Adopted: 11-1-90

Log # 2265A

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: December 14, 1990

In reply refer to: A-90-176

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On July 19, 1989, at 1516, a DC-10-10, N1819U, operated by United Airlines (UAL) as flight 232, experienced a catastrophic failure of the No. 2 tail-mounted engine during cruise flight. The separation, fragmentation and forceful discharge of stage 1 fan rotor assembly parts from the No. 2 engine led to the loss of the three hydraulic systems that powered the airplane's flight controls. The flightcrew experienced severe difficulties controlling the airplane, which subsequently crashed during an attempted landing at Sioux Gateway Airport, Iowa. There were 285 passengers and 11 crewmembers onboard. One flight attendant and 110 passengers were fatally injured.[1]

The National Transportation Safety Board determines that the probable cause of this accident was the inadequate consideration given to human factors limitations in the inspection and quality control procedures used by United Airlines' engine overhaul facility which resulted in the failure to detect a fatigue crack originating from a previously undetected metallurgical defect located in a critical area of the stage 1 fan disk that was manufactured by General Electric Aircraft Engines. The subsequent catastrophic disintegration of the disk resulted in the liberation of debris in a pattern of distribution and with energy levels that exceeded the level of protection provided by design features of the hydraulic systems that operate the DC-10's flight controls.

Commercial air carriers certificated under Title 14 Code of Federal Regulations Part 121 operate per the basic maintenance regulations contained in Subpart L - Maintenance, Preventive Maintenance and Alterations. Key elements are trained personnel, proper instructions, and the required tooling and facilities.

[1] For more detailed information, read Aircraft Accident Report "United Airlines Flight 232, McDonnell Douglas DC-10-10, Sioux City, Iowa, July 19, 1989" (NTSB/AAR-90-06)

There were six maintenance inspections of the accident fan disk, including an inspection 760 cycles before the accident, which was performed in accordance with UAL procedures.

Fracture mechanics evaluations showed that at the time of the disk separation, a fatigue crack existed that was large enough to cause fracture and resulting separation of the fan disk under normal loads. The number of major striations on the fatigue region was nearly equal to the total number of takeoff/landing cycles on the disk (15,503), indicating that the fatigue crack initiated very early in the life of the disk.

The Safety Board attempted to determine the size of the fatigue crack at the time of UAL's fluorecent penetrant inspection (FPI) of the disk 760 cycles prior to the accident. One possibility was that the discolored portion of the fatigue crack was created during the alkaline cleaning of the disk in preparation for the inspection. The fractographic examination of the fatigue region disclosed no topographic explanation for the discoloration. In addition, the Safety Board is not aware of any operational environment or conditions that would cause such discoloration. For these reasons, the Safety Board concludes that the discoloration on the surface of the fatigue crack was created during some step in the FPI process performed by UAL 760 cycles prior to the accident, and that the discolored area marks the size of the crack at the time of this inspection. The actual surface length of the discolored area is 0.476 inch. The fracture mechanics analysis was also used to estimate the size of the fatigue crack at the time of the inspection. The analysis estimated that the surface length of the crack was 0.498 inch long at the last inspection.

Analytical procedures were developed to examine the smaller piece of the disk to determine if chemical residues from the UAL inspection were present on the fatigue fracture surface. Secondary Ion Mass Spectroscopy measurements on the fatigue fracture surface showed an ion fragmentation pattern that was consistent with chemical compounds used in the FPI fluid.

The UAL procedure warned inspectors that titanium parts resist the capillary action of the penetrant and that "complete penetrant coverage is required for these materials." Also, the procedure cautioned not to overwash the parts or the penetrant might be flushed out of true indications. The disk bore is mentioned as one of the critical areas for inspection.

A review of the inspection process suggests several explanations for the inspector's failure to detect the crack. It is possible that the inspector did not adequately prepare the part for inspection or that he did not rotate the disk, while it was suspended by a cable, to enable both proper preparation and subsequent viewing of all portions of the disk bore, particularly the area hidden by the suspension cable/hose. It is also possible that loose developer powder, which could have dropped from the suspension cable, obscured the crack sufficiently to prevent its recognition as a flaw. Finally, inspection experience indicates that certain areas of CF-6 disks, because of their geometry, frequently show large FPI indications and that other areas rarely do so. One such area of frequent indications is around the perimeter of the disk near the dovetail posts. By contrast, the

central bore area has apparently rarely produced FPI indications. Thus, it is possible that the inspector did not consider the bore area a critical area for inspection, as stated in UAL's inspection directives, and that he gave the bore area only cursory attention, thereby reducing the likelihood that a crack would be detected. Any of these possibilities, or some combination of them, could have contributed to nondetection of the crack.

The UAL maintenance program is comprehensive and based on industry standards. The company's inspection requirements for the CF6-6 stage 1 fan disk are generally consistent with other airline practices and comply with Federal regulations. Further, UAL's procedures for selecting, training, and qualifying nondestructive inspection (NDI) personnel are also consistent with industry practices. However, it is clear that the adequacy of the inspections is dependent upon the performance of the inspector. That is, there are human factors associated with NDI processes that can significantly degrade inspector performance. Specifically, NDI inspectors generally work independently and receive very little supervision. Moreover, there is minimum redundancy built into the aviation industry's FPI process to prevent human error or other task or workplace factors that can adversely affect inspector performance. Because of these and other similar factors, the Safety Board is concerned that NDI inspections in general, and FPI in particular, may not be given the detailed attention that such a critical process warrants.

The Safety Board addressed the issue of human factors in NDI inspector reliability following the Aloha Airlines B-737 accident near Maui, Hawaii, in April 1988. As a result of its investigation of the Aloha accident, the Safety Board issued two recommendations to the Federal Aviation Administration (FAA) that are relevant to the maintenance and inspection issues identified in this case.

A-89-56

Require formal certification and recurrent training of aviation maintenance inspectors performing nondestructive inspection functions. Formal training should include apprenticeship and periodic skill demonstration.

A-89-57

Require operators to provide specific training programs for maintenance and inspection personnel about the conditions under which visual inspections must be conducted. Require operators to periodically test personnel on their ability to detect the defined defects.

In its response to these recommendations, the FAA acknowledged that its Aging Fleet Evaluation Program has highlighted some of the same deficiencies outlined by the Safety Board and that it is addressing these issues as part of regulatory reviews of 14 CFR Parts 65 and 147. The FAA also indicated that the utilization of inspector personnel, and the human factors aspects

of such utilization, are also being examined. Based on the FAA's response, these recommendations have been classified as "Open--Acceptable Action."

The Safety Board also believes that the manual inspection systems used to inspect most aircraft structural and engine components are inherently susceptible to human factors problems that can significantly reduce the probability of detecting defects. Automation of NDI is already available with current technology. Automated eddy current, ultrasonic, and FPI equipment can be employed by airline maintenance centers. The Safety Board believes that the FAA should intensify research to identify emerging technologies for NDI that simplify or automate inspection processes, provide funding to initiate demonstration programs, and encourage operators and other parties that perform inspections to adopt superior techniques and equipment. The FAA should also encourage the development and implementation of redundant ("second set of eyes") inspection oversight for critical part inspections, such as for rotating engine parts.

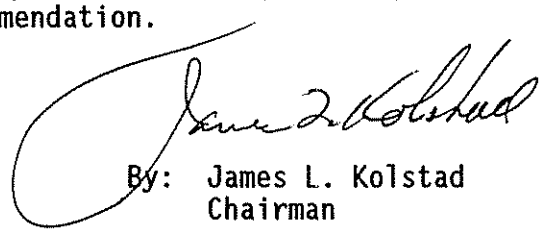
Therefore, as a result of its investigation, the National Transportation Safety Board recommends that the Air Transport Association:

> Encourage members to incorporate specific maintenance inspection techniques in their maintenance manuals and maintenance contracts that simplify, automate and provide redundant ("second set of eyes") inspection oversight for critical part inspection, such as for rotating engine parts. (Class II, Priority Action) (A-90-176)

Also, the Safety Board issued Safety Recommendations to the Aerospace Industries Association of America, the Federal Aviation Administration and the U.S. Department of the Air Force.

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 recommendation in this letter. Please refer to Safety Recommendation A-90-176 in your reply.

KOLSTAD, Chairman, COUGHLIN, Vice Chairman, LAUBER, BURNETT, and HART, Members, concurred in this recommendation.



By: James L. Kolstad
Chairman