04/28/88 Aloha Airlines

Official Accident Report Index Page

Report Number	NTSB/AAR-89/03
Access Number	PB89-91C404
Report Title	Aircraft Accident Report--Aloha Airlines, Flight 243, Boeing 737-200, N73711, near Maui, Hawaii, April 28, 1988
Report Date	June 14, 1989
Organization Name	National Transportation Safety Board Bureau of Accident Investigation Washington, D.C. 20594
WUN	4886A
Sponsor Name	NATIONAL TRANSPORTATION SAFETY BOARD Washington, D.C. 20594
Report Type	Aircraft Accident Report April 28, 1988
Distribution Status	This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161
Report Class	UNCLASSIFIED
Pg Class	UNCLASSIFIED
Pages	262
Keywords	decompression; disbonding; fatigue cracking; corrosion; multiple site damage (MSD); FAA surveillance; maintenance program; nondestructive inspection
Abstract	On April 28, 1988, at 1346, a Boeing 737-200, N73711, operated by Aloha Airlines Inc., as flight 243, experienced an explosive decompression and structural failure at 24,000 feet, while en route from Hilo, to Honolulu, Hawaii. Approximately 18 feet of the cabin skin and structure aft of the cabin entrance door and above the passenger floorline separated from the airplane during flight. There were 89 passengers and 6 crewmembers on board. One flight attendant was swept overboard during the decompression and is presumed to have been fatally injured; 7 passengers and 1 flight attendant received serious injuries. The flightcrew performed an emergency descent and landing at Kahului Airport on the Island of Maui. The safety issues raised in this report include: the quality of air carrier maintenance programs and the FAA surveillance of those programs, the engineering airworthiness of the B-737 with particular emphasis on multiple site fatigue cracking of the fuselage lap joints, the human factors aspects of air carrier maintenance and inspection for the continuing airworthiness of transport category airplanes, to include repair procedures and the training, certification and qualification of mechanics and inspectors.

Facts of the Accident

Accident NTSB ID	89-03
Airline	Aloha Airlines
Model aircraft	737-200, N73711
Year shipped	1969
Aircraft manufacturer	Boeing
Engine type	JT8D-9A
Engine manuafacturer	Pratt & Whitney
Date	04/28/88
Time	1346
Location	Near Maui, Hawaii
Country	USA
IFR or VFR?	VFR
Fatalities	1
Injuries	8
Fire during flight?	N
Fire on the ground?	N
Probable cause	Failure of the Aloha Airlines maintenance program to detect the presence of significant disbonding and fatigue damage which ultimately led to failure of the lap joint at S-10L and the separation of the fuselage upper lobe.
Contributing causes	The failure of Aloha Airlines management to supervise properly its maintenance force; the failure of the FAA to evaluate properly the Aloha Airlines maintenance program and to assess the airline's inspection and quality control deficiencies; the failure of the FAA to require Airworthiness Directive 87-21-08 inspection of all the lap joints proposed by Boeing Alert Service Bulletin SB 737-53A1039; and the lack of a complete terminating action (neither generated by Boeing nor required by the FAA) after the discovery of early production difficulties in the B-737 cold bond lap joint which resulted in low bond durability, corrosion, and premature fatigue cracking.
Weather conditions	No significant adverse weather experienced
Total crew size	5
Cockpit crew size	2
Cabin crew size	3
Passengers	90
Report ID	NTSB/AAR-89/03
Pages	262
Day or night?	Day

Flight number	243
Flight origin	Hilo, Hawaii
Flight destination	Honolulu, Hawaii
Description	Aloha flight 243 experienced an explosive decompression and structural failure at 24,000 feet. Approziately 18 feet of cabin skin and structure above the passenger floorline separated from the airplane during flight. One flight attendant was swept overboard and presumed dead. The flightcrew performed an emergency descent and landing at Maui.

Executive Summary

On April 28, 1988, at 1346, a Boeing 737-200, N73711, operated by Aloha Airlines Inc., as flight 243, experienced an explosive decompression and structural failure at 24,000 feet, while en route from Hilo, to Honolulu, Hawaii. Approximately 18 feet from the cabin skin and structure aft of the cabin entrance door and above the passenger floorline separated from the airplane during flight. There were 89 passengers and 6 crewmembers on board. One flight attendant was swept overboard during the decompression and is presumed to have been fatally injured; 7 passengers and 1 flight attendant received serious injuries. The flight crew performed an emergency descent and landing at Kahului Airport on the Island of Maui.

The National Transportation Safety Board determines that the probable cause of this accident was the failure of the Aloha Airlines maintenance program to detect the presence of significant disbonding and fatigue damage which ultimately led to failure of the lap joint at S-10L and the separation of the fuselage upper lobe. Contributing to the accident were the failure of Aloha Airlines management to supervise properly its maintenance force; the failure of the FAA to evaluate properly the Aloha Airlines maintenace program and to assess the airline's inspection and quality control deficiencies; the failure of the FAA to require Airworthiness Directive 87-21-08 inspection of all the lap joints proposed by Boeing Alert Service Bulletin SB 737-53A1039; and the lack of a complete terminating action (neither generated by Boeing nor required by the FAA) after the discovery of early production difficulties in the B-737 cold bond lap joint which resulted in low bond durability, corrosion, and premature fatigue cracking.

The safety issues raised in this report include:

· The quality of air carrier maintenance programs and the FAA surveillance of those programs.

· The engineering design, certification, and continuing airworthiness of the B-737 with particular emphasis on multiple site fatigue cracking of the fuselage lap joints.

· The human factors aspects of air carrier maintenance and inspection for the continuing airworthiness of transport category airplanes, to include repair procedures and the training, certification and qualification of mechanics and inspectors.

Recommendations concerning these issues were addressed to the Federal Aviation Administration, Aloha Airlines, and the Air Transport Association.

1. Factual Information

1.1 History of the Flight

On April 28, 1988, an Aloha Airlines Boeing 737, N73711, based at the Honolulu International Airport, Hawaii, was scheduled for a series of interisland flights to be conducted under Title 14 Code of Federal Regulations (CFR) Part 121. A captain and first officer were assigned for the first six flights of the day with a planned first officer change to complete the remainder of the daily schedule.

The first officer checked in with the dispatch office about 0500 Hawaiian standard time at the Aloha Airlines Operations Facility. After familiarizing himself with the flight operations paperwork, he proceeded to the Aloha Airlines parking apron and performed the preflight inspection required by company procedures before the first flight of the day. He stated that the airplane maintenance log release was signed and that there were no open discrepancies. He prepared the cockpit for the external portion of the preflight, exited the airplane in predawn darkness, and performed the visual exterior inspection on the lighted apron. He stated that he found nothing unusual and was satisfied that the airplane was ready for flight.

The captain checked in for duty about 0510; he completed his predeparture duties in the dispatch office and then proceeded to the airplane.

The crew flew three roundtrip flights, one each from Honolulu to Hilo, Maui, and Kauai. They reported that all six flights were uneventful and that all airplane systems performed in the normal and expected manner. Flightcrew visual exterior inspections between flights were not required by Federal Aviation Administration (FAA) accepted company procedures, and none were performed.

At 1100, a scheduled first officer change took place for the remainder of the day. The crew flew from Honolulu to Maui and then from Maui to Hilo. As with the previous flights of the day, no system, powerplant, or structural abnormalities were noted during these operations, and the flights were uneventful. Neither pilot left the airplane on arrival in Hilo, and the crew did not perform any visual exterior inspection nor were they required to do so.

At 1325, flight 243 departed Hilo Airport en route to Honolulu as part of the normal scheduled service. In addition to the two pilots, there were three flight attendants, an FAA air traffic controller, who was seated in the observer seat in the cockpit, and 89 passengers on board. Passenger boarding, engine start, taxi, and takeoff were uneventful.

The planned routing for Aloha flight 243 was from Hilo to Honolulu at flight level 240. Maui was listed as the alternate landing airport.

The first officer conducted the takeoff and en route climb from Hilo. The captain performed the nonflying pilot duties. The first officer did not recall using the autopilot.

The flight was conducted in visual meteorological conditions. There were no advisories for significant meteorological information (SIGMET) or airman's meteorological information (AIRMET) valid for the area along the planned route of flight.

No unusual occurrences were noted by either crewmember during the departure and climbout. As the airplane leveled at 24,000 feet, both pilots heard a loud "clap" or "whooshing" sound followed by a wind noise behind them. The first officer's head was jerked backward, and she stated that debris, including pieces of gray insulation, was floating in the cockpit. The captain observed that the cockpit entry door was missing and that "there was blue sky where the first-class ceiling had been." The captain immediately took over the controls of the airplane. He described the airplane attitude as rolling slightly left and right and that the flight controls felt "loose."

Because of the decompression, both pilots and the air traffic controller in the observer seat donned their oxygen masks. The captain began an emergency descent. He stated that he extended the speed brakes and descended at an indicated airspeed (IAS) of 280 to 290 knots. Because of ambient noise, the pilots initially used hand signals to communicate. The first officer stated that she observed a rate of descent of 4,100 feet per minute at some point during the emergency descent. The captain also stated that he actuated the passenger oxygen switch. The passenger oxygen manual tee handle was not actuated.

When the decompression occurred, all the passengers were seated and the seat belt sign was illuminated. The No. 1 flight attendant reportedly was standing at seat row 5. According to passenger observations, the flight attendant was immediately swept out of the cabin through a hole in the left side of the fuselage. The No. 2 flight attendant, standing by row 15/16, was thrown to the floor and sustained minor bruises. She was subsequently able to crawl up and down the aisle to render assistance and calm the passengers. The No. 3 flight attendant, standing at row 2, was struck in the head by debris and thrown to the floor. She suffered serious injuries including a concussion and severe head lacerations.

The first officer said she tuned the transponder to emergency code 7700 and attempted to notify Honolulu Air Route Traffic Control Center (ARTCC) that the flight was diverting to Maui. Because of the cockpit noise level, she could not hear any radio transmissions, and she was not sure if the Honolulu ARTCC heard the communication.

Although Honolulu ARTCC did not receive the first officer's initial communication, the controller working flight 243 observed an emergency code 7700 transponder return about 23 nautical miles (nmi) south-southeast of the Kahalui Airport, Maui. Starting at 1348:15, the controller attempted to communicate with the flight several times without success.

When the airplane descended through 14,000 feet, the first officer switched the radio to the Maui Tower frequency. At 1348:35, she informed the tower of the rapid decompression, declared an emergency, and stated the need for emergency equipment. Maui Tower acknowledged and began emergency notifications based on the first officer's report of decompression.

At the local controller's direction, the specialist working the Maui Tower clearance delivery position notified the airport's rescue and firefighting personnel, via the direct hot line, that a B-737 had declared an emergency, was inbound and that the nature of the emergency was a decompression. Rescue vehicles took up alert positions along the left side of the runway.

At the Maui Airport, ambulance service was available from the nearby community when notified by control tower personnel through the local "911" telephone number. Tower personnel did not consider it necessary at that time to call for an ambulance based on their understanding of the nature of the emergency.

At 1349:00, emergency coordination began between Honolulu Center and Maui Approach Control. Honolulu advised Maui Approach Control that they had received an emergency code 7700 transponder return that could be an Aloha 737 and stated, "You might be prepared in case he heads your way." Maui Approach Control then advised Honolulu Center that flight 243 was diverting to land at Maui.

The local controller instructed flight 243 to change to the Maui Sector transponder code to identify the flight and indicate to surrounding air traffic control (ATC) facilities that the flight was being handled by the Maui ATC facility. The first officer changed the transponder as requested.

The flight was operating beyond the local controller's area of radar authority of about 13 nmi. At 1350:58, the local controller requested the flight to switch to 119.5 MHz. (approach frequency) so that the approach controller could monitor the flight. Although the request was acknowledged, the flight was not heard on 119.5 MHz. Flight 243 continued to transmit on the local controller frequency.

At 1353:44, the first officer informed the local controller, "We're going to need assistance. We cannot communicate with the flight attendants. We'll need assistance for the passengers when we land." An ambulance request was not initiated as a result of this radio call. The first officer also provided the local controller with the flight's passenger count, but she did not indicate the fuel load. The local controller did not repeat the request for the fuel load even after a query from the chief of the emergency response team.

The captain stated that he began slowing the airplane as the flight approached 10,000 feet mean sea level (msl). This maneuver is required as a routine operations practice to comply with ATC speed limitations. He retracted the speed brakes, removed his oxygen mask, and began a gradual turn toward Maui's runway 02. At 210 knots IAS, the flightcrew could communicate verbally. The captain gave the command to lower the flaps. Initially flaps 1 were selected, then flaps 5. When attempting to extend beyond flaps 5, the airplane became less controllable, and the captain decided to return to flaps 5 for the landing.

Because the captain found the airplane becoming less controllable below 170 knots IAS, he elected to use 170 knots IAS for the approach and landing.

Using the public address (PA) system and on-board interphone, the first officer attempted to communicate with the flight attendants; however, there was no response.

At the command of the captain, the first officer lowered the landing gear at the normal point in the approach pattern. The main gear indicated down and locked; however, the nose gear position indicator light did not illuminate. Manual nose gear extension was selected and still the green indicator light did not illuminate; however, the red landing gear unsafe indicator light was not illuminated. After another manual attempt, the handle was placed down to complete the manual gear extension procedure. The captain said no attempt was made to use the nose gear downlock viewer because the center jumpseat was occupied and the captain believed it was urgent to land the airplane immediately.

At 1355:05, the first officer advised the tower, "We won't have a nose gear," and at 1356:14, the crew advised the tower, "We'll need all the equipment you've got."

While advancing the power levers to maneuver for the approach, the captain sensed a yawing motion and determined that the No. 1 (left) engine had failed. At 170 to 200 knots IAS, he placed the No. 1 engine start switch to the "flight" position in an attempt to start the engine; there was no response.

A normal descent profile was established 4 miles out on the final approach. The captain said that the airplane was "shaking a little, rocking slightly and felt springy."

Flight 243 landed on runway 02 at Maui's Kahului Airport at 1358:45. The captain said that he was able to make a normal touchdown and landing rollout. He used the No. 2 engine thrust reverser and brakes to stop the airplane. During the latter part of the rollout, the flaps were extended to 40° as required for an evacuation. An emergency evacuation was then accomplished on the runway.

After the accident, a passenger stated that as she was boarding the airplane through the jet bridge at Hilo, she observed a longitudinal fuselage crack. The crack was in the upper row of rivets along the S-10L lap joint, about halfway between the cabin door and the edge of the jet bridge hood. She made no mention of the observation to the airline ground personnel or flightcrew.

1.2 Injuries to Persons

Injuries	Crew	Passengers	Others	Total
Fatal	1*	0	0	1*
Serious	1	7	0	8
Minor	0	57	0	57
None	3	25	1**	29
Total	5	89	1	95

*Lost in flight; a sea search was unsuccessful.

**Air traffic controller seated in the observer seat in the cockpit.

1.3 Damage to Airplane

1.3.1 General

A major portion of the upper crown skin and structure of section 43 separated in flight causing an explosive decompression1 of the cabin. (See figure 1 and figure 2.) The damaged area extended from slightly aft of the main cabin entrance door, rearward about 18 feet to the area just forward of the wings and from the left side of the cabin at the floor level to the right side window level.

The value of the airplane was estimated at about $5 million. As a result of the accident, the airplane was determined to be damaged beyond repair. It was dismantled on the site and sold for parts and scrap.

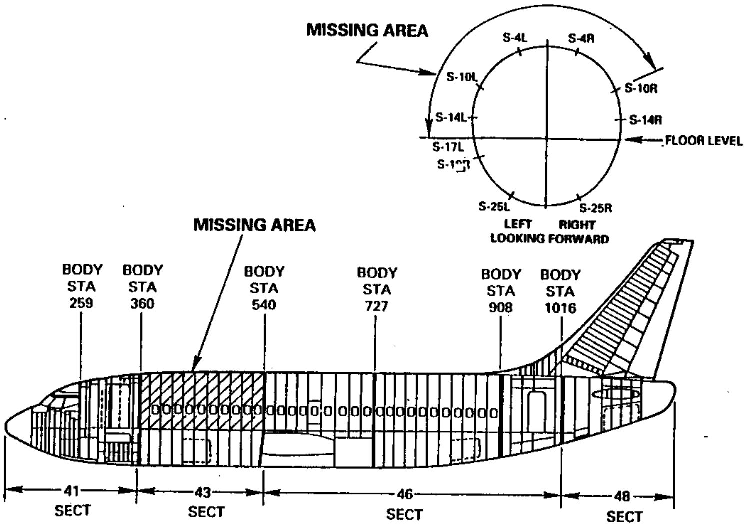

Figure 1.--Boeing 737-200--Body Stations, Stringers, and Section Locations.

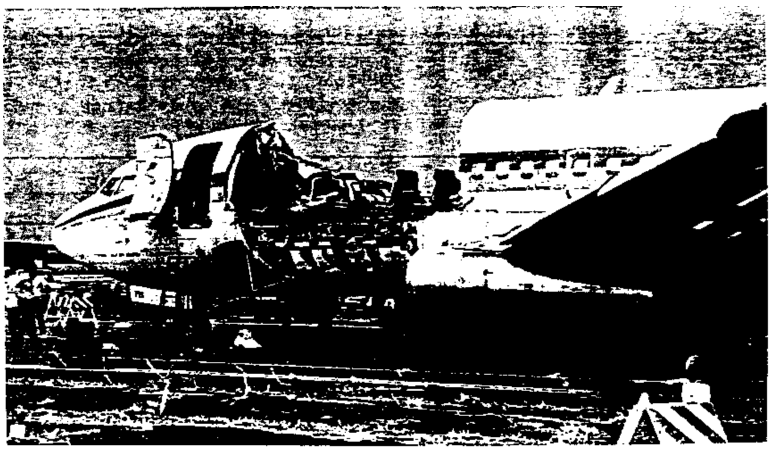

Figure 2a.--General view, left side of forward fuselage, N73711

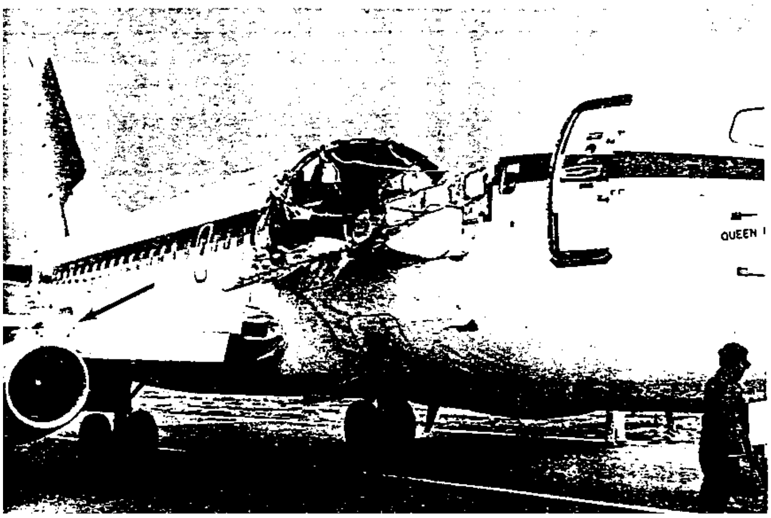

Figure 2b.--General view, right side of forward fuselage, N73711. Arrow marks fragments of S-4R lodged in the leading edge flap.

1.3.2 Fuselage Separation Area

The fuselage structure consists primarily of skin, frames,2 and stringers.3 Skin panels are joined longitudinally at lap joints where the sheet metal of the upper skin panel overlaps the sheet metal of the lower skin panel about 3 inches. When manufactured, this overlapped area was bonded and riveted with three rows of countersunk rivets. (See 1.6.2 Lap Joint Design and Bonding History.)

The area where the structure was missing extended from body station4 (BS) 360 aft to about BS 540, and circumferentially from just above the floor on the left side of the airplane (at S-15L), across the crown and down the right side to a position above the window belt (at S-10R). The structure from the top of the window belt to the floor on the right side was distorted severely and bent outward more than 90°. The skin had peeled in this area leaving the frames, stringers, and window forgings in place. On the left side below the floor level, the skin had peeled off the structure in large V-shaped areas.

Five consecutive floor beams5 at BS 420, 440, 460, 480, and 500 were broken all the way through. Also, the adjacent floor beams at BS 400 and 500A were cracked nearly all the way through. The fractures and cracks were slightly to the left of the airplane centerline. The frames at these same seven stations were broken on the left side just below the floor beams. Most of the center floor panels from BS 360 to BS 947 were displaced upward except in the overwing area. The right side cabin floor panels had not been displaced and little if any distress had occurred at the fastener locations for these panels. However, on the left side of the airplane between BS 400 and BS 500 along the inboard seat track, there was extensive floor panel displacement. The floor panels had displaced upward and had reached their maximum displacement of 4 inches at BS 440 (matching the displacement of the broken floor beams).

A fuselage section from BS 365 to BS 420 between S-4R and S-8R was trapped between the leading edge flap and inboard side of the right engine strut. This was the only significant piece of structure from the damaged area that was recovered. The recovered piece contained two skin repairs along S-4R. This section and several samples cut from the remaining fuselage skin were submitted to the Safety Board's Materials Laboratory for further analysis. (See 1.16.3 Materials Laboratory Analysis.)

An examination of the remaining structure immediately surrounding the separation area, including skin, rivet, and stringer deformations, revealed the following failure patterns:

- Left side, BS 360 to 540--The skin was peeled from the structure in a down and aft direction.

- Right side, BS 360 to 540--The skin was peeled from the structure in a down and aft direction, changing to directly aft near BS 540.

- Circumferential break at BS 360--Fracture of the stringers and deformed rivets indicated that the separated structure was pulled generally aft except between S-5L and S-4R, where the direction was about 30° to the right of directly aft. Fractures and deformations showed that the separated skin had generally pulled through the butt joint rivets, except at several locations where the separation was in the butt splice strap.

- Circumferential break at BS 540, left side--From the top center of the fuselage to S-10L, the skin fracture transitioned from several inches forward of BS 540 to about 20 inches forward of BS 540 and was not associated with any rivet line. At the S-10L lap joint, the fracture followed the upper rivet line of the skin lap joint from a position 20 inches forward of BS 540 to a position about 6 inches forward of BS 540. There were indications of preexisting fatigue cracks associated with seven consecutive rivet holes along this portion of the rivet line. From S-10L to the floor line, the skin generally had separated several inches forward of station 540.

- Circumferential break at BS 540, right side--From the top center of the fuselage to S-10R the fractures in the stringers and deformed rivets indicated that the separated structure was pulled directly forward. In the vicinity of S-11R, a small area of structure had been pulled forward and up. Below S-11R, the skin had been torn but the departure direction was unclear.

Indications of preexisting cracks were found in the S-10L lap joint forward of BS 540, on each side of a rivet hole in the BS 360 butt strap near S-7R, and in lap joint rivet holes in a piece recovered from the right wing. All other fractures adjacent to the separation area were typical of overstress separations.

The fracture surfaces and the immediate areas surrounding the separation perimeter generally were corrosion free. However, areas of corrosion and disbonded surfaces6 were noted in the butt joints at BS 360 and 540. Additionally, some areas of bulged skin were noted on the intact skin lap joints and circumferential butt joints that remained with the airplane.

1.3.3 Additional Airplane Damage

There was minor impact damage on the leading edges of both wings, although the damage was more extensive on the right wing. In addition, both horizontal stabilizers and the lower portion of the vertical stabilizer had random dents in the leading edges.

The inlet cowls of both engines were dented, and several first stage fan blades of both engines were damaged. Remnants of fuselage structure were found against the inlet guide vanes and embedded in the acoustic liner of the right engine.

A cable in the closed loop cable system for the left engine thrust lever and a cable in the left engine start lever system were broken near a pulley cluster located in the leading edge of the left wing immediately inboard of the engine strut. The broken start lever cable prevented motion of the fuel control to the start position; the broken thrust lever cable prevented any power increase on the engine. The left engine fuel control was found in the "cutoff" position. Initial examination of the broken cables showed signs of heavy corrosion in the area of the separation. Routing of these cables between the cockpit and the left engine pod was traced through the area of maximum upward floor defection at BS 440 under the cabin floor. The cables were retained and submitted to the Safety Board's Materials Laboratory for further examination. (See 1.16.3 Materials Laboratory Analysis.)

The upper fuselage crown separation resulted in damage to overhead wire bundles, and a number of circuit breakers in the cockpit were tripped. Most of these circuit breakers were related to passenger service unit and lavatory wiring. The potable water line was leaking and its conduit was broken. The pitot line and the static line to the flight data recorder (FDR) were broken, as was the conditioned air distribution ducting. The passenger oxygen manifold was severed which prevented use of the passenger oxygen system; however, the flightcrew oxygen system was undamaged. The flightcrew and passenger oxygen cylinders were fully discharged. Both engine fire bottles were empty, and both of the engine fire extinguisher switches in the cockpit had been activated, per the airplane emergency evacuation procedures.

The hydraulic system was not damaged. All the landing gear were down and locked, the flaps and leading edge devices were fully extended, the spoilers were retracted, and there was no loss of hydraulic fluid. An examination of the nose gear position indicator light module revealed that one of the two bulbs was burned out and that the module was slightly loose in its housing. No other discrepancies were found in the nose gear position indicating system.

1.3.4 Pressurization System

The main (aft) outflow valve and the forward outflow valve were fully closed. The forward outflow valve receives position signals from the main outflow valve. The pressurization controller was found in "automatic" and the flight/ground mode selector switch was found in the "flight" position. The flight position causes the cabin altitude controller to conform to the selected flight profile and also to modulate the main outflow valve toward the closed position to pressurize the cabin slightly (0.1 psi) during ground operation. The switch is normally set to flight after engine start to pressurize the airplane; the switch is set to "ground" to depressurize after the landing rollout.

Continuity checks showed normal system operation. All relevant system components were removed from the airplane for further functional tests. (See 1.16.1 Pressurization System.)

1.4 Other Damage

None.

1.5 Personnel Information

The flightcrew consisted of the captain, first officer, and three flight attendants. (See appendix B.)

The captain was hired by Aloha Airlines on May 31, 1977, as a B-737 first officer. he was upgraded to captain on June 1, 1987. He possessed a current first-class medical certificate with no limitations. He held an airline transport certificate with a type rating for the B-737. At the time of the accident, the captain had accrued about 8,500 total flight hours with 6,700 hours in the B-737. His pilot-in-command time with Aloha Airlines was 400 hours, all in the B-737.

The first officer was hired by Aloha Airlines on June 4, 1979, as a B-737 first officer. She possessed a current first-class medical certificate with a limitation for corrective lenses. She holds an airline transport certificate without type ratings. At the time of the accident, the first officer had accrued about 8,000 total flying hours with about 3,500 hours in the B-737.

A dispatch records review indicated that the crew had complied with all relevant flightcrew duty time limitations.

Flightcrew training records included documentation of normal and emergency procedures training. The Aloha Airlines flightcrew training program outline required emphasis on cockpit resource management (CRM) concepts; however, the training program did not include a specific CRM course, and line oriented flight training (LOFT) programs were not conducted, nor were they required by regulation.

1.6 Airplane Information

1.6.1 General

The accident airplane, N73711, a Boeing 737-297, serial number 20209, was manufactured in 1969 as production line number 152. It was equipped with two Pratt and Whitney JT8D-9A engines. The airplane was delivered on May 10, 1969, to Aloha Airlines, the original operator.

According to the limitations section of the FAA-approved Airplane Flight Manual for B-737, N73711, the maximum zero fuel weight is 88,000 pounds, the maximum certificated takeoff weight is 100,000 pounds. The actual weights for the departure on the accident flight were calculated at 80,253 pounds zero fuel weight and 93,133 pounds actual takeoff weight. The center of gravity (CG) computed for departure was 22 percent mean aerodynamic chord (MAC). The calculated CG limits for this gross weight were 4.0 percent and 30.5 percent MAC, respectively.

The Aloha Airlines fleet consisted of eleven airplanes, all B-737s. Four of the airplanes were considered high time, in excess of 60,000 cycles; one was the worldwide fleet leader.

At the time of the accident, the N73711 had accumulated 35,496 flight hours and 89,680 flight cycles (landings), the second highest number of cycles in the worldwide B-737 fleet. Due to the short distance between destinations on some Aloha Airlines routes, the maximum pressure differential of 7.5 psi was not reached on every flight. Therefore, the number of equivalent full pressurization cycles on the accident airplane is significantly less than the 89,680 cycles accumulated on the airplane.

A review of B-737 accidents and incidents reported to the Safety Board revealed one previous mishap involving N73711. On February 21, 1979, the airplane was operated into clear air turbulence that resulted in serious injury to two flight attendants. No record of any damage or required repair to the airplane was found.

There had been one previous accident involving in-flight structural failure of a B-737 fuselage. A Far Eastern Air Transport, Ltd. (FEAT) B-737-200, Republic of China registration B-2603, experienced and explosive decompression and in-flight breakup on August 22, 1981.[7] The accident occurred near Sanyi, Miaoli, Taiwan, and was investigated by the Civil Aeronautics Administration (CAA) of the Ministry of Communications, Taiwan, Republic of China. The Safety Board, Boeing, and the FAA participated in the investigation. The Republic of China CAA determined that the probable cause of the accident was:

extensive corrosion damage in the lower fuselage structures, and at a number of locations there were corrosion penetrated through pits, holes and cracks due to intergranular corrosion and skin thinning exfoliation corrosion, and in addition, the possible existence of undetected cracks because of the great number of pressurization cycles of the aircraft (a total of 33,313 landings), interaction of these defects and the damage had so deteriorated that rapid fracture occurred at a certain flight altitude and pressure differential resulting rapid decompression and sudden break of passenger compartment floor beams and connecting frames, cutting control cables and electrical wiring. And eventually loss of power, loss of control, midair disintegration.[8]

Questions arose during the Aloha Airlines accident investigation regarding certain information in the CAA report about cabin floor beam bending that suggested that the initial failure may have been in the upper lobe of the fuselage as opposed to the lower lobe as cited by the CAA. Testimony of Boeing and FAA experts at the Safety Board's public hearing (See appendix A.) on the Aloha Airlines accident revealed that the evidence cited in the CAA report was consistent with an initial failure in the lower lobe of the FEAT airplane.

A review of N73711's discrepancy logbook, the flight attendant cabin log, the line maintenance activity log, and the dispatch logs for the day of the accident revealed no significant entries prior to the accident.

1.6.2 Lap Joint Design and Bonding History

The B-737 fuselage is divided into four sections with sections 41, 43, and 46 comprising the majority of the pressure vessel.(See figure 1.) These sections, along with section 48, are butt joined at circumferential frames to form the entire fuselage. Section 43 forms the forward cabin area from BS 360 to BS 540, where the area of skin separation occurred. The sections are constructed of circumferential frames and longitudinal stringers that are covered by formed aluminum skin panels that are riveted to the underlying structure. Each skin panel in the upper lobe of section 43 is the length of the entire section -- about 18 feet.

Adjacent skin panels are joined longitudinally by overlapping the edge of the upper panel about 3 inches over the edge of the lower panel. The overlap (joint) area is fastened with three rows of rivets and a bonding process. The center row of rivets secures the lap joint to a stringer underneath the skin, which, in turn, is attached to the circumferential frames by riveted clips. Below the window belt and in the lower lobe, the skin is connected to the frames between the stringers using riveted L-shaped brackets (shear ties). In section 43, the skin panel lap joints exist at S-4L and S-4R, S-10L and S-10R, and S-14L and S-14R in the upper lobe and at S-19L and S-19R and S-26L and S-26R in the lower lobe.

The upper lobe skin panels in section 43 are fabricated from two complete preformed sheets of 0.036-inch thick aluminum that are joined together using a "hot" bonding process. An acid etch is used to prepare the surfaces of the sheets before bonding. Since the epoxy hot bonding material is nonreactive at room temperature, the bond is cured at 250°F at 45 psi (hot-bond process). The inner sheet is then masked and the panel is milled chemically leaving the "waffle" doublers that provides circumferential tear straps at 10-inch intervals and a longitudinal double thickness at each stringer location.

On the early model airplanes (through production line number 291), the doubler sheet was milled away chemically at the lap joint locations; for production line number 292 and the subsequent numbers, the doubler sheet was retained on the outer panel of each lap joint to provide an extra 0.036 inch of material thickness in the joint.(See figures 3, 4a and 4b.) Additionally, for production line number 465 and the subsequent numbers, an improved bond surface pretreat process using a phosphoric acid anodize was employed.

For B-737 production line numbers 1 through 291, the fuselage skin lap joints were "cold" bonded. A cold-bonded process used an epoxy impregnated woven "scrim" cloth to join the longitudinal edges of the single thickness 0.036-inch skin panels together. In addition, the joint was mechanically assembled with three rows of countersunk rivets. The metal surfaces to be bonded were etched to ensure cleanliness and to prepare a suitable bonding surface. Since the epoxy "cold" bond material was reactive at room temperature, it was stored in rolls at dry ice temperature until shortly before its use. It was then allowed to warm to room temperature before installation. This bond cured at room temperature after assembly.

The cold bonding process was intended to provide structural efficiency and manufacturing cost advantages plus overall airplane weight reduction over traditionally riveted thick skin panels. Fuselage hoop loads (circumferential pressurization loads) were intended to be transferred through the bonded joint, rather than through the rivets, allowing the use of lighter, thinner fuselage skin panels with no degradation in fatigue life. Laboratory "coupon" tests[9] of the bonded joints, as well as the "quonset hut"[10] full scale fuselage section fatigue test were performed by the Boeing Company and were used to assess cold bond durability. According to Boeing, the results indicated that certification requirements were met.

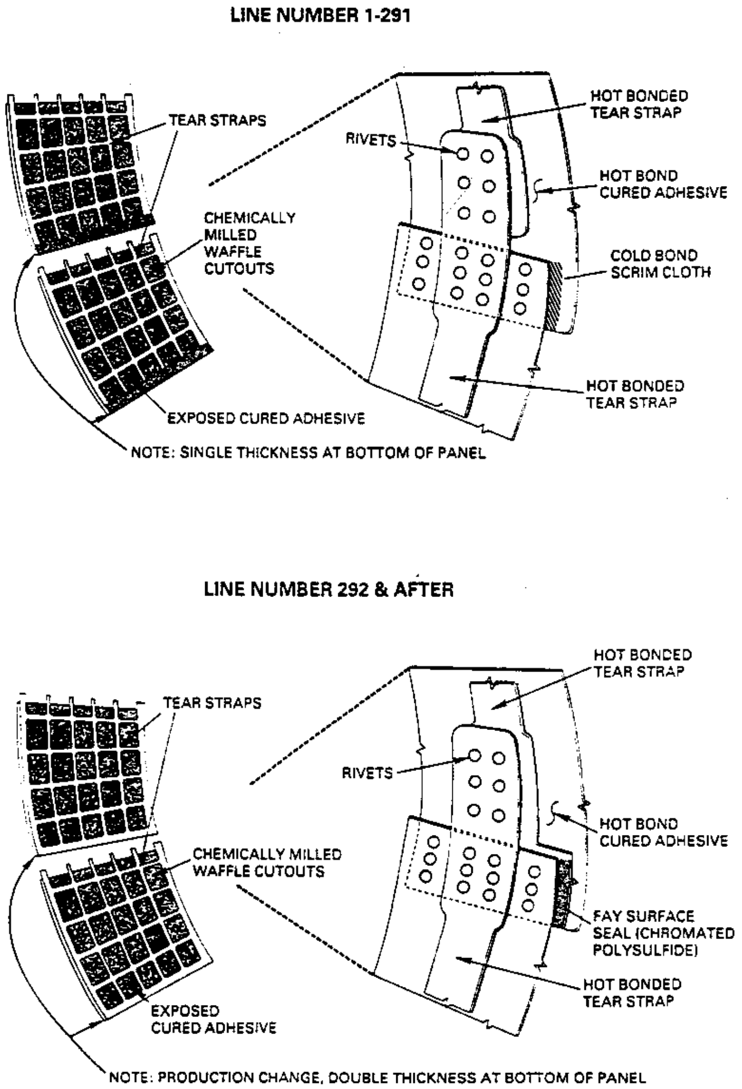

Figure 3.--B-737 Lap splice configuration

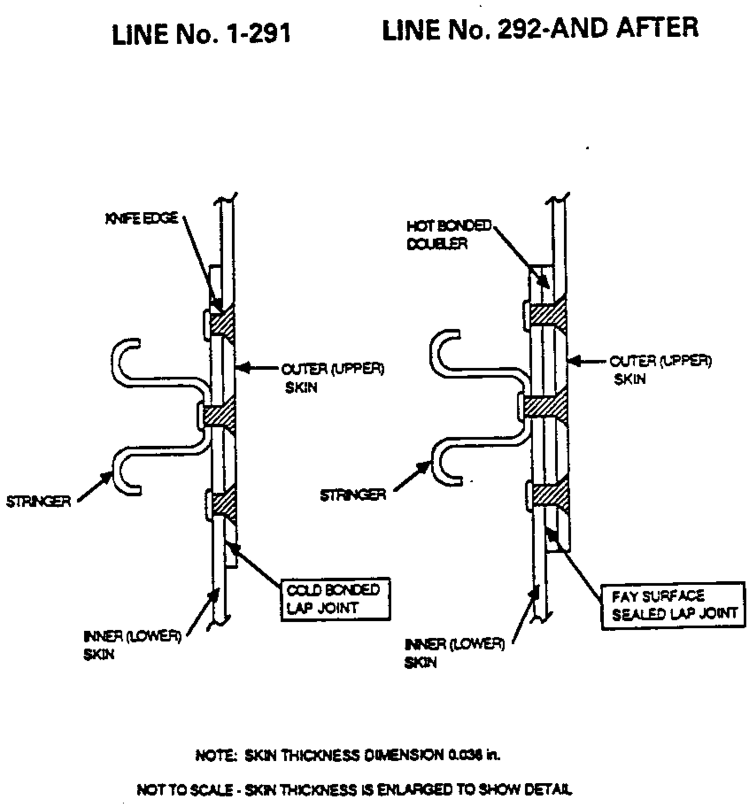

Figure 4a.--Lap joint section between tearstraps

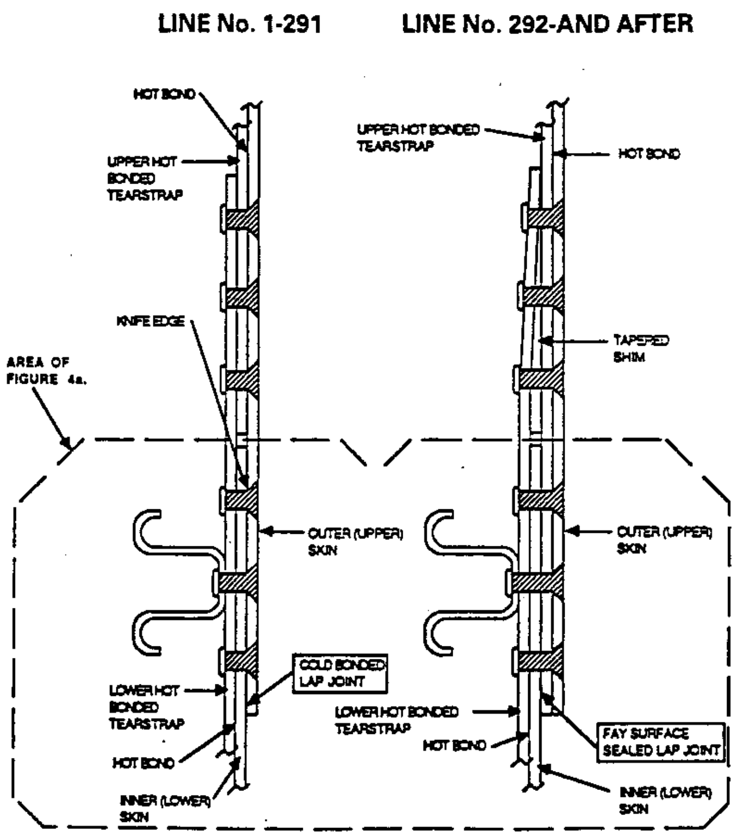

Figure 4b.--Lap joint section at tearstraps

The early service history of production B-737 airplanes with cold-bonded lap joints (plus B-727 and B-747 airplanes with the same construction technique) revealed that difficulties were encountered with this bonding process. It was found that the cleaning and etching process used on the skin panels had not provided a consistent quality thin surface oxide to be used as a bonding surface.

The service history compiled by Boeing has shown that bond quality can also be degraded if condensation is not removed from the scrim cloth before installation or if the scrim cloth sits at room temperature too long causing it to cure prematurely. According to Boeing engineers, these production process difficulties resulted in the random appearance of bonds with low environmental durability, with susceptiblity to corrosion, and with some areas of the lap joints that did not bond at all. Once in service, moisture could enter the joint in the areas of disbond, and corrosion could occur. The moisture and corrosion in some cases contributed to further disbonding of the joint because of the accumulation of oxides, water wicking in the joints, and the freeze-thaw cycles. The cold-bond lap joint production process on the B-737 was discontinued by the manufacturer in 1972.(See figure 5.) A redesigned smooth, close-fitting, "fay" surface sealed lap joint with increased joint thickness was introduced with B-737 production line number 292. This is a riveted joint with chromated polysulfide sealing compound, but it contains no bonding. Production of B-727 line number 850 and subsequent numbers and B-747 line number 201 and subsequent numbers also included fay surface sealed lap joints.

According to Boeing engineers, when disbond occurs in the bonded lap joint, as designed for the B-737, the hoop load transfer through the joint is borne by the three rows of countersunk rivets that mechanically fasten the skin panels together. Because of the single thickness skin surface that was facilitated by the bonded construction, the countersink for the flush rivet heads extended through the entire thickness of the outer 0.036-inch sheet. A knife edge was created at the bottom of the hole which concentrated stresses. These stresses were cyclic with pressurization loads, and fatigue cracking ultimately occurred at the site.

In a cylindrical fuselage like the B-737, the circumferential pressurization stresses are twice as large as the longitudinal stresses. As fatigue effects take lace, cracks propagate longitudinally, perpendicular to the dominant pressurization (hoop) loads. In the B-737, fatigue cracking initially is expected to occur in the outer layer of skin along the lap joint because the outer layer contains a knife edge at each of the countersunk rivet holes. Furthermore, the fatigue cracking primarily is found in the upper row of the outer skin panel lap joint rivet holes because this area carries the greatest stress. For the underlying skin of the lap joint, the area of greatest stress is through the lower row of lap joint rivet holes. However, since the rivet holes in this skin panel are not countersunk, fatigue cracking is not as likely to initiate at this location.

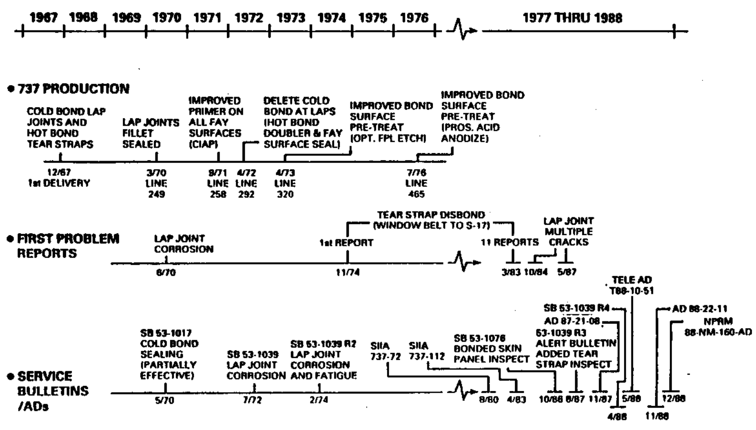

Figure 5.--Production, first problem reports, and Service Bulletins/ADs for 737 bonded body skin lap joints and tear straps

Random cracking at lap joints (See Section 1.17.4, Service Difficulty Report Information) on individual B-737 airplanes has occurred over time, related to the original quality of the joint bond and the environment in which the airplane operated. The rate of crack propagation has been dependent on, among other things, the degree of disbond at the given location within the joint and the accumulation by the airplane of equivalent full pressurization cycles.

During the service history of the B-737, Boeing issued several service bulletins (SBs) pertaining to corrosion detection and repair on fuselage skin panels, lap joint corrosion, disbond and repair, and lap joint fatigue cracking inspection. The earliest of these was SB 737-53-1017 dated May 13, 1970, "Sealing Of Cold Bonded Structure For Corrosion Protection." Two years later, the information was moved to the Structural Repair Manual and the SB was deleted on July 20, 1972. As a follow-up, SB 737-53-1039 was issued on July 19, 1972, and initially addressed the area of lap joint corrosion and repair on the first 291 airplanes produced. This SB received a minor revision in October 1972. A revision/reissue in February 1974 reported lap joint disbond and corrosion on 30 airplanes and stated "in most instances these areas could be positively identified only after corrosion caused exterior skin bulges, cracks or missing fastener heads," and "prolonged operation with large areas of delamination (disbonding) will eventually result in fatigue cracking." The SB program outlined "the minimum requirements for maintaining the structural integrity of the lap joints." Corrosion and fatigue inspection details and intervals and repair instructions were presented. Operator compliance was not made mandatory by the FAA.

On August 20, 1987, the subject SB was elevated to "Alert" status with Revision 3. The following was reason for the upgraded status:

Since the release of Revision 2 an operator has reported multiple fatigue cracks on three airplanes which have accumulated 40,400/42,800 flight hours and 44,700/49,900 flight cycles. Cracks were located in the upper skin at stringer four (S-4), left and right, S-10 right and S-14 right, between Body Stations 360 and 907.

Therefore, Revision 3 was issued to up-grade this service bulletin to an "ALERT" status and to revise the repeat inspection thresholds for detecting fatigue cracking of the outer skin panel at the lap joint upper row of fasteners. Part I of SB 1039 Revision 3 dealt with "Corrosion Inspection" and Part II addressed "Fatigue Damage and Repair." The subject areas were lap joints at S-4, S-10, S-14, S-19, S-20, and S-24. Part III covered "Tear Strap Inspection and Repair" in the same structural areas as Part II.

The FAA issued an Airworthiness Directive (AD) 87-21-08 effective November 2, 1987, which stated in part:

To prevent rapid depressurization as a result of failure of certain fuselage lap splices, accomplish the following: .... (instructions followed)

The AD made the inspection for fatigue cracking referenced in SB 737-53A1039 Revision 3 mandatory for S-4L and R (note only S-4L and R) on production line numbers 1 through 291, before the accumulation of 30,000 landings or within the next 250 landings after the effective date of the AD. Repairs for cracks found were to be accomplished in accordance with instructions contained in the referenced Boeing SB. (The AD and SB revisions 2 and 3, with nondestructive testing (NDT) instructions, are included as appendix C.)

An additional SB 737-53-1076 dated October 30, 1986, deals with skin bonding problems. (A summary of SB 737-53-1076 is included as appendix D.)

Boeing issued revision 4 to SB 737-53A1039 dated April 14, 1988, to permit an interim repair when cracks were detected and time was not available for complete restoration per the previous instructions. This information was not relevant to the accident.

1.6.3 Aloha Maintenance History

1.6.3.1 Maintenance Program

Airplanes operated by Aloha Airlines are maintained under an FAA-approved Continuous Airworthiness Maintenance Program as required by 14 CFR Part 121, Subpart L. The maintenance, based on guidance provided in the Boeing Maintenance Planning Document (MPD) (Document number D6-17594), recommended that aircraft maintenance inspections be divided into four series of checks with specific recurring frequency. The checks are referred to as follows:

A. Check--Primary inspection to disclose general condition

B. Check--Intermediate check to determine general condition

C. Check--System and component check, airworthiness evaluation

D. Check--Structural inspection, determine airworthiness

A Boeing study of early MPD documents revealed overlap between C and D check items. Revision A of the MPD in 1974 redistributed task items to other appropriate check intervals and the D check terminology was eliminated. However, no maintenance items were deleted and many airlines, including Aloha, continued with the original terminology.

Table 1. **Frequency of Inspection. (by flight hours)**

Check	Boeing Recommendation	Industry Average (1987)	Aloha Schedule
A	125	150	175
B	750	650	750
C	3,000	3,000	3,000
D	20,000	21,000	15,000

The Aloha Airlines work schedule for D checks initially was prepared in 1972. The tasks from the Boeing MPD were organized into 52 increments (blocks) to be accomplished during the D check interval. The C check tasks were organized into four increments and integrated with the B check schedule of work. B, C, and D checks were actually combined and accomplished in overnight segments.

Aloha Airlines was participating in the Supplemental Structural Inspection Program (SSIP) for Large Transport Airplanes in accordance with FAA Advisory Circular (AC) 91-56 dated May 6, 1981. The SSIP is a continuous structural inspection to identify cracks, corrosion, and other damage. While the program is not a substitute for the operator's existing FAA-approved structural inspection program, the SSIP and the Supplemental Structural Inspection Document (SSID)[11] provide the operator with procedures to evaluate and supplement their existing program. The SSID provides for the inspection of Significant Structural Items (SSI) that have damage or fatigue characteristics that could affect the airplane's structural integrity. Should cracking occur, the examination of SSIs allows operators to detect fatigue damage before the airplane's residual strength falls below the regulatory fail-safe requirements. (See 1.17.5 Supplemental Structural Inspection Program.)

Though not related to airplane fuselage skin in section 43, the review of the maintenance records found several SSID items for which no maintenance entry could be found. These SSID items were F-20, F-22B, F-24B, F-29A, and F-29B which pertained to the inspection of bulkheads and door or hatch frames. Aloha Airlines personnel reported that these inspections had been incorporated into its letter check maintenance program. However, the Component Historical Record card for these inspections showed no such maintenance entries to indicate that the inspections had actually been accomplished.

1.6.3.2 Maintenance Records Review

To review N73711's most recent complete cycle of A, B, C, and D checks, the Safety Board examined airplane records from May 15, 1980, to April 28, 1988. Aloha Airlines aircraft utilization was such that 8 years of flight activity was necessary to accumulate the 15,000 hours which constitute the D check inspection interval. There are eight structural inspection blocks (portions of the complete D check) that require the removal of airplane interior components. These inspection blocks were proposed by the airline and approved by the local FAA principal maintenance inspector (PMI) to be accomplished sequentially, one block at a time. A one-time heavy maintenance hanger visit for a D check was not scheduled. A complete interior removal at any one time was not required nor was it accomplished.

The maintenance records review indicated that the previous cycles of A, B, C, and D checks were recorded as accomplished within the prescribed intervals. The most recent scheduled maintenance checks were: A--April 25, 1988; B--March 31, 1988; C-4--March 31, 1988; D (block 5)--June 22, 1987, (This block called for inspection of fuselage skin and framing around windshields and windows.); and D (block 8)--February 20, 1981, (This block called for inspection of fuselage skin and stringer splices at BS 320 and a general inspection of the fuselage at BS 400 and BS 520 areas).

The D check structural inspection included an FAA-approved 1/4 sampling program. This meant that certain blocks of the D check were accomplished on 1/4 of the airplanes in the Aloha 10-airplane fleet at the normal 15,000-hour interval, and if no adverse findings were encountered, another 1/4 of the fleet was inspected at 30,000 hours. Again, with no adverse findings, another 1/4 was to be inspected at 45,000 hours, etc.

The Boeing MPD states,

Should an operator encounter an adverse finding, the following actions are recommended: (1) Inspect remaining aircraft in his fleet at the earliest opportunity, (2) Evaluate findings from these inspections together with data from Boeing on the inspection time or area, (3) Determine if a change in frequency of the time interval and/or the fraction needs to be accomplished and then make the change in the program.

There were no adverse findings recorded in any of the records reviewed; therefore, there were no changes in the frequency of inspection or the fraction related to the sampling program.

After the accident, the Safety Board conducted visual inspections of the exterior of the airplanes in the Aloha Airlines B-737 fleet. Considerable evidence of corrosion on the fuselage of the airplanes in the fleet was seen. Swelling and bulging of the skin (pillowing), dished fastener heads, pulled and popped rivets, and blistering, scaling, and flaking paint were present at many sites along the lap joints of almost every airplane.

Aloha Airlines did not produce evidence that it had in place specific severe operating environment corrosion detection and corrosion control programs employing the techniques outlined in the Boeing Commercial Jet Corrosion Prevention Manual (Boeing Document D6-41910). Program requirements in the manual include extensive application of water displacing corrosion inhibiting compounds, reapplication at fastener locations and panel edges of exterior fuselage skin every 6 months and internal treatment at 2-year intervals, washing the aircraft at 15-day intervals, plus regular buffing and brightening of the unpainted surfaces. Aloha Airlines maintenance D check instructions for structural inspection addressed corrosion with an introductory note. This notation defined the inspection as a rigorous visual examination for condition (damage, cracks, galling, scratches, wear, corrosion, rust, evidence of overheating, rubbing, or age) without further definition. Aloha Airlines inspectors and quality control personnel stated that the corrosion was corrected when detected during normal inspection and maintenance activities as part of their normal task card activity.

The Safety Board subcategorized and evaluated all pressurization discrepancies recorded from 1980 to 1988 to determine adverse trends or significant anomalies. This maintenance historical review produced no evidence of prior structural overstress incidents for N73711 as a result of pressurization or other malfunction.

1.6.3.3 Service Bulletins

Boeing periodically issued information via SBs to inform operators of reported or anticipated difficulties with various airplane models. The following communications were relevant to the B-737 fuselage structure, including section 43:

- Structural Item Interim Advisories (SIIA)
- Service Bulletins (SB)
- Service Letters (SL)
- In-Service Activity Reports (ISAR)
- Significant Service Items (SSI)

Nine SBs provided guidance for maintenance or information otherwise applicable to section 43. Of these nine SBs, entries referring to the following five SBs were found in the Aloha Airlines fleet maintenance records:

SB 737-53-1017 Sealing of Cold Bonded Splices

SB 737-53A1027 Cargo Compartment Body Frames

SB 737-53A1039 Skin Lap Joint Inspection

SB 737-53A1042 Lower Lobe Skins

SB 737-53A1064 Frames Stations 351 and 360

Due to the method of entering the SBs in the Aloha Airlines maintenance records, the recurring nature of inspections could not be determined. Also, entries for the following four SBs were not located in the records:

SB 737-53-1076 Fuselage-Bonded Skin Panel Inspection and Repair

SB 737-53-1078 Fuselage Window Belt Skin Panel Inspection and Repair

SB 737-53-1085 Fuselage Stringer to Frame Tie Clips Inspection and Replacement

SB 737-53-1089 Fuselage Skin Crack At Stringer 17 Inspection and Preventive Modifications

Aloha Airlines personnel stated that the information contained in these particular SBs had been incorporated into Aloha Airlines letter check inspection system; however, specific documentation of this fact was not produced.

1.6.3.4 FAA Airworthiness Directive (AD) Compliance AD 87-21-08

Airworthiness Directive (AD) 87-21-08, which became effective on November 2, 1987, was issued "to prevent rapid depressurization as a result of failure of certain fuselage lap splices...." The AD required operators to perform a "close visual inspection"12 of S-4L and R, and if cracks were found, operators were required to perform an eddy current inspection13 of the skin around the upper row of lap joint rivets for the full length of the panel. Compliance with the AD was required before the accumulation of 30,000 landings or within 250 landings after the effective date, whichever occurred later. The AD was based on Boeing Alert Service Bulletin (ASB) 737-53A1039, Revision 3, dated August 20, 1987. The ASB required an inspection of the skin around the upper row of rivets along the lap joints at S-4, -10, -14, -19, -20, and -24 left and right. An FAA employee testified at the public hearing that the decision to limit the scope of the mandatory inspection was based on analysis of statistical information available to them and the recognition of the scope of work required.

A review of the maintenance discrepancy logs found that two repairs to cracks on the S-4R lap joint on N73711 were accomplished on November 12, 1987. The small separated section of upper fuselage recovered after the accident contained both of the repaired areas. The maintenance log for N73711 indicated that a visual inspection had been accomplished in accordance with AD 87-21-08; however, the record contained no evidence that the required eddy current inspection had been accomplished.

An Aloha Airlines inspector testified at the public hearing that it was company practice to perform an eddy current confirmation inspection whenever a crack was detected visually. Both the Aloha Airlines director of quality control and the staff vice president for quality assurance and engineering stated that a Nondestructive Testing Report (Form No. M-86) should be filled out by the inspector when any NDT inspection is performed. The form is then used by management for tracking purposes. A search of the records for N73711 failed to find a copy of an NDT inspection report of the S-4R lap joint.

The inspector who performed the initial AD inspection on N73711 stated that he did not believe that documenting the eddy current inspection was necessary or required. During the investigation, Aloha Airlines did not produce a written maintenance policy regarding the requirement for the entry of an eddy current inspection in the maintenance log. However, a broad examination of maintenance records revealed that other inspectors had made such entries during this same time period.

Two inspectors working on separate shifts conducted the inspection required by AD 87-21-08 on the accident airplane. They followed guidance in the AD and the related SB (SB-737-53A1039) which were taken to the work site. The first inspector started on November 12, 1987, and visually detected the cracks on S-4L. This inspector stated that after visually detecting the cracks, he performed an eddy current inspection of the lap joint upper rivet holes along the length of the panel (BS 360 to BS 540) and found no additional cracks.

After maintenance personnel accomplished two sheet metal repairs, the first inspector inspected the work and signed the log book. The second inspector stated that he performed a complete visual inspection of the airplane, including the area inspected by the first inspector and the two repaired areas, and he signed off the completion of the AD in the maintenance log on November 14, 1987. The related inspections on the lap joints at S-10, -14, -19, -20, and -24, which were recommended by SB 737-53A1039 but not by the AD, were not accomplished. At the time of the AD inspection and repair, N73711 had accumulated 87,056 cycles. The accident occurred at 89,680 cycles.

1.7 Meteorological Information

The accident occurred in day visual meteorological conditions. There was no significant adverse weather experienced.

1.8 Aids to Navigation

Not relevant to this accident.

1.9 Communications

There were radio communications difficulties between flight 243 and ATC shortly after the explosive decompression. At 280 to 290 knots IAS and with a part of the forward cabin structure and the cockpit door missing, high noise levels impeded air/ground communications briefly. There were no other communication anomalies.

1.10 Aerodrome Information

After the explosive decompression, the airplane proceeded to the nearest suitable landing field, Kahului Airport, a 14 CFR Part 139 certificated Index D airport on the island of Maui, Hawaii. The only instrument runway, 02/20, is 6,995 feet long, 150 feet wide, and constructed of asphalt with a grooved surface.

1.11 Flight Recorders

The airplane was equipped with a Fairchild model 5424 foil type analog FDR, S/N 7274, and a Collins model 642C-1 cockpit voice recorder (CVR), S/N 54. After the accident, the recorders were removed from the airplane and sent to the Safety Board's Flight Recorder Laboratory in Washington, D.C. for examination and readout of pertinent data. (See appendix E.)

Examination of the FDR recorded traces indicated that the flight was normal from liftoff to the accident. The airspeed trace abruptly ceased at the time of the accident and dropped to a position below zero KIAS. The other recorder parameters appeared to operate normally. Peak vertical acceleration (G) excursions recorded as a result of the accident were -0.48 and +2.95. These peak values were not sustained.

The CVR revealed normal communications before the decompression. Following the decompression, loud wind noise from the opening in the fuselage prevented normal cockpit conversations. Hand signals were used to communicate. When the airspeed and related wind noise had been reduced to a level where conversations were intelligible, the flightcrew discontinued using the oxygen masks. Cockpit conversations then continued to be recorded in the normal manner.

1.12 Wreckage and Impact Information

The extensive air and surface search of the ocean failed to locate the portions of the airplane lost during the explosive decompression.

1.13 Medical and Pathological Information

The flight attendant who was ejected from the fuselage was not found and she is assumed to have been fatally injured in the accident.

Two passengers who were seated in the first class cabin in seats 2A and 2C were struck by debris and wiring which resulted in multiple lacerations and electrical shock burns to the face and hands. Passengers seated in seats 4A and 4F (window seats) sustained serious injuries including cerebral concussions and multiple lacerations to their heads and faces. Passengers seated in 4B, C, D, and E (center and aisle seats) sustained multiple lacerations and were treated and released on the day of the accident.

Passengers seated in rows 5, 6, and 7 also sustained cerebral concussions and multiple lacerations. An 84-year-old female passenger seated in 5A was the most seriously injured with a skull fracture, lacerations and a skeletal system fracture. The passenger seated in 6A sustained a broken right arm, multiple facial lacerations, and blood effusion in both ears.

The majority of the passengers seated in rows 8 through 21 received minor injuries including lacerations, abrasions, and barotrauma. They were treated and released on the day of the accident. Twenty-five passengers reported no injuries and continued to their destinations that same evening. There were no reported injuries as a result of using the emergency evacuation slides.

1.14 Fire

There was no fire.

1.15 Survival Aspects

This was a survivable accident; the fatality was the result of the explosive nature of the decompression. The flight attendant was swept violently from the airplane and passed through an opening of jagged metal. There were blood stains on seat cushions at seat 5A on the left side of cabin near BS 500 and on the exterior left side of the fuselage where the flight attendant was standing when the decompression occurred. Passengers who observed her during the explosive decompression stated that they saw the flight attendant pulled upward and toward the left side of the cabin at seat row 5.

1.15.1 Supplemental Oxygen Systems

The flightcrew and the cockpit observer seat occupant used the airplane-installed crew oxygen system. Postaccident inspection showed that both the crew and the passenger oxygen bottles that were located in the forward cargo compartment had zero quantity and pressure. The passenger oxygen distribution manifolds were part of the material lost during the structural separation, and thus, there was no supply of oxygen to the first-class and coach cabins.

1.15.2 Sea Search

At 1430, the FAA notified the U.S. Coast Guard that an Aloha Airlines B-737 was diverting to Maui airport due to an "inflight explosion." A Coast Guard helicopter, airborne on a training mission, was assigned to search the area for debris and the flight attendant. The Coast Guard cutter CAPE CORWIN was also directed into the search area as was a Marine Corps helicopter. A full search effort by ships, helicopters, and fixed-wing aircraft continued for 3 days without success.

1.15.3 Rescue and Firefighting Response

The Maui Airport fire department responded with five emergency vehicles. After the ambulatory passengers had evacuated the airplane via slides and the aft airstair, fire department personnel entered the airplane and assisted the injured still on board. All occupants were removed from the airplane in 25 minutes.

1.15.4 Ambulance Response

The flightcrew initially communicated the nature of the emergency as a "rapid decompression." The full nature of the structural damage was not verbalized. ATC notified rescue and firefighting personnel, but did not immediately call for ambulance assistance. A subsequent call from the flightcrew at 1353, "We'll need assistance for the passengers when we land," was confirmed by ATC personnel. Police dispatcher records indicated the "Medic I" ambulance was notified at 1358, about the time of touchdown. A reason for the notification delay was not determined. The first ambulance arrived at the scene at 1405 and radioed for assistance. Other ambulance vehicles arrived at 1411.

1.16 Tests and Research

1.16.1 Pressurization System

All of the pressurization system wiring from the selector panel to the pressure controller to the outflow valve was examined. No discrepancies were found. Additionally, a visual examination of the components including the outflow valve, both relief valves, the controller, and the selector panel did not reveal any discrepancies. These components were removed from the airplane after the accident and subjected to standard acceptance test procedures for new units. There were no significant anomalies discovered.

1.16.2 Eddy Current and Visual Inspection

An Aloha Airlines inspector under supervision of the Safety Board conducted postaccident eddy current inspections on selected portions of the remaining fuselage lap joints to determine the extent of fatigue cracking of the skin along the top row of rivets (the area of highest stress). The inspected areas included the left and right lap joints at S-4, -10, and -14 from BS 540 to BS 1016.

Initially, the skin around 53 rivets exhibited crack indications along S-4L and S-4R, some visually detectable by paint cracks. To make the rivet heads more discernible, the paint was sanded off and the skin was reinspected. Twenty-eight of the original 53 indications were confirmed cracks. Stripping of the paint layers was not attempted. (It is not normal Aloha Airlines or industry practice to remove paint by sanding.) Two samples of the lap joint were cut from S-4L between BS 727 and 747 and between BS 847 and 867 for further examination.

The eddy current inspection along S-10 and S-14 revealed 17 cracks along S-10L and 2 cracks along S-14R. There were no cracks along S-10R or S-14L. No attempt was made to strip the paint layers. (Appendix F provides details of these inspections.)

There were 25 locations where previous fuselage skin repairs or rework had been performed. Most of these areas consisted of external doubler patches at various stringer and frame locations. In several areas, countersunk rivets had been replaced with universal buttonhead rivets in lap joints, mostly in the lower lobe. (Appendix G provides a description of the repairs or reworked areas and their locations.)

1.16.3 Materials Laboratory Examination

Selected pieces of the fuselage skin and associated structures were returned to the Safety Board's Materials Laboratory for analysis. These pieces included lap joint samples (S-4R, S-4L and S-10L) and a section of a circumferential butt joint strap.

The lap joint sample, S-4R between BS 360 and BS 420 (found wedged in the right wing area), contained two external doubler patches. The patches were removed to examine the holes for evidence of cracks. There was extensive fatigue cracking in the upper row rivet holes both under and between the patches. The examination found one of the longest cracks on the airplane, 0.27 inch, in this piece. This stringer section (S-4R) contained three areas where the tear straps are riveted above the primary 1ap joint. There was extensive fatigue cracking present in all three locations. Also, the entire cold-bonded lap joint had become disbonded. There was light to moderate corrosion with severe corrosion (unrepairable depletion of metal) in some areas. Nearly all of the hot-bonded tear straps were disbonded in the vicinity of the lap joint.

The lap joint samples, S-4L from BS 727 to BS 747 and from BS 847 to BS 867, each contained 18 columns of lap joint rivets. The laboratory examination revealed fatigue cracking in the skin adjacent to nearly every hole in the upper rivet row with the larger crack lengths located in the mid-bay areas (half way between two adjacent circumferential tear straps). A comparison of the final results of the postaccident on-scene eddy current inspection conducted by Aloha Airlines technicians and the Safety Board laboratory findings revealed that the on-scene eddy current inspection only successfully identified cracks larger than 0.08 inch. The laboratory examination found five cracks that measured 0.08 inch (+/-.005). The postaccident inspection had identified only one of these five cracks. This crack-length inspection threshold of 0.08 inch varies from the Boeing NDT Manual which states, "This inspection can find cracks 0.040 or longer beneath the countersunk fastener heads...."

The lap joint piece, S-4L, from BS 519 to BS 536, exhibited fatigue cracking from 16 consecutive rivet holes along the upper row of lap joint rivets. The largest single fatigue crack in one direction measured 0.18 inch from the knife edge of the countersink. (See figure 6.) The longest total combined crack length in both directions across a rivet hole (end to end of the crack including the hole) measured 0.53 inch. Both the cold-bonded lap joint and the hot-bonded tear straps in this area had disbonded. Light to moderate corrosion was present on the previously bonded surfaces.

At the request of the Safety Board, Boeing performed a striation count on several of the larger fatigue cracks from the skin along S-4R and S-10L to determine age and crack propagation rate. Although data could not be obtained from all the cracks examined, Table 2 provides the estimated number of cycles of crack growth found on the seven crack samples that provided suitable data.

Table 2. Striation counts on selected cracks from the lap joints along S-4R and S-10L

Specimen location	Estimated number of cycles (+/-20%)	Crack length in inches
S-4R	28,670	0.105
S-4R	37,148	0.130
S-4R	28,656	0.142
S-4R	26,449	0.154
S-4R	24,056	0.110
S-10L	23,628	0.161
S-10L	36,379	0.145

An examination of the butt strap section from BS 360 at S-7R revealed circumferentially propagating fatigue cracks from both sides of a rivet hole just forward of the joint line. The fatigue regions extended 0.09 inch above the rivet hole and 0.03 inch below the rivet hole.

The separated ends of the No. 1 engine control cables were also examined for condition and failure mode. The separation areas of the No. 1 engine control cables were cleaned and examined. Each break exhibited corrosion; only a few of the individual wires were relatively unaffected. Many of the strands exhibited corrosion damage through most of the wire diameter.

1.17 Additional Information

1.17.1 General Inspection of Other Aloha Airlines Airplanes

The Safety Board reviewed 2-year maintenance records of three other high-cycle B-737s operated by Aloha Airlines--N73712, N73713, and N73717. All of the required A, B, C, and D checks had been signed off at the appropriate intervals. The supplemental structural inspections were accounted for with the exception of SSID items pertaining to bulkheads and door or hatch frames which also were not addressed in the Component Historical Record cards of the accident airplane. The same SBs that had been applicable to the maintenance of N73711 were applied to the three airplanes.

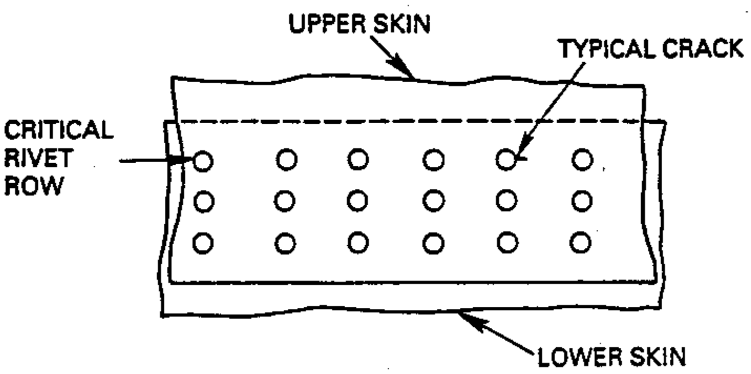

Figure 6a.--Typical lap joint

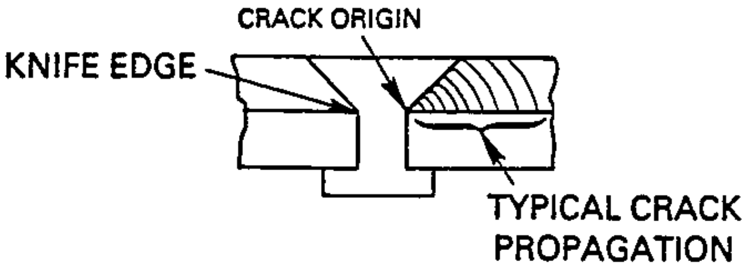

Figure 6b.--Cross section of a rivet and skin

In accordance with AD 87-21-08, N73712 had been inspected on November 5, 1987. At the time of the inspection, the airplane had accumulated 32,642 hours and 87,551 cycles. No defects were reported during that inspection. On April 9, 1988, with an accumulated 33,676 hours and 90,051 cycles, the airplane was hangared for heavy maintenance. It was the highest cycle B-737 in the world fleet. Following the N73711 accident, the N73712 airplane received a thorough corrosion/fatigue inspection and evaluation of the structure. It was determined that the airplane was beyond economical repair. It was dismantled on the site and sold for parts and scrap.

On April 14, 1988, N73713 had accumulated 32,026 hours and 85,409 cycles and received its last A check. No discrepancies were noted during that inspection. The inspection required by AD 87-21-08 had been accomplished on December 15, 1987, at 83,488 cycles. In 1984, Aloha Airlines submitted a Service Difficulty Report (SDR) to report a 7 1/2-inch crack on this airplane. The crack was located along the top row of rivets along the lap joint at S-10R. The discrepancy log entry referred to SB 737-53-1039. Following the N73711 accident, N73713 received a thorough corrosion/fatigue inspection and evaluation of the structure which indicated that this airplane was also beyond economical repair. The airplane also was dismantled on the site and sold for parts and scrap.

On April 27, 1988, N73717 had accumulated 39,986 hours and 68,954 cycles and received its last A check. No discrepancies were noted during that inspection. The inspection required by AD 87-21-08 was accomplished on January 12, 1988, at 67,429 cycles. The MIB maintenance form stated that both a visual and an eddy current inspection had been accomplished. The entry showed that the fuselage crown from S-4R to S-4L had been repaired at station BS 540. Also, corrosion of the forward section of the skin joint on the left side from S-9L to S-4L resulted in repairs.

After the N73711 accident, N73717 remained parked for almost 6 months awaiting final disposition. It was then flown on a ferry permit to an independent aircraft overhaul facility for refurbishment. During initial inspection after paint stripping, fatigue cracking was found visually at multiple rivet locations on the S-14R lap joint at BS 380 and numerous tearstrap disbonds and skin corrosion sites were apparent. All outstanding SB actions and terminating (permanent) repairs for the ADs pertaining to the structure were accomplished. The airplane was out of service for about 1 year.

1.17.2 The B-737 Fail-Safe Design

Boeing designed the B-737 for an "economic service life"[14] of 20 years and to include 51,000 flight hours and 75,000 cycles. At the time the B-737 was certificated in 1967, Federal Air Regulations required that the airplane's structure be capable of sustaining 80 percent of limit load[15] with any complete or obvious partial failure of any single structural element. However, the B-737 was designed to sustain full-limit load to account for dynamic effects. The fail-safe design criteria for the B-737 established by the manufacturer required that the fuselage be able to withstand a 40-inch crack without suffering catastrophic failure. These criteria were derived from an estimate of the maximum external damage expected to occur to the fuselage as a result of external damage that might occur from the penetration of projectiles produced by an uncontained engine failure. There was no consideration given to the joining of adjacent cracks which might develop during extended service other than normal "state-of-the-art" fatigue evaluation. Boeing design included the placement of tear straps with 10-inch spacing in the fuselage skin in both directions (longitudinal and circumferential) to redirect running cracks from external damage in a direction perpendicular to the crack. The fail-safe concept was based upon the theory that the redirection of a progressing crack would cause the fuselage skin to "flap" open, releasing internal pressure in a controlled manner without adversely affecting the residual strength of the fuselage as a whole.

Supporting the skin are circumferentially oriented frames spaced 20 inches apart and longitudinally oriented stringers located 10 inches apart. Each area bounded between adjacent frames and stringers (20 inches by 10 inches) is considered a frame bay. The fail-safe design requirement was to allow for failure within two frame bays without compromising the structural integrity of the fuselage.

Boeing demonstrated the ability of the fuselage to fail safely within two frame bays during certification of the airplane by "guillotine" tests on a fuselage half section. The guillotine tests involved two 15-inch blades located nearly side by side which were used to penetrate longitudinally the test fuselage section within two adjacent frame bays while it was under full pressure. The guillotines produced an instantaneous 40-inch separation in the fuselage skin with a break in the center tear strap. As anticipated by the design, the separation redirected itself circumferentially, produced a flap, and resulted in a controlled decompression. Similar results were obtained when the guillotine test was oriented circumferentially.

During the certification program for the B-737, some of the knowledge gained on the B-727 full-scale certification testing was used by Boeing to validate fatigue performance on the B-737. Skin thickness of the B-737 (0.036 inch) was slightly less than that of the B-727 (0.040 inch). However, fatigue testing of a complete B-737 was not accomplished as it was on the B-727. That is, the complete B-727 fuselage was cycled for 60,000 cycles (one economic design life goal) during certification whereas the B-737 fuselage design concept was demonstrated by fatigue testing a representative crown-to-keel half section of the fuselage. The test section for the B-737, or "quonset hut," was cycled 150,000 times to full pressurization differential (two times the 75,000-cycle economic design life goal). No fatigue cracks developed on the test section and no disbonding occurred. These test results were used to verify the B-737 fatigue life expectations.

There was no consideration given in the fatigue evaluation to the possibility of disbonding or the effects of corrosion on the strength of the fuselage lap joints.

1.17.3 In-Service Model Fuselage Tests

In 1986, Boeing acquired a B-737 that had been involved in an in-service accident. At the Safety Board public hearing, Boeing personnel stated that the airplane was purchased for two reasons:

to conduct a thorough teardown of the airplane from nose to stern, from wing tip to wing tip, fuselage, wing, empennage; and also to run some damage tolerance testing of the aft fuselage, since the aft body was in good condition, to verify some areas we wanted to understand further about pressure bulkheads.

The fuselage, line No. 90, was acquired with just over 59,000 actual flight cycles. Lap joint and tear strap bonds were inspected and found to be in good condition. Boeing then applied over 70,000 additional test cycles. The first skin cracks (seven) located around BS 780 were discovered in August 1987 by NDT at 79,000 cycles. In September 1987, at 89,000 cycles, there were about 15 cracks detected in a 20-inch bay area around BS 820. The cracks ranged from about 0.37 inch to 0.67 inch tip to tip. At this point, Boeing engineers placed additional straps on the test article at BS 760 and BS 820. At the Safety Board public hearing, Boeing indicated this step was taken to preserve the test article in the event of a catastrophic failure. Boeing further indicated that the added straps would not alter the results of the fatigue testing.

When additional cycles were applied, individual cracks joined to form a large crack that grew to about 32 inches at 100,000 cycles. Testing continued to 100,673 cycles; when the crack reached almost 40 inches, the skin flapped and controlled pressure release occurred. During the latter portion of the testing, the structure and skin yielded (deformed), and the crack gap remained open with interior insulation material visible after each full pressurization cycle.

1.17.4 Service Difficulty Report Information

The FAA SDR data base was queried by the Safety Board after the accident for information pertaining to the B-737 fuselage. From the beginning of the current data base (January 1983) until the date of the accident, 1,352 records were found. Of these, 198 were reports of fuselage skin cracks, and 10 of these reports were of cracking at or near lap joints. Six of the 10 reports involved lap joints in the upper lobe, while the remaining 4 reports indicated cracks from the lower lobe of the fuselage. (See Appendix H.) One report was submitted after the effective date of AD 87-21-08, November 2, 1987. All of the airplanes cited in the 10 reports were among the first 291 B-737 airplanes assembled by Boeing.

There were 18 SDRs on file pertaining to airplanes in the Aloha Airlines fleet. Three reports were on lap joint cracks/corrosion previously cited, and two reports were about upper lobe skin cracking where lap joint involvement could not be established from the information given. Three of the reports pertained to lower lobe skin corrosion; an additional three reports cited corrosion at cargo door frames and the nose gear wheel well structure. The remaining seven reports involved cracks in fuselage structure other than skin or lap joints.

1.17.5 Supplemental Structural Inspection Program (SSIP)

As the high-time airplanes in the world fleet of jet transport category airplanes began to approach their original lifetime design objectives, the industry questioned the continued airworthiness of the aging fleet since many of the airplanes would continue in service beyond design objectives. This concern ultimately led to a requirement for a structural reassessment or audit and the development of a continuing structural integrity program for older transport airplanes. The air transport airframe manufacturers developed the required programs, utilizing different concepts, to achieve continued airworthiness of their aging airplanes. The structural integrity programs have resulted in directed inspections of SSIs (any detail, element, or assembly that contributes significantly to carrying flight, ground, pressure, or control loads and whose failure could affect the structural integrity necessary for the safety of the airplane) at appropriate initiating thresholds and repeated intervals to detect fatigue damage before the loss of residual strength of the airplane's structure.

In 1978, the portion of 14 CFR 25.571 dealing with fail-safe requirements was revised to reflect state-of-the-art advances in fracture mechanics and structural analysis. The new regulation required consideration of damage growth characteristics at multiple sites, and an inspection program to incorporate these analyses to ensure that the damage was detected before the residual strength of the airplane dropped below the regulatory fail-safe requirements. This was called the damage tolerance concept.

Boeing's approach to the aging fleet problem for the 727/737/747 (which were certificated under the pre-1978 14 CFR 25.571 criteria) was to reassess these airplanes using the revised 14 CFR 25.571 damage tolerance requirements. This reassessment required determination of residual strength with the presence of multiple active cracks, extensive analysis of crack growth rates, and incorporation of these engineering determinations into the airplane's maintenance program. Boeing applied the same methodology to the reassessment of the early model airplanes that was developed to certificate the models 757/767 in accordance with revised airworthiness regulations. The development of the program was a cooperative effort between Boeing and an industry steering group. The FAA and the Civil Aviation Authority of the United Kingdom were observers, and the FAA subsequently mandated implementation of the program by an AD. For the B-737, the program was to be in effect no later than November 1985.

Using a probabilistic approach which assumed that fatigue cracking had occurred in the fleet and that the highest time airplanes were the ones that would encounter cracks first, Boeing recommended a candidate fleet of high-time airplanes to be inspected under the SSIP. For the B-737, the candidate fleet consisted of about 125 airplanes, including the accident airplane operated by Aloha Airlines. Positive crack indications were to be reported promptly to Boeing, where the discrepancy would be evaluated. If the problem was applicable to the rest of the fleet, an SB for inspection or repair would be issued and subsequently mandated by the FAA through AD action. Since the program was devised to detect instances of previously unknown fatigue cracking of a structure, the SSI was to be dropped from the program once fatigue cracking became known and corrected through the AD process.

During the program formulation, a structural classification system was devised to determine which SSIs ultimately would be included in the SSIP. Only the SSIs where damage detection was to be achieved through planned inspection were included in the SSIP. One of the classifications by which SSIs were excluded from directed supplemental inspections was that of "damage obvious or malfunction evident." An example of a structure that meets this classification is wing skin, where surface cracks are evident through fuel leakage, and fuselage minimum gage skin that annunciates a failure by controlled decompression through flapping. Other manufacturers include fuselage skin in their structural inspection requirements.

Aloha Airlines had incorporated the SSIP into the maintenance programs of the candidate airplanes they operated. Among these airplanes were N73711, the accident airplane, and N73712, as stated before, the highest cycle 737 in the world fleet.

Aloha Airlines' incorporation of the SSID program into its maintenance schedule was approved by the FAA. The SSID provides the operator with procedures to evaluate and supplement their existing structural inspection program by utilizing directed supplemental inspections. Aloha Airlines had not discovered or reported any items following the performance of SSID inspections.

1.17.6 FAA Surveillance of Aloha Airlines Maintenance

The FAA's Principal Maintenance Inspector (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 PMI's position description reads as follows:

Provides guidance to the assigned air carrier in the development of required maintenance manuals and record keeping 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 the accident, the PMI for Aloha Airlines at the time of the accident stated that he was trained as an FAA air carrier inspector and had been assigned to Aloha Airlines since January 1987. He attended a recent course in maintenance planning; however, he had not received any specific training in corrosion control, multiple site fatigue damage, or management of high time "lead the fleet" aging aircraft. He stated that he was not aware of an FAA course devoted specifically to PMI duties.

The Honolulu FAA Flight Standards District Office (FSDO-13) held the FAA certificates of Aloha Airlines. The office Work Planning Management System (WPMS) records were reviewed for aircraft records examinations and spot and ramp inspections accomplished on N73711 and N73712, for 6 months before the accident. The review of these records disclosed that all required WPMS activities had been accomplished and that the PMI maintained a continuous surveillance of the airline. In addition, the PMI had been informed when skin cracks on S-4L and S-4R were found on N73712 on April 26, 1988. No record was found nor required indicating that the PMI examined the S-4R repair on N73711 which was signed off by the Aloha Airlines inspector on November 14, 1987.

FAA surveillance of Aloha Airlines maintenance activities was organized around the daily work schedule of the PMI. In a few cases, the PMI visited the Aloha Airlines maintenance facility early in the morning to assess maintenance practices. In most cases, his visits took place after the majority of the maintenance work had been accomplished. Thus, the PMI primarily observed completed maintenance actions rather than work in progress or the actual condition of airplanes before the start of a repair.

The PMI stated that his heavy workload assignment made frequent visits to observe Aloha Airlines maintenance program impossible. The PMI was responsible for nine air carriers and seven repair stations. These carriers and repair stations were spread throughout the Pacific basin and were situated in the People's Republic of China, Taiwan, Hong Kong, Singapore, the Philippines, and Hawaii. He stated that the travel distances reduced the time available for surveillance of each operator. The PMI stated that he was "zeroing in on getting the organization [Aloha's maintenance department] up to date, modernized, getting the program changed to a program that would recognize the changes that [had] taken place over the years." The PMI stated that he had recognized a "lack of depth in Aloha management" and was concentrating his efforts at Aloha Airlines to resolve this issue. The PMI believed that improving management would also result in improvements in Aloha Airlines operational maintenance program.

The Aloha Airlines Operations Specifications for maintenance inspection time intervals in effect at the time of the accident was dated August 30, 1982, well before the arrival of the current PMI. A D-check interval of 11,000 hours was extended to 15,000 hours by the previous PMI at the request of the operator. The time increase was based on the "excellent reliability of the airframe structure and inspections (which) disclosed no significant findings...." The Aloha Airlines Maintenance Manual containing the D check program[16] had been established in 1972.

Further, the PMI was not familiar with Aloha Airlines prior to his assignment as PMI. He testified at the Safety Board public hearing that other members of the FSDO, including the previous PMI, had informed him that Aloha Airlines was a good operator and that there were no problems with the maintenance department. The new PMI stated that he was not made aware of the high-time status of some Aloha Airlines aircraft, nor did he receive any information regarding the in-service model testing of the B-737 conducted by the manufacturer in the fall of 1987.