrast with the background environment and optimize daytime and nighttime visibility and identification." Further guidance for the high visibility color of ARFF vehicles is provided in a Federal Aviation Administration Advisory Circular where the vehicle paint color is specified as, "lime yellow" Dupont No. 7744 UH or its equivalent.[5]

Because flight attendants are vital to the safety and survival of the passengers following a decompression, measures should be taken to prevent flight attendants from being incapacitated by hypoxia. The Safety Board believes that oxygen masks should be attached to the emergency oxygen bottles to avoid any delay in their use in order to be in compliance with the intent of 14 CFR 25.1447 (c)(4). Therefore, the FAA should direct its inspector staff to survey B-747 airplanes for compliance with 14 CFR 25.1447(c)(4), and correct deficiencies found.

In this accident, the use of megaphones was vital because of the inability to be heard over the public address (PA) system. Title 14CFR 121.309 (f)(l) requires one megaphone on each airplane with a seating capacity of more that 60 and less that 100 passengers; 14 CFR 121.309 (f)(2) requires two megaphones in the cabins on each airplane with a seating capacity of more than 99 passengers. As this decompression demonstrated, additional megaphones are necessary on wide-body and large narrow-body airplanes to ensure communication in the cabin during emergencies when the PA system is inoperative.

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[4]NFPA 414 - Aircraft Rescue and Fire Fighting Vehicles, National Fire Protection Association, 1984, Batterymarch Park, Quincy, MA 02269.

[5]Airport Fire and Rescue Vehicle Specification Guide, AC 150/5220-14, March 15, 1979, Federal Aviation Administration, Washington, D.C. 20591.

Had there been a need for an immediate evacuation, or a water ditching, rapid egress would not have been possible at doors 2-left and 2-right because they were blocked by open storage compartments and spilled contents. The possibility also exists that a compartment door could release during a hard landing or turbulence and swing down and injure a flight attendant. Thus, the Safety Board believes that improved latches should be installed and the downward movement of stowage compartments doors should be restricted to prevent the doors from striking a seated flight attendant or block the exit door.

The Safety Board believes that the problems with life preserver donning and adjustment demonstrated in this accident should be addressed by the FAA. The straps and fittings on life preservers need to be evaluated to determine where improvements can be made, and clearer donning instructions should be developed. TSO-C13d, Life Preservers 1/3/83 prescribes the minimum performance standards for life preservers. With regard to donning, the TSO requires:

Donning. It must be demonstrated that an adult, after receiving only the customary preflight briefing on the use of life preservers, can don the life preserver within 15 seconds unassisted while seated. It must be demonstrated that an adult can install the life preserver on another adult, a child, or an infant within 30 seconds unassisted. The donning demonstration is begun with the unpackaged life preserver in hand.

Based on flight attendant interviews and information obtained from passengers these donning times were exceeded in many instances.

The Safety Board has made numerous recommendations to the FAA in the past regarding needed improvements in life preserver donning instructions, donning procedures, and timing of donning.[6] The FAA has adopted most of the Safety Board's recommendations in its April 23, 1986, revision to TSO-C13e, Life Preservers, which now requires the wearer to be able to secure the preserver with no more than one attachment and make no more than one adjustment for fit. Also, donning tests are required for age groups of users starting with 20-29 years and ending with 60-69 years. At least 60% of the test subjects in each age group must be able to don then life preserver within 25 seconds unassisted with their seatbelts fastened starting with the life preserver in its storage package. TSO-C13e contains

[6]"Air Carrier Overwater Emergency Equipment and Procedures" (NTSB/SS-85/02)

requirements that would have eliminated some of the problems that passengers had in this accident in correctly donning and adjusting their life preservers.

The Safety Board has recommended (A-85-35 through-37) to the FAA to amend 14 CFR 121,125, and 135 to require air carriers to install life preservers that meet TSO-C13e within a reasonable time. The FAA adopted TSO-C13e on April 23, 1986, and originally had specified an effective date of April 23, 1988, after which all newly manufactured life preservers approved under the TSO system would have to meet the requirements of TSO-C13e. The objective of the cut off date was to introduce life preservers into the fleets with the higher performance level as specified in TSO-C13e by assuring that replacement articles met the higher standards. On March 3, 1988, the FAA rescinded the cut off date to seek further public comments of fleet retrofit in accord with the proposed rulemaking. See Section 4.0 for FAA action and status of the recommendations.

3. CONCLUSIONS

3.1 Findings

1. There were no flightcrew or cabincrew factors in the cause of the accident or injuries.

2. There were no air traffic control or weather factors in the cause of the accident.

3. The airplane had not been maintained in accordance with the provisions of AD-88-12-04 that required an inspection of the cargo door locking mechanisms after each time the door was operated manually and restored to electrical operation. However, this circumstance was determined not to be a factor in the accident.

4. All but one of the electrical components remaining with the airplane or found with the cargo door that were necessary to have malfunctioned in order to cause an inadvertent electrical opening of the cargo door after dispatch were found to function properly.

5. The forward cargo door lock sectors were found in the locked position (actually in an "over-locked" position) and jammed against the latch cams. The latch cams were found in the nearly open position.

6. The latch actuator manual drive port seal was found damaged from the forces involved in the separation of the door and did not indicate that the drive port had been used to open the door latches manually before the accident.

7. Electrical continuity tests indicated that the S2 master latch lock switch was in the "not locked" position when it was recovered with the cargo door. Because it had sustained damage from being submerged in the sea, its preaccident condition could not be determined.

8. An S2 switch functioning as found after recovery would permit electrical power to the door during ground operation so that additional failure modes or activation of the door control switch could result in movement of the latching cams.

9. All other switches associated with operation of the cargo door were found damaged from being submerged in the sea; however, they were determined to be properly installed and probably functional.

10. Short circuit paths in the cargo door circuit were identified that could have led to an uncommanded electrical actuation of the latch actuator; this situation occurred most likely before engine start, although limited possibilities for an uncommanded electrical actuation exist after engine start while an airplane is on the ground with the APU running.

11. It was not possible for electrical short circuits to command the cargo door to open at the time of the loss of the door, and it is highly improbable that such an event occurred when the airplane was airborne during the short period while the APU was running.

12. Insulation breaches were found on recovered portions of the cargo door wires that could have allowed short circuiting and power to the latch actuator, although no evidence of arcing was noted. All of the wires were not recovered, and tests showed that arcing evidence may not be detectable.

13. An uncommanded movement of cargo door latches that occurred on another UAL B-747 on June 13, 1991, was attributed to insulation damage and a consequent short between wires in the wiring bundle between the fuselage and the moveable door. Because the S2 switch functioned properly on that airplane, movement of the latches would not have occurred after the door was locked.

14. UAL's maintenance trend analysis program was inadequate to detect an adverse trend involving the cargo door on N4713U.

This circumstance was determined not to be a factor in the accident.

15. FAA oversight of the UAL maintenance and inspection program did not ensure adequate trend analysis and adherence to the provisions of airworthiness directives. This circumstance was determined not to be a factor in the accident.

16. The smooth wear patterns on the latch pins of the forward cargo door installed on N4713U were signs that the door was not properly aligned (out of rig) for an extended period of time, causing significant interference during the normal open/close cycle.

17. The rough heat-tinted wear areas on the latch pins of the forward cargo door installed on N47 13U marked the positions of the cams at the time the door opened in flight.

18. The design of the B-747 cargo door locking mechanisms did not provide for the intended “fail-safe” provisions of the locking and indicating systems for the door.

19. Boeing’s Failure Analysis, which was the basis upon which the FAA granted an alternative method of compliance with the provisions of 14 CFR 25.783 (e), was not valid as evidenced by the findings of the Pan Am incident in 1987, and the accident involving flight 8 11.

20. Boeing and the FAA did not take immediate action to require the use of the cam position view ports following the Pan Am incident, and did not include this requirement in the provisions of the Alert Service Bulletins or AD-88-12-04.

21. There were several opportunities for the manufacturer and the FAA to have taken action during the service life of the Boeing 747 that might have prevented this accident.

22. The fact that the crash fire rescue vehicles responding to this accident did not use a common radio frequency led to problems in communication among the responding vehicles.

23. The camouflage paint scheme of the military fire rescue units led to reduced visibility of these units and resulted in at least one near-collision.

24. Megaphones were used in flight to communicate with passengers because of the high ambient noise level. However, more megaphones would have afforded better communication in all parts of the cabin.

25. Some flight attendants and passengers had difficulties tightening straps of their life preservers around their waists because of the fabric used, the design of the adjustment fittings, and the angle the straps were pulled.

26. Articles that fell to the floor from stowage bins above the L-2 and R-2 exits and galley service items had to be cleared away from the exits before the emergency evacuation could be initiated.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of this accident was the sudden opening of the forward lower lobe cargo door in flight and the subsequent explosive decompression. The door opening was attributed to a faulty switch or wiring in the door control system which permitted electrical actuation of the door latches toward the unlatched position after initial door closure and before takeoff. Contributing to the cause of the accident was a deficiency in the design of the cargo door locking mechanisms, which made them susceptible to deformation, allowing the door to become unlatched after being properly latched and locked. Also contributing to the accident was a lack of timely corrective actions by Boeing and the FAA following a 1987 cargo door opening incident on a Pan Am B-747.

4. RECOMMENDATIONS

As a result of the investigation, including evidence from the recovered cargo door and a June 13, 1991, incident involving the uncommanded electrical operation of a cargo door on a UAL Boeing 747 at JFK Airport, the National Transportation Safety Board recommends that the FAA:

> Require that the electrical actuating systems for nonplug cargo doors on transport-category aircraft provide for the removal of all electrical power from circuits on the door after closure (except for any indicating circuit power necessary to provide positive indication that the door is properly latched and locked) to eliminate the possibility of uncommanded actuator movements caused by wiring short circuits. (Class II, Priority Action) (A-92-21)

As a result of this investigation, on August 23, 1989, the Safety Board issued the following safety recommendations to the FAA:

> Issue an Airworthiness Directive (AD) to require that the manual drive units and electrical actuators for Boeing 747 cargo doors have torque limiting devices to ensure that the lock sectors, modified per AD-88-12-04, cannot be overridden during mechanical or electrical operation of the latch cams. (Class II, Priority Action) (A-89-92)

> Issue an Airworthiness Directive (AD) for non-plug cargo doors on all transport category airplanes requiring the installation of positive indicators to ground personnel and flightcrews confirming the actual position of both the latch cams and locks, independently. (Class II, Priority Action) (A-89-93)

> Require that fail-safe design considerations for non-plug cargo doors on present and future transport category airplanes account for conceivable human errors in addition to electrical and mechanical malfunctions. (Class II, Priority Action) (A-89-94)

The FAA responded to Safety Recommendations A-89-92 through -94 on November 3, 1989. During its evaluation of Safety Recommendation A-89-92, the FAA determined that Boeing 747 cargo doors with lock sectors, modified in compliance with AD 88-12-04, cannot be overridden during mechanical or least one torque-limiting device. The Safety Board has reviewed AD 88-12-04 and has confirmed the FAA's findings. Based on this, Safety Recommendation A-89-92 has been classified as "Closed--Reconsidered."

The FAA responded to Safety Recommendations A-89-93 and -94 describing action to review all outward opening (nonplug) doors and all jet-powered transport-category airplanes to determine what, if any, modifications are needed to ensure that these doors will not open in flight. The FAA pointed out that the door latch indicating system is to be only part of the review and that door designs will be evaluated against criteria specified in 14 CFR 25.783 as amended by Amendment 25-54, and the policy material published in Advisory Circular 25.783.1, adopted in 1980 and will take into account human factors involved in the routine operation of closing and locking doors to ensure that the latch and lock systems are fail-safe. Further, to emphasize the importance of human factors, the FAA has developed a training program for FAA certification personnel to enhance their knowledge of human factors in aircraft design. This training program will be offered to approximately 100 certification personnel during the next year. Based on this response, Safety Recommendations A-89-93 and -94 have been classified as "Open--Acceptable Action." The Safety Board believes it necessary to point out that this hazard exists for <u>any</u> pressurized aircraft using nonplug doors and that the FAA should not be limiting this review to only those transports which are jet-powered.

On November 29, 1990, Boeing issued service bulletin number 747-52-2224 applicable to all 747-100, 747-200, and 747-300 airplanes to add a new "door latch" switch to all 747 cargo doors.

In addition to the door warning switch that monitors the position of the pressure relief doors, the new door latch switch is activated by the latch cam bellcrank to separately sense the position of the latch cams. The existing "door closed" switch is also replaced with a double pole switch. The additional pole is used to separately sense the position of the door. Another single pole switch is also added to redundantly sense the position of the door. If any of these switches are not actuated, the warning light on the flight engineer's panel and a new light added to pilot's glareshield panel will be illuminated. The modification also requires installation of new cargo door control panels on the forward and aft lower cargo doors. The new panel incorporates an additional light to indicate proper door locking.

The FAA mandated the incorporation of this service bulletin within 18 months by AD 90-09-06, Amendment 39-6581, effective May 29, 1990.

Also, as a result of this accident, on May 4, 1990, the National Transportation Safety Board issued the following safety recommendations to the FAA:

> Amend 14 CFR 25.1447(c)(4) to require that face masks be attached to the regulators of portable emergency oxygen bottles. (Class II, Priority Action) (A-90-54)
>
> Require, in accordance with the requirements of 14 CFR 25.1447(c)(4), that a portable oxygen bottle be located at the flight attendant stations at exit door 5 right and at exit door 5 left in B-747 airplanes. (Class II, Priority Action) (A-90-55)
>
> Require that no articles be placed in storage compartments that are located over emergency exit doors. (Class II, Priority Action) (A-90-56)
>
> Amend 14 CFR 121.309(f) to require a readily accessible megaphone at each seat row at which a flight attendant is stationed. (Class II, Priority Action) (A-90-57)
>
> Take corrective action to improve direct visibility to passengers from the upper level flight attendant jumpseat in the B-747 airplanes using eye reference data contained in Federal Aviation Administration report FAA-AM-75-2 "Anthropometry of Airline Stewardesses." (Class II, Priority Action) (A-90-58)
>
> Issue an Airworthiness Directive to require that stronger latches be installed in oversized storage compartments that formerly held liferafts on all B-747 airplanes and also limit the distance that these compartments can be opened. (Class II, Priority Action) (A-90-59)
>
> Demonstrate for each make and model of life preserver that it can be donned, adjusted, and tightened within the elapsed time required by TSO-C13d. Direct particular attention to the ease with which straps pass through adjustment fittings when the straps are pulled at all possible angles. (Class II, Priority Action) (A-90-60)

Establish a cutoff date of [within 1 year of this recommendation letter] after which all life preservers manufactured for passenger-carrying aircraft would be required to meet the specifications of TSO-Cl3e. (Class II, Priority Action) (A-90-61)

The FAA first responded to these safety recommendations in a July 26, 1990, letter. Further responses to various safety recommendations in the group came in letters dated October 26, 1990 (A-90-59); May 13, 1991 (A-90-58); September 23, 1991 (A-90-55, -56, and -59); and March 9, 1992 (A-90-59). The current status of each safety recommendation is:

A-90-54: "Open--Acceptable Response," pending outcome of potential rulemaking initiative by the FAA.

A-90-55: "Open--Unacceptable Response," pending a review by the FAA of B-747 airplanes for compliance with portable oxygen bottle placement and securement requirements and for modifications that do not meet the intent of the type certification.

A-90-56: "Open--Unacceptable Response," pending a reexamination by the FAA of the potential for contents of compartments spilling out during an emergency and obstructing passengers.

A-90-57: "Open--Unacceptable Response," pending the FAA's review of its position regarding a requirement for multiple megaphones on passenger airplanes.

A-90-58: "Closed--Reconsidered" as a result of the Safety Board's acceptance of the FAA position that the cabin jumpseat design on B-747's does not constitute an unsafe condition.

A-90-59: "Open--Acceptable Response," pending the issuance of an Airworthiness Directive to require stronger latches on oversized storage compartments on B-747 airplanes.

A-90-60: "Open--Acceptable Response," pending the implementation of the latest iteration of TSO-C13.

A-90-6 1: "Open--Unacceptable Response," pending inclusion in TSO-Cl3 (latest iteration) of a cutoff date after which all life preservers manufactured for passenger-carrying aircraft would be required to meet the specifications of the TSO.

The FAA's March **9, 1992,** response to Safety Recommendation A-90-59 included the final AD addressing this issue. The AD does meet the intent of the recommendation, which is now classified as "Closed--Acceptable Action."

Also as a result of this accident, on May 4, 1990, the Safety Board reiterated the following recommendations to the FAA:

<u>A-85-35</u>

Amend 14 CFR 121 to require that all passenger-carrying air carrier aircraft operating under this Part be equipped with approved life preservers meeting the requirements of the most current revision of TSO-Cl3 within a reasonable time after the adoption of the current revision of the TSO; ensure that 14 CFR 25 is consistent with the amendments to Part 121.

<u>A-85-36</u>

Amend 14 CFR 125 to require that all passenger-carrying air carrier aircraft operating under this Part be equipped with approved life preservers meeting the requirements of the most current revision of TSO-Cl3 within a reasonable time after the adoption of the current revision of the TSO; amend Part 125 to require approved flotation-type seat cushions (TSO-C72) on all such **aircraft;** ensure that 14 CFR 25 is consistent with the amendments of Part 125.

<u>A-85-37</u>

Amend 14 CFR 135 to require that all passenger-carrying air carrier aircraft operating under this Part be equipped with approved life preservers meeting the requirements of the most current revision of TSO-Cl3 within a reasonable time after the adoption of the current revision of the TSO; Amend Part 135 to require approved floatation-type seat cushions (TSO-C72) on all such **aircraft;** ensure that 14 CFR SFAR No. 23 is consistent with the amendments to Part 135.

In a November 28, 1988, letter to the FAA, the Safety Board recommended that a cutoff date January 1, 1989, be reestablished. Based on this accident, the Safety Board's again urges the FAA to establish a cutoff date by which life preservers meeting TSO-C13e would be introduced into the fleets within a reasonable time (A-85-36). The Safety Board recognizes that the FAA has complied with the part of this recommendation pertaining to the flotation-type seat cushions.

Safety Recommendations A-85-35 and -37 are being held in an "Open--Acceptable Action" status pending the publication of the final rule. Safety Recommendation A-85-36 is being held in an "Open--Unacceptable Action" status because Part 125 operations were not included in the FAA rulemaking action.

As a result of its investigation, on May 4, 1990, the Safety Board also recommended that the State of Hawaii, Department of Transportation, Airports Division:

> Develop, in cooperation with the Department of Defense, procedures for direct radio communication between aircraft rescue and fire fighting vehicles operated by the State of Hawaii and Hickam Air Force Base that would be used when responding to airport emergencies at Honolulu International Airport. (Class II, Priority Action) (A-90-62)

Additionally, as a result of its investigation, on May 4, 1990, the Safety Board recommended that the Department of Defense:

> Develop, in cooperation with the State of Hawaii Department of Transportation, procedures for direct radio communication between aircraft rescue and firefighting vehicles operated by Hickam Air Force Base and the State of Hawaii that would be used when responding to airport emergencies at Honolulu International Airport. (Class II, Priority Action) (A-90-63)
>
> Comply with Federal Regulation 14 CFR 139.3 19(f)(2) and the guidance contained in Federal Aviation Administration Advisory Circular 150/5220-14 by using high visibility color for aircraft rescue and firefighting vehicles that operate at Honolulu International Airport. (Class II, Priority Action) (A-90-64)

The Department of Defense responded to Safety Recommendations A-90-63 and -64 on August 17, 1990, citing the establishment of emergency radio communication ability between ARFF vehicles operated by Hickam Air Force Base and the State of Hawaii at Honolulu International Airport. Based on this action, Safety Recommendation A-90-63 was classified as "Closed--Acceptable Action" on December 12, 1990. With the establishment of the communications system as recommended, the Safety Board now classifies Safety Recommendation A-90-62 as "Closed--Acceptable Action."

Also, with regard to Safety Recommendation A-90-64, the Department of Defense pointed out that the Air Force has initiated a program to repaint the vehicles over a 3-year period to spread out funding concerns. This safety recommendation is being held as "Open--Acceptable Response," pending the completion of the repainting program in 1993.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

SUSAN COUGHLIN
Acting Chairman

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Member

CHRISTOPHER A. HART
Member

JOHN HAMMERSCHMIDT
Member

JAMES L. KOLSTAD
Member

March 18, 1992

5. APPENDIXES

APPENDIX A

INVESTIGATION AND HEARING

1. Investigation

The Washington Headquarters of the National Transportation Safety Board was notified of the United Airlines accident within a short time after the occurrence. A full investigation team departed Washington, D.C. at 1400 eastern daylight time on the same day and arrived in Honolulu at 0030 Hawaiian standard time the next day.

The team was composed of the following investigation groups: Operations, Structures/Systems, Maintenance Records, Metallurgy, and Survival Factors. In addition, specialist reports were prepared relevant to the CVR, FDR and radar plots.

Parties to the field investigation were United Airlines, the FAA, the Boeing Commercial Airplane Company, the Air Line Pilots Association, the International Association of Machinists, and the Association of Flight Attendants.

2. Public Hearing

A 3-day public hearing was held in Seattle, Washington, beginning on April 25, 1989. Parties represented at the hearing were the FAA, United Airlines, the Boeing Commercial Airplanes Company, the Air Line Pilots Association, and the International Association of Machinists.

APPENDIX B

PERSONNEL INFORMATION

Captain David Cronin

Captain David Cronin, 59, was hired by UAL on December 10, 1954. The captain holds Airline Transport Pilot (ATP) Certificate No. 1268493 with airplane multiengine land ratings and commercial privileges in airplane single-engine land, sea and gliders. The captain is type rated in the B747, DC10, DC8, B727, Convair (CV) 440, CV340, CV240 and the learjet. The captain was issued a first class medical certificate on November 1, 1988, with no limitations.

The captains initial operating experience (IOE) check out in the B747 occurred in December, 1985. The captain's latest line and proficiency checks in the B747 were completed in August and December, 1988, respectively. Training in ditching and evacuation was included with the proficiency check. The captain had flown a total of about 28,000 hours, 1,600 to 1,700 hours of which were in the B747. During the 24-hour, 72-hour and 30-day periods, prior to the accident, the captain had flown: 1 hour, 5 minutes; 13 hours, 35 minutes; and 76 hours, 18 minutes, respectively.

First Officer Gregory Slader

First Officer Gregory Slader, 48, was hired by UAL on June 15, 1964. The first officer holds ATP Certificate No. 1528630 with airplane multiengine land ratings and commercial privileges in airplane single-engine land. The first officer is type rated in B747, DC10, B727, and B737. The first officer was issued a fiit class medical certificate on February 14, 1989, with no limitations.

The first officer's initial operating experience (IOE) check out in the B747 occurred in August, 1987. The first officer's latest proficiency check in the B747 was completed in October, 1988. Training on ditching and evacuation was included with the proficiency check. The first officer had flown a total of about 14,500 hours, 300 hours of which were in the B747. During the 24-hours, 72-hour and 30-day periods prior to the accident, the first officer had flown: 1 hour, 5 minutes; 13 hours, 35 minutes; and 46 hours, 25 minutes, respectively.

Second Officer Randal Thomas

Second Officer Randal Thomas, 46, was hired by UAL on May 22, 1969. The second officer holds Flight Engineer Certificate No. 1947041 for turbo jet powered airplanes, issued July 18, 1969. The second officer holds commercial pilot certificate No. 1585899 with ratings and limitations of airplane single and multiengine land with instrument privileges. The second officer was issued a first class medical certificate on December 6, 1988, with no limitations.

The second officer's IOE check out in the B747 occurred in March, 1987. The second officer's latest proficiency check in the B747 was completed in October, 1988. Training in ditching and evacuation was included with the proficiency check. He had flown a total of about 20,000 hours, about 1,200 hours of which were as second officer on the B747. During his 24-hour, 72-hour and 30 day-periods, prior to the accident, the second officer had flown: 1 hour, 5 minutes; 13 hours, 35 minutes; and 46 hours, 25 minutes, respectively.

Flight Attendant and Chief Purser Laura Brentlinger

Flight attendant Laura Brentlinger, 38, was employed by UAL in May 1982; and had completed B747 recurrent training on September 19, 1988.

Flight Attendant and AFT Purser Sarah Shanahan

Flight attendant Sarah Shanahan, 42, was employed by UAL in August 1967; and had completed B747 recurrent training on October 10, 1988.

Flight Attendant Richard Lam

Flight attendant Richard Lam, 41, was employed by UAL on April 1970; and had completed B747 recurrent training on September 16, 1988.

Flight Attendant John Horita

Flight attendant John Horita, 44, was employed by UAL in June 1970; and had completed B747 recurrent training on November 1, 1988.

Flight Attendant Curtis Christensen

Flight attendant Curtis Christensen, 34, was initially employed by PAA in May 1978. He was subsequently employed by UAL in February 1986 when UAL purchased PAA Pacific Division. Flight attendant Chrisensen had completed B747 recurrent training on December 12, 1988.

Flight Attendant Tina Blundy

Flight attendant Tiia Blundy, 36, was employed by UAL in May 1973; and had completed B747 recurrent training on October 28, 1988.

Flight Attendant Jean Nakayama

Flight attendant Jane Nakayama, 37, was employed by UAL in August 1973; and had completed B747 recurrent training on December 6, 1988.

Flight Attendant Mae Sapolu

Flight attendant Mae Sapolu, 38, was initially employed by Pan American Airlines (PAA) in March 1973. She was subsequently employed by UAL in February 1986; when UAL purchased PAA Pacific Division. Flight attendant Sapolu completed B747 recurrent training on October 13, 1988.

Flight Attendant Robyn Nakamoto

Flight attendant Robyn Nakamoto, 26, was employed by UAL in April, 1986, and transferred to the Inflight Service Division in May, 1988. She was initially trained on the B747 in May 1988; and had not attended recurrent training.

Flight Attendant Edward Lythgoe

Flight attendant Edward Lythgoe, 37, was employed by UAL in December 1978; and had completed B747 recurrent training on October 21, 1988.

Flight Attendant Sharol Preston

Flight attendant Sharol Preston, 39, was employed by UAL in July 1970; and had completed B747 recurrent training on July 29, 1988.

Flight Attendant Ricky Umehira

Flight attendant Ricky Umehira, 35, was employed by UAL in November 1983; and had completed B747 recurrent training on November 15, 1988.

Flight Attendant Darrell Blankenship

Flight attendant Darrell Blankenship, 28, was employed by UAL in February 1984; and had completed B747 recurrent training on February 10, 1988.

Flight Attendant Linda Shirley

Flight attendant Linda Shirley, 30, was employed by UAL in March 1979; and had completed B747 recurrent training on November 3, 1989.

Flight Attendant Ilona Benoit

Flight attendant Ilona Benoit, 48, was initially employed by PAA in November 1969. She was subsequently employed by UAL in February 1986; and had completed B747 recurrent training on November 17, 1988.

Lead Ramp Serviceman Paul Engalla

Lead ramp serviceman Paul Engalla was employed by UAL in 1959. Because of his extensive ramp service experience, Mr. Engalla was selected as a ramp service trainer in 1986.

Ramp Serviceman Daniel Sato

Ramp serviceman Daniel Sato was employed by UAL in May 1987. Company records indicate that his proficiency in the opening and closing of B747 cargo doors and the operation of container loads was attained in September 1988.

Ramp Serviceman Brian Kitaoka

Ramp serviceman Brian Kitaoka was employed by UAL in November 1986. Company records indicate that his proficiency in the operation of container loaders was attained in November 1987. His proficiency in the opening and closing of B747 cargo doors was attained in October 1988.

Dispatch Mechanic Steve Hajanos

Dispatch mechanic Steve Hajanos was employed as an airplane mechanic by UAL on October 30, 1986. He holds FAA Airplane and Powerplants Certificate No. 362583850, issued November 14, 1981. He was formerly employed by Aloha Airlines as a maintenance supervisor and by World Airways as a mechanic and maintenance supervisor. He began his aviation career as an airplane mechanic in the United States Air Force.

APPENDIX C

AIRPLANE INFORMATION

Type of Inspection	Date of Inspection	Total Hours	Total Cycles	Maximum Interval
Service No. 1				
Current	02/23/89	58,814:24	15,027	Note 1
Previous	02/23/89	58,809:02	15,026	
Service No. 2				
Current	02/22/89	58,802:35	15,024	65 Hours
Previous	02/18/89	58,747:12	15,016	Note 2
A Check				
Current	02/14/89	58,710:14	15,009	350 Hours
Previous	01/16/89	58,368:57	14,947	
B Check				
Current	11/28/88	57,751:44	14,839	131 Days
Previous	07/28/88	56,635:36	14,632	
C Check				
Current	11/28/88	57,751:44	14,839	393 Days
Previous	11/19/87	53,789:00	14,146	
MPV Check				
Current	04/30/84	43,731:0	11,857	5 Years
Previous	01/30/80	30,906:0	8,638	

D Check

Current	04/30/84	43,731	19,237	9 Years
Previous	09/09/76	19,237	5,591	

Note 1: Service No. 1 to be accomplished on through flights or at trip termination whenever time is less than 12 hours per Maintenance Manual Procedures BX 12-0-l -1.

Note 2: Aircraft with layover of 12 hours or more will receive a Service No. 2 not to exceed 65 flight hours between checks.

APPENDIX D

IN JURY INFORMATION

Flight Crewmember.-The second officer sustained minor superficial brush bums to both elbows and forearms, during the evacuation.

Cabin Crewmembers.--The cabin crewmembers sustained the following injuries during the evacuation:

Plight attendant No. 1 sustained a strained left shoulder;

Flight attendant No. 2 sustained acute thoracic and lumbosacral strain;

Flight attendant No. 3 sustained a mild right bicep strain;

Flight attendant No. 4 sustained a left elbow contusion, left shoulder dislocation, and mild lumbosacral strain;

Flight attendant No. 5 sustained a left calf contusion;

Flight attendant No. 6 sustained a mild left elbow bruise:

Flight attendant No. 7 sustained mild left arm and lower back strain;

Flight attendant No. 8 sustained a soft tissue injury to the back;

Flight attendant No. 9 sustained abrasions to both palms and the left knee;

Flight attendant No. 10 sustained a fracture of the left tenth rib;

Flight attendant No. 11 sustained a minimal injury to the right middle finger PIP joint and left first MP joint;

Flight attendant No. 12 sustained. a pulled muscle on the left side of the neck;

Flight attendant **No.** 13 sustained a cornminuted fracture of the right ulna and radius:

Flight attendant No. 14 sustained a mild thoracic back strain;

Flight attendant No. 15 sustained a non-displaced fracture of C-6, a cerebral concussion, a fracture of the proximal right humerus, and multiple lacerations;

A flight attendant, flying as a passenger, sustained mild **lumbosacral** strain, a laceration of the right little fmger, and a left elbow abrasion.

Passengers.--Nine Passengers who were seated in seats **8H, 9FGH, 10GH, 11GH,** and **12H,** were ejected from the fuselage and were not found; and thus, are assumed to have been fatally injured in the accident.

Passengers seated in the indicated seats sustained the following injuries:

Seat		
7c	-	Barotraurna to both ears
9C	-	Half-inch laceration to the upper **left** arm, superficial abrasions to left arm and hand, barotrauma to both ears
9E	-	Superficial abrasions and contusions to the left hand, mild barotrauma to both ears
10B	-	Superficial abrasions to the left elbow and left middle finger
10E	-	Superficial abrasions to the torso and left forearm, bruising of the left hand and fingers
11E	-	Laceration on the right ankle tendon, multiple bruises

11F - Slight contusion of the right shoulder

13D - Barotrauma to both ears

13E - Bleeding in both ears

13H - Contusion to the left periorbital area

14A - Laceration in the parietal occipital area, barotrauma to both ears

15J - Cornminuted fracture of the lateral epicondyle of the left distal humerus (about 5mm separation)

16B - Superficial abrasions to the right arm

16J - Barotrauma to both ears

16K - Right temporal abrasions

26A - Barotrauma to both ears

26B - barotrauma to both ears

26H - Barotitis to both ears, low back pain, irritation to the right eye due to foreign bodies

27A - Barotrauma to the right ear

28J - Superficial abrasions and a contusion to the left hand, mild barotrauma to both ears

APPENDIX E

MAINTENANCE HISTORY OF N4713U

STATION	INBOUND FLT/DATE		OUTBOUND FLT/DATE		PROBLEM
HNL	830	12/5	8225	12/5	Report - forward cargo dour will not open. Corrective action: cranked door latches to close an recycled, checked okay.
HNL	824	12/6	812	12/7	Report - forward cargo door will not open electrically. Corrective action: cranked door latches to close and recycled. Checked okay.
LAX	812	12/7	811	12/7	No problem
HNL	‘811	12/7	811	12/7	No problem
AKL	811	12/7	811	12/7	No problem
SYD	811	12/7	812	12/9	No problem
AKL	812	12/9	812	12/9	Ho problem
HNL	812	12/9	812	12/9	No problem
LAX	812	12/9	811	12/9	No problem
HNL	811	12/9	811	12/9	No problem
AKL	811	12/9	811	12/9	lo problem
SYD	811	12/9	812	12/11	No problem
AKL	812	12/11	812	12/11	Report - forward cargo door failed to close fully electrically, manually cranked 'pull in' hooks half 8 turn to close and. latches ran okay. Corrective rctlon: adjusted on hook switches Deferred maintenance item 0827 initiated.
HNL	812	12/11	812	12/12	Report - door cycled 3 times, opened and closed normally. Corrective action: cleared deferred maintenance item 827
LAX	812	12/12	811	12/12	No problem
HNL	811	12/12	811	12/12	no problem
AKL	811	12/12	811	12/12	Report - forward cargo door fails to close ● lectrk8lly. Manually turned hooks to close with door switch selected close until power transferred to latch motor. Hook motor switch requires re-rigging. Corrective action: Deferred maintenance item 831 initiated.

STATION		INBOUND FLT/DATE	OUTBOUND FLT/DATE	PROBLEM
SYD		811 12/12	812 12/14	Report - forward cargo door will not latch electrically. When manually closing, latches fail to close sufficiently to close master latch lock after repeated attempts. Comctlw action: latches opened manually, door recycled again and operation was normal electrically. (Deferred maintenance item 0831 continued open for future repair.)
AKL		812 12114	812 12/14	Report - when the aircraft landed, the door operated like the deferred write up. The aft lower corner of the door appears to be trailing. Suspect tht hook motor may bt over-heating causing the problem. Note: adjusted S-8 door switch, the door operates okay. The adjustment stop for S-8 is bent. Corrective action: (Deferred maintenance Item 0831 continued open far future repair.)
HNL		812 12/14	812 12/14	Manual operation
LAX		812 12/14	811 12/14	Manual operation
HNL		811 12/14	811 12/14	Manual operation
HNL	(layover)	811 12/14 (Ret blks)	825 12116	Manual operation
OSA		825 12/16	824 12/17	Manual operation
HNL		824 12/17	831 12/17	Report .a necessary to cycle door 3 times to get It to latch manually. Corrective action: deferred maintenance item 0831 continued open for future repair.
NRT		831 12/17	831 12/17	Manual operation
HKG	(layover)	831 12/17	830 12/19	Report - deferred maintenance item 0831. Corrective action: replaced hook position relay K1. Checked door several times. It checked okay.● &feWed maintenance item 0831 corrected.
NRT		830 12/19	58 12/19	No problem

FORWARD CARGO DOOR
HISTORY - 12/1/88 THROUGH 2/22/89

STATION		INBOUND FLT/DATE		OUTBDUND FLT/DATE		PROBLEM
SFO		58	12/19	53	12/19	No problem
NRT		53	12/19	830	12/20	No problem
HNL		830	12/20	827	12/20	No problem
NRT		827	12/20	801	12/20	No problem
TPE	(layover)	801	12/20	800	12/22	no problem
NRT		800	12/22	150	12/22	Report - prior to departure, forward cargo door inoperative electrically. Manually closed. Corrective action: deferred . maintenance item 0835 initiated for future repair.
SEA		150	12/22	150	12/22	Manual operation
ORD	(layover)	150	12/22	143	12/23	Report - dtftmd maintenance item 0835. Corrective action: operated door several times, could not duplicttt. Checked hook closed switch & hook positi switch for being closed per MM-52-34-60 procedure 13. Defer maintenance item 0835 corrected
SEA		143	12/23	143	12/23	No problem
NRT		143	12/23	150	12/24	lo problem
SEA		150	12/24	150	12/24	No problem
ORD	(layover)	150	12/24	1	12/25	No problem
HNL	(layover)	1	12/25	812	12125	No problem
LAX		812	12/26	811	12/26	No problem
HNL		811	12/26	811	12/26	No problem
AKL		811	W26	611	12/26	No problem
SYD		811	12/26	812	12/28	No problem
AKL		812	12/28	612	12/28	No problem
HNL		812	12/28	812	W28	No problem
LAX		812	12/28	811	12/28	lb problem
HNL		611	12/28	611	W28	No problem
AKL		811	12/28	611	12/28	No problem
SYD		811	12/28	812	12/30	No problem
AKL		812	12/30	812	12/30	No problem

Figure 1.--Overall view of forward cargo door area
on the right side of the aircraft.

Figure 2.--Close-up view of hole and surrounding structure damage.


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