SP 20

National Transportation Safety Board

Washington, D.C. 20594

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In reply refer to: A-89-70 through 72

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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 flightcrew performed an emergency descent and landing at Kahului Airport on the Island of Maui.[1]

The Safety Board determined that the accident sequence initiated with the structural separation of the pressurized fuselage skin. As a result of this separation, an explosive decompression occurred, and a large portion of the airplane cabin structure comprising the upper portion of section 43 was lost.

A postaccident examination of N73711 revealed that the remaining structure did not contain the origin of the failure. Since the sea and air search did not locate recoverable structure from the airplane, it was necessary to determine the failure origin by examining and analyzing the remaining structure and the airworthiness history of the airplane.

The Safety Board determined that the fuselage of N73711 most probably failed catastrophically at the lap joint along stringer S-10L, initially near BS 440, allowing the upper fuselage to rip free. The reason for this catastrophic failure, rather than the intended fail-safe "flapping" of the skin as designed, was evaluated by the Safety Board.

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[1]For more detailed information, read Aircraft Accident Report--"Aloha Airlines, Flight 243, Boeing 737-200, N73711, near Maui, Hawaii, April 28, 1988" (NTSB/AAR-89/03).

Multiple site damage (MSD) describes multiple fatigue cracks along a rivet line. MSD can range from a few fatigue cracks among many rivet holes to the worst case of small, visually undetectable fatigue cracks emanating from both sides of rivet holes along a complete row of skin panel fasteners. Numerous areas of MSD were discovered in the fuselage skin of N73711 during postaccident investigation. The presence of MSD also tends to negate the fail-safe capability of the fuselage.

It is probable that numerous small fatigue cracks in the lap joint along S-10L joined to form a large crack (or cracks) similar to the crack at S-10L that a passenger saw when boarding the accident flight. The damage discovered on the accident airplane, damage on other airplanes in the Aloha Airlines fleet, fatigue striation growth rates, and the service history of the B-737 lap joint disbond problem led the Safety Board to conclude that, at the time of the accident, numerous fatigue cracks in the fuselage skin lap joint along S-10L linked up quickly to cause catastrophic failure of a large section of the fuselage.

The Safety Board believes that sufficient fatigue cracking or tear strap disbond (or a combination of both) existed in the lap joint at S-10L to negate the design-intended controlled decompression of the structure.

The Safety Board further believes that Aloha Airlines had sufficient information regarding lap joint problems to have implemented a maintenance program to detect and repair the lap joint damage. The information available to Aloha Airlines on lap joint problems included the following:

- the B-737s in the Aloha Airlines' fleet were high-cycle airplanes accumulating cycles at a faster rate than any other operator;
- Aloha Airlines operated in a harsh corrosion environment;
- Aloha Airlines previously had discovered a 7.5-inch crack along lap joint S-10L on another B-737 airplane;
- Boeing had issued, and records indicate that Aloha Airlines was aware of, a Service Bulletin (SB) covering lap joint inspection and repair in 1972, revised in 1974, and upgraded to an Alert Service Bulletin (ASB) in 1987; and
- the FAA had issued an Airworthiness Directive (AD) in 1987 requiring inspections of the lap joints along S-4 and referencing the Boeing ASB, which called for inspection of all other lap joint locations, including along S-10.

The Safety Board identified three factors of concern in the Aloha Airlines maintenance program. They were: a high accumulation of flight cycles between structural inspections, an extended time period between inspections that allowed the related effects of lap joint disbond, corrosion, and fatigue to accumulate, and the manner in which a highly segmented structural inspection program was implemented.

The Aloha Airlines structural D check inspection interval for the continuing airworthiness of their B-737 fleet was approved by the FAA at 15,000 hours. The selection of 15,000 hours appears to have been more conservative than the 20,000-hour interval recommended by Boeing. However, because of the daily frequency of short duration flights, the rate of accumulation of flight cycles on Aloha Airlines airplanes exceeded the rate which Boeing forecast when the B-737 Maintenance Planning Data (MPD) was created. Aloha Airlines records of aircraft utilization indicated that their airplanes accumulated about three cycles for each hour in service. The Boeing economic design life projections were based on accumulating about 1 1/2 cycles per flight hour. Thus, Aloha Airlines airplanes were accumulating flight cycles at twice the rate for which the Boeing MPD was designed. Even with an adjustment for partial pressurization cycles on short flights, and thus partial loading of the fuselage, the accumulation of cycles on Aloha Airlines airplanes remained high and continued to outpace the other B-737 airplanes in the world fleet and Boeing's assumptions in developing the MPD.

The Aloha Airlines maintenance program did not adequately recognize and consider the effect of the rapid accumulation of flight cycles. The Safety Board notes that flight cycles are the dominant concern in the development of fatigue cracking in pressurized fuselages and the accumulation of damage as a result of flight and landing loads. The Aloha Airlines maintenance program allowed one and one half times the number of flight cycles to accumulate on an airplane before the appropriate inspection. The Safety Board believes Aloha Airlines created a flight-hour based structural maintenance program without sufficient regard to flight cycle accumulation.

The Boeing MPD assumed a 6- to 8-year interval for a complete D check cycle, and the Aloha Airlines D check maintenance program required 8 years to complete a D check cycle. The Safety Board believes that the 8-year inspection intervals in the Aloha Airlines maintenance program was too lengthy to permit early detection of disbond related corrosion, to allow damage repair, and to implement corrosion control/prevention with the maximum use of inhibiting agents.

Of additional concern to the Safety Board was Aloha Airlines' practice of inspecting the airplane in small increments. The Aloha Airlines D check inspection of the B-737 fleet was covered in 52 independent work packages. Limited areas of the airplane were inspected during each work package and this practice precluded a comprehensive assessment of the overall structural condition of the airplane.

The Safety Board believes that the use of 52 blocks/independent work packages is an inappropriate way to assess the overall condition of an airplane and effect comprehensive repairs because of the potential for air carriers to hurry checks in order to keep airplanes in service. Further, the fact that the FAA found this practice to be acceptable without analysis is a matter of serious concern.

The effectiveness of Aloha Airlines inspection programs was further limited by time and manpower constraints and inadequate work planning methods. Maintenance scheduling practices utilized the overnight nonflying periods to accomplish B checks which, in reality, included portions of the C and D check items. However, since there were usually no spare airplanes in the fleet, it was obvious to both the maintenance and inspection personnel that each airplane would be needed in a fully operational status to meet the next day's flying schedule. Thus, only a few hours were available during each 24 hour period to complete B, C, and D inspection items and to perform any related or unscheduled maintenance on the airplane.

The Safety Board believes that the FAA should include in its procedures for the approval of airline maintenance programs, deviations in airplane use by the operator as compared to the manufacturer's original design estimate, tempered by the operating history of the existing fleet. A calendar cap for low-flight hour operators and a maximum cycle limit for short flight operators are more appropriate inspection intervals for these operators.

The Safety Board also believes that the FAA should reevaluate the criteria and guidance provided to principal inspectors for approving individual operator's maintenance plans that divide structural inspections into a large number of independent work packages (segments) to be spread over the normal D check interval. The Safety Board recognizes the concept that the D check, as outlined in the MPD, for each aircraft is accomplished in a reasonable time period such as 3 to 5 weeks. A true heavy maintenance inspection involves extensive work which may take several days. Comprehensive structural inspections for aging airplanes, likewise, can best be accomplished by a D check in which the entire airplane is inspected and refurbished in one hangar visit. As an alternative, some operators have found it efficient to use yearly block C checks with a phased 1/4 D check inspection. Any deviation from this "full airplane" inspection at "seasonal scheduling intervals" should be evaluated carefully before approval.

An examination of the remaining portion of the S-4R fuselage structure of N73711 indicated that the S-4R lap joint had been inspected and repaired as a result of AD 87-21-08 in November 1987. At that time, cracks were detected visually and two repairs were accomplished. Although Aloha Airlines maintenance personnel stated that an eddy current inspection of the remaining rivets in the panel was conducted to comply with the requirements of the AD, no mention of this inspection was found in the maintenance records.

Initial examination of the lap joint between the two repairs disclosed visually detectable fatigue cracks that emanated from the fastener holes of the top row of rivets. Laboratory examination revealed the presence of many more cracks that were well within the eddy current detectable range. Additionally, it was noted that the upper rivet row between the repairs and forward and aft of the repairs still contained the original configuration countersunk rivets.

Striation counts of five of the largest fatigue cracks that were present in the upper fastener holes of the section outside the repaired area indicated these cracks grew less than 0.020 inch during the time between the inspection in November 1987 and the accident. A total of 2,624 cycles had accumulated on the accident airplane during this time. After the accident, the cracks ranged in length between 0.110 to 0.154 inch. Therefore, at the time of the AD inspection in November, the five cracks ranged from a low of about 0.09 inch to a high of about 0.13 inch.

Eddy current inspections performed by Aloha inspectors on N73711 after the accident could not detect cracks that were less than 0.08 inch in length, but the inspection reliably detected cracks that were larger than 0.08 inch. Since the striation counts indicated cracks existed in the structure that were above this value (0.08 inch) in length, and that were well within the detectable size for eddy current inspection, such cracks should have been detected along the upper row of rivets in S-4R during the November 1987 inspection. This finding suggests that either the eddy current inspection was not performed in November or that the quality of the inspection was such that the cracks were not found.

There are several possibilities why the inspectors, when complying with the AD, failed to find the detectable crack in the S-4R lap joint on N73711, even though the area reportedly was given an eddy current inspection and two inspectors performed independent visual inspections. First, the human element associated with the visual inspection task is a factor. A person can be motivated to do a critical task very well; but when asked to perform that same task repeatedly, factors such as expectation of results, boredom, task length, isolation during the inspection task, and the environmental conditions all tend to influence performance reliability.

Another factor that can affect the human element involved in maintenance and inspection pertains to the effect of circadian rhythms on human behavior. Airline maintenance is most often performed at night and during the early morning hours; the time of day that has been documented to cause adverse human performance. Maintenance programs are most effective if task scheduling takes into account the possible adverse effects of sleep loss, irregular work and rest schedules, and circadian factors on the performance of mechanics and inspectors.

For example, compliance with AD-87-21-08 required a close visual inspection of the lap joints along S-4L and R and eddy current inspection of the upper row of lap joint rivets along the entire panel in which defects were found. This imposed considerable demands on the inspector if the results of the inspection were to be reliable. The AD required a "close visual inspection" of about 1,300 rivets and a possible eddy current inspection of about 360 rivets per panel. Inspection of the rivets required inspectors to climb on scaffolding and move along the upper fuselage carrying a bright light with them; in the case of an eddy current inspection, the inspectors needed a probe, a meter, and a light. At times, the inspector needed ropes attached to the rafters of the hangar to prevent falling from the airplane when it was necessary to inspect rivet lines on top of the fuselage. Even if the temperatures were comfortable and the lighting was good, the task of examining the area around one rivet after another for signs of minute cracks while standing on a scaffolding or on top of the fuselage is very tedious. After examining more and more rivets and finding no cracks, it is natural to begin to expect that cracks will not be found. Further, when the skin is covered with several layers of paint the task is even more difficult. Indeed, the physical, physiological, and psychological limitations of this task are clearly apparent.

Another factor that may have affected the performance of Aloha's maintenance and inspection personnel is related to the quality of support provided by Aloha management to assist these persons in the performance of their tasks. Proper training, guidance, and procedures are needed as well as an adequate working environment, sufficient aircraft down time to perform the tasks (i.e. flexible scheduling), and an understanding of the importance of their duties to ensure the airworthiness of the airplanes. Aloha Airlines training records revealed that little formal training was provided in NDI techniques and methods. The inspector who found the S-4R lap joint cracks requiring repair stated that only on-the-job training (OJT) had been provided since he became an inspector in August 1987; his training records show formal NDI training on September 17, 1987, when a 2-hour training session was given by a Boeing representative. Records indicate the inspector who provided the initial OJT had only 2 hours of formal NDI training, during the same 2-hour training session on September 17, 1987, provided by Boeing. Thus, the Safety Board is concerned about how much knowledge the inspector staff may have possessed about disbonding, corrosion, and fatigue cracking at the time that they were required to perform the critical AD inspection task. In fact, during deposition proceedings, the inspector who performed the first AD inspection on N73711 could not articulate what he should look for when inspecting an airplane for corrosion signs.

Also, Aloha's flying schedule involved full utilization of its airplane fleet in a daytime operation. Thus, the majority of Aloha's maintenance was normally conducted only during the night. It was considered important that the airplanes be available again for the next day's flying schedule. Such aircraft utilization tends to drive the scheduling, and indeed, the completion of required maintenance work. Mechanics and inspectors are forced to perform under time pressure. Further, the intense effort to keep the airplanes flying may have been so strong that the maintenance personnel were reluctant to keep airplanes in the hangar any longer than absolutely necessary.

Inadequate guidance and support from Aloha management to its inspectors was evident also when the Production and Planning department sent to the inspector's mail box, the AD and SB on the inspection requirements of the lap joints along S-4 without further review or technical comment. These documents were complicated, critical to airworthiness, and subject to interpretation as evidenced by the disagreement about its content expressed by experts at the Safety Board's public hearing. These documents needed higher level review and written guidance as to their disposition before being sent to maintenance for action. Therefore, the Safety Board concludes that Aloha's management failed to provide adequate guidance and support to its maintenance personnel and this failure contributed directly to the cause of this accident.

The policies, procedures, and organization of Aloha Airlines aircraft maintenance and inspection program significantly affected the control of corrosion of its airplanes. According to airplane maintenance records, lap joint and other areas of corrosion were detected, but corrective action was frequently deferred without recording the basis for such deferrals. Routine inspection task cards contained the "check for corrosion" instruction for specific areas; however, a programatic approach to corrosion prevention and control of the whole airplane was not evident. It appears that even when Aloha Airlines personnel observed corrosion in the lap joints and tear straps, the significance of the damage and its criticality to lap joint integrity, tear strap function, and overall airplane airworthiness was not recognized by the Aloha Airlines inspectors and maintenance managers. This was particularly noteworthy when one considers that Aloha Airlines indicated that SB 737-53-1039, Revision 2 (1974), was incorporated in their maintenance plan. The overall condition of the Aloha Airlines fleet indicated that pilots and line maintenance personnel came to accept the classic signs of on-going corrosion damage as a normal operating condition.

The Safety Board was also concerned about the uncommanded shutdown of the left engine during the accident sequence. The left engine fuel control was found in the "cutoff" position; the control apparently was positioned there by the residual tension in the intact cable or motion of that cable induced by the cabin floor deflection since the cables are routed through cutouts in the floor beams.

Since the point of maximum upward floor deflection (hence maximum cable deflection) was at BS 440 in the cabin, the actual location of the throttle cable failures (in the wing leading edge) seemed an unlikely one. Additionally, the broken cable ends lacked the unraveling that is characteristic of cables that fail in tension overload. When the appropriate cable sections were removed from the airplane and inspected more closely, there were indications of corrosion. These observations were confirmed by laboratory examination which concluded that the diameters of many of the individual wires that comprise the cables had been reduced significantly by corrosion damage. This corrosion likely weakened the cables so that they separated at a lower than designed load when placed in tension by the displacement of the left side floor beams. The cables of the right engine also exhibited extensive surface corrosion where they were routed through the leading edge of the wing. These cables may have remained intact during the separation sequence only because of the much smaller amount of floor beam deflection that occurred on the right side of the cabin.

The damage to the throttle cables appears much the same as the type of corrosion described in Boeing Service Letter (SL) 737-SL-76-2-A issued on August 25, 1977. This SL was issued as a result of the discovery by Aloha Airlines that a carbon steel thrust control cable had corroded and frayed. Only five of the seven strands of the cable were reported intact. The remaining five strands were also corroded, and the corrosion was present on the entire length of that portion of the cable routed through the wing leading edge.

The Boeing recommended action following this discovery was to replace the carbon steel engine control cables with corrosion resistant stainless steel cables on the production line beginning with production line number 503 which was delivered in September 1977. Boeing recommended that operators of existing airplanes replace the original carbon steel cables on production line numbers 1 through 502 as required. At this date, the number of aircraft modified in accordance with the applicable SL has not been established accurately. Laboratory examination of the separated cables from N73711 confirmed that they were the original carbon steel type. The Safety Board is concerned that Aloha Airlines did not take advantage of the manufacturer's corrective action for these cables, especially in light of their initial discovery of the problem and recognition of their own harsh operating environment.

The record establishes that corrosion problems were detected by Aloha maintenance personnel and, on occasion, repairs were deferred without a full evaluation by management of the airworthiness implications or appropriate reference to the structural repair manual. This leads the Safety Board to conclude that economic considerations, a lack of structural understanding, airplane utilization, and the lack of spare airplanes were factors which may have induced Aloha Airlines to allow these deferrals.

While it is the responsibility of the operator to develop and implement a proper and complete maintenance program applicable to the operating environment, the Safety Board believes that the FAA should define acceptable corrosion control program parameters and provide them as a guide for both the operator and the PMI. The Safety Board believes that an operator's comprehensive corrosion control program, fully supported by the manufacturer and enforced by the FAA, is a critical and necessary step in the continued airworthiness of an aging airplane fleet.

At the time of the accident, Aloha Airlines, like many small operators, did not have an engineering department. Some of the functions that are usually performed by engineers at large airlines were accomplished by Aloha Airlines Quality Assurance (QA) department.

The responsibilities of an airline engineering department generally include evaluating and implementing manufacturer's SBs and ADs, evaluating airplane accidental or corrosion damage, designing or evaluating repairs, establishing aircraft maintenance schedule specifications, and providing technical assistance to other areas of the airline. Another important aspect of engineering staff activities is the oversight of inspector performance and related quality assurance activites.

The condition of high cycle B-737s in the Aloha Airlines fleet with respect to lap joint corrosion, multiple repairs, and detection of fatigue cracking is an example of what can occur in the absence of regular and knowledgeable evaluations of aircraft condition by qualified engineering staff.

Aloha Airlines management could have recognized the importance of Alert SB 737-53A1039 in light of their own experience with the previous crack along the lap joint at S-10R and could have inspected all the lap joints called out in the referenced SB while they accomplished the requirements of AD 87-21-08. The same concept applies to the SL recommending replacement of engine control cables which were recognized by Aloha as susceptible to corrosion.

In addition, a qualified engineer should have interpreted the lap joint AD regarding the use of oversize protruding head fasteners in the event that fatigue damage was found. More importantly, a comprehensive structural engineering and maintenance program likely would have precluded the deteriorated condition of the airplanes by evaluating and implementing the appropriate corrosion control techniques and SBs, thus retaining company assets.

An additional area of concern to the Safety Board is the extent and number of skin repairs evident on the airplane and the effect that these repairs may have on the damage tolerance properties of the original design. The accident airplane had over two dozen fuselage repairs; the majority were skin repairs using doubler patches. This condition illustrates the extent to which aging airplanes may continue to be repaired (patched) in accordance with existing manufacturers and FAA requirements.

A large repair or the cumulative effects of numerous small repairs can adversely impact the ability of the structure to contain damage to the extent necessary to meet fail-safe or damage tolerant regulations. Additionally, the structure underlying the repairs can be difficult if not impossible to inspect, which can be detrimental where fuselage lap joints are concerned. These types of evaluations are typically beyond the expertise of QA and maintenance departments and must be addressed by qualified engineering personnel.

The Safety Board believes that the continued airworthiness of airplanes as they age would be enhanced by including qualified engineers in the operator's organization. While the Safety Board recognizes that situation may be economically unrealistic for all operators, it believes that an equivalent level of safety can be achieved only by using engineering representatives from some other source. Qualified engineers could evaluate service information and airworthiness directives with particular respect to the fleet aircraft and operating conditions. The assistance of these qualified engineers may be available through an industry group or the manufacturer.

In summary, the Safety Board believes that the Aloha Airlines maintenance department did not have sufficient manpower, the technical knowledge, or the required programs to meet its responsibility to ensure the continued structural integrity of its airplanes.

Therefore, as a result of its investigation of this accident, the National Transportation Safety Board recommends that Aloha Airlines:

> Revise the maintenance program to recognize the high-time high cycles nature of the fleet operations and initiate maintenance inspection and overhaul concepts based on realistic and acceptable calendar and flight cycle intervals. (Class II, Priority Action) (A-89-70)

Initiate a corrosion prevention and control program designed to afford maximum protection from the effects of harsh operating environments (as defined by the airplane manufacturer). (Class II, Priority Action) (A-89-71)

Revise and upgrade the technical division manpower and organization to provide the necessary management, quality assurance, engineering, technical training and production personnel to maintain a high level of airworthiness of the fleet. (Class II, Priority Action) (A-89-72)

The National Transportation Safety Board is an independent Federal agency with the statutory responsibility "... to promote transportation safety by conducting independent accident investigations and by formulating safety improvement recommendations" (Public Law 93-633). The Safety Board is vitally interested in any actions taken as a result of its safety recommendations and would appreciate a response from you regarding action taken or contemplated with respect to the recommendations in this letter. Please refer to Safety Recommendations A-89-70 through -72 in your reply.

Also, the Safety Board issued Safety Recommendations A-89-53 through -69 to the Federal Aviation Administration and A-89-73 to the Air Transport Association.

KOLSTAD, Acting Chairman, and BURNETT, LAUBER, NALL, and DICKINSON, Members, concurred in these recommendations.

By: James L. Kolstad
Acting Chairman