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National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

DCA-89-MA063

Date: June 18, 1990

In reply refer to: A-90-88 through -91

Honorable James B. Busey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

The National Transportation Safety Board's investigation of the United Airlines DC-10 accident in Sioux City, Iowa, on July 19, 1989, has revealed that the separation of the fan Stage I rotor disk of the No. 2 engine (a General Electric CF6-6D engine) initiated from a metallurgical anomaly (hard alpha) on the inside diameter surface of the disk bore near its forward corner. As a result of the accident, the Federal Aviation Administration issued Airworthiness Directive (AD) 89-20-01, effective October 7, 1989. This AD required that certain CF6-6 engine fan Stage I rotor disks be inspected in accordance with General Electric Aircraft Engines (GEAE) Service Bulletin 72-947, dated September 15, 1989. Both the service bulletin and the AD were issued before the pieces of the separated disk were recovered in October, 1989.

Titanium metal is processed in batches, referred to as "heats", that have the composition of the final alloy. The raw material that goes into a given heat can consist of processed ore (primarily pure titanium), alloying elements, scrap, and portions of other heats. Each heat of metal is homogenized and purified by repeatedly arc melting the heat in a vacuum furnace. Many of the CF6-6 engine fan disks were made from heats that had been melted twice (the double vacuum melting process). After 1971, General Electric changed their specifications to require three vacuum meltings (the triple vacuum melting process). The AD and service bulletin identify those CF6-6 engine fan Stage I rotor disks that records indicate are from the same heat of metal as the separated disk (Category I disks), those that have raw material in common with the separated disk (Category II disks), and those that were made with the double vacuum melting process instead of the triple vacuum melting process (Category III disks). The service bulletin also describes a contact ultrasonic inspection, which can be accomplished on-wing, and an immersion ultrasonic inspection, which requires that the disk be removed from the engine. The disks listed in AD 89-20-01 as being in

Category I have been removed from service.[1] In accordance with AD 89-20-01, all Category II and III disks should have been subjected to an initial contact ultrasonic inspection, and all Category II disks should have received an immersion ultrasonic inspection by April 1, 1990. The immersion ultrasonic inspection of Category III disks can be postponed until December 31, 1990, as long as the disks are subjected to the contact ultrasonic inspection at intervals of 500 cycles or less.

For some time the Safety Board has expressed concerns about the ability of ultrasonic inspections to detect cracks initiating from the surface of the bore area of the CF6-6 fan Stage I rotor disk. Because of noise associated with entrance of an ultrasonic beam into a part, ultrasonic inspections are not capable of detecting flaws in a volume of material immediately adjacent to the beam's entry point. In addition, the curved surfaces and the complex geometry of the final disk shape give rise to areas that are difficult to ultrasonically inspect. Because of these factors, the Safety Board believes that not all portions of the subject disks are receiving an adequate inspection by ultrasonics. One area that is not adequately inspected by ultrasonics is the forward corner of the bore inside diameter surface. This area is especially critical because the hoop stresses (circumferential stresses that act to expand the diameter of the disk) are greatest at this location. Using fracture mechanics and finite element computer models, GEAE engineers have estimated the propagation behavior of a surface crack (as opposed to a subsurface crack) at the forward corner of the bore inside diameter surface. This estimate shows that a surface crack at this location could propagate from a size just below the level of detectability (using the contact ultrasonic inspection) to a critical size in significantly fewer than 500 cycles. Information in AD 89-20-01 indicates that a subsurface crack in the most critical location would propagate from just below the level of detectability to failure in approximately 1000 cycles. This difference in the number of cycles to failure demonstrates the importance of a reliable surface inspection method that is capable of detecting a surface crack well before it reaches a critical size.

One of the scan modes that is part of the contact ultrasonic inspection is specifically designed to detect radial/axial cracks in the bore of the disk. However, this mode can not inspect either the forward or aft corners of the bore inside diameter surface. Although the immersion ultrasonic inspection may have a greater sensitivity for the detection of interior defects, none of the scan modes used during the immersion inspection generate an ultrasonic beam that would impinge on a radial/axial crack in the bore of the disk and reflect the beam back to the receiver at the optimum angle to be detected. Consequently, the Safety Board is concerned that the immersion ultrasonic inspection may not be any more capable of detecting radial/axial surface cracks in the disk bore than the contact ultrasonic inspection. Therefore, the Safety Board concludes that the provisions of AD 89-20-01, taken alone, are inadequate to detect these potentially critical cracks.

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[1] The Safety Board's investigation of the Sioux City accident has produced chemical analyses indicating that the disks listed as Category I disks may be from two or more heats of metal. If this is correct, the disks intended to be in Category I and II may not be correctly identified. The Safety Board's

GEAE has indicated that the ultrasonic inspections are to be used in conjunction with surface inspection methods to ensure the airworthiness of the CF6-6 disks. The Safety Board is unaware of any surface inspection method, other than fluorescent penetrant inspection, that is currently being used for these disks. The Safety Board recognizes that the United Airlines FAA-approved maintenance procedures for the CF6-6 engine require that the Stage I disk be florescent penetrant inspected each time it is disassembled from other engine components. However, the fatigue crack that led to the separation of the fan Stage I disk on the accident airplane was not detected by United Airlines personnel when the disk was fluorescent penetrant inspected 760 cycles prior to the accident. The Safety Board's investigation has revealed evidence suggesting that, at the time of this fluorescent penetrant inspection, the crack was of a detectable size. United Airlines believes that stresses associated with the shot peened surface of the disk may have kept the crack closed, making it undetectable, or caused the surface length of the crack to be very small. The Safety board has not yet determined if the crack was not detected because of an inadequate inspection method, an inadequate application of that method, or a combination of both. Nevertheless, because the crack was not detected, the Safety Board is concerned about the adequacy of fluorescent penetrant inspections and believes that there is a need for an alternate surface inspection method, such as eddy current inspection, to ensure that a critically-sized crack does not develop in one of the CF6-6 fan disks currently in use.

The Safety Board is also concerned that there are no requirements for a CF6-6 engine fan disk to be repeatedly subjected to any type of surface inspection at an interval that will ensure that an undetectable surface crack does not grow to a critical size. The Safety Board believes that fracture mechanics and damage tolerance concepts need to be applied to the disk to determine the maximum number of cycles that should be allowed to accumulate on the disk before it is reinspected using the alternate surface inspection method. This cyclic inspection interval should be based upon the minimum crack size detectable by the alternate inspection method, the stress level in critical areas of the disk, and the crack propagation characteristics of the disk material.

The Safety Board is aware that most of the major rotating components in turbine engines are designed according to "safe life" principles. However, the Safety Board believes that the circumstances of the Sioux City accident demonstrate the need for interim inspections at specific intervals to ensure the airworthiness of critical rotating turbine engine components. Interim inspections of these components would lessen the probability that an undetected crack or other flaw could grow to a critical size and lead to the separation of a major rotating component, with possible catastrophic damage to the structure or systems of an airplane.

For the above reasons, the Safety Board believes that the critical rotating components in all currently-certificated engines should receive damage tolerance or fracture mechanics evaluations similar to the damage tolerance evaluations afforded significant structural elements of an airplane. These damage tolerance evaluations should assume that the component material contains flaws below the detectable inspection limit in critically-stressed areas. Inspections methods and inspection intervals indicated by these evaluations should become a mandatory part of the maintenance of all engines. Furthermore, the Safety Board believes that a damage tolerance approach should be incorporated into the certification process for all engine models that are certificated in the future.

The metallurgical anomaly that led to the separation of the disk involved in the Sioux City accident was located on the disk bore surface near the most critical location. During the manufacturing process, GEAE performed an ultrasonic inspection of the disk while it was in an intermediate shape that was slightly larger than the final part shape in the bore area. No defects were reported during this ultrasonic inspection. However, ultrasonic inspection would not be expected to detect the metallurgical anomaly (hard alpha) that existed in the accident disk if there were no voids or areas of significant cracking associated with the defect. GEAE also performed a surface macroetch inspection of the intermediate shape of the disk during the manufacturing process; no defects were reported. However, the Safety Board concludes that the metallurgical anomaly could have been detected during the manufacturing process if the surface macroetch inspection had been applied to the final part shape instead of to the intermediate shape.

Although there have been many improvements over the years in the methods of processing titanium, there are no assurances that the defect rate of titanium parts is now, or will ever be, zero. Therefore, it is possible that currently-produced titanium parts could also contain metallurgical anomalies. Thus, the Safety Board believes that a surface macroetch inspection of currently-produced critical titanium-alloy parts should be performed on the final shape of the part.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

1) Develop, with the assistance of General Electric Aircraft Engines, an alternate method of inspecting the bore area of the CF6-6 engine fan Stage I rotor disks for the presence of surface cracks; issue an Airworthiness Directive to require that these disks be inspected with this method on an expedited basis, that disks found to have cracks be removed from service, and that the inspection be repeated at a cyclic interval based upon the crack size detectable by the inspection method, the stress level in the applicable area of the disk, and the crack propagation characteristics of the disk material. (Class I, Urgent Action) (A-90-88)

2) Evaluate currently certificated turbine engines to identify those engine components that, if they fracture and separate, could pose a significant threat to the structure or systems of the airplanes on which the engines are installed; and perform a damage tolerance evaluation of these engine components. Based on this evaluation, issue an Airworthiness Directive to require inspections of the critical components at intervals based upon by the crack size detectable by the approved inspection method used, the stress level at various locations in the component, and the crack propagation characteristics of the component material. (Class III, Longer Term Action) (A-90-89)

3) Amend 14 CFR part 33 to require that turbine engines certificated under this rule are evaluated to identify those engine components that, if they should fracture and separate, could pose a significant threat to the structure or systems of an airplane; and require that a damage tolerance evaluation of these components be performed. Based on this evaluation, require that the maintenance programs for these engines include inspections of the critical components at intervals based upon the crack size detectable by the inspection method used, the stress level at various locations in the component, and the crack propagation characteristics of the component material. (Class III, Longer Term Action) (A-90-90)

4) Require turbine engine manufacturers to perform a surface macroetch inspection of the final part shape of critical titanium alloy rotating components during the manufacturing process. (Class II, Priority) (A-90-91)

On August 17, 1989, the Safety Board issued Recommendations A-89-95, A-89-96, and A-89-97. These recommendations requested a directed safety study of the CF6-6 engine, issuance of an Airworthiness Directive to require inspections identified by the directed safety study, and an evaluation of the need for a directed safety study of all GEAE CF6 series engines. The Safety Board believes that Recommendations A-90-88, A-90-89, and A-90-90 (the first three recommendations in this letter) encompass these earlier recommendations, and the Safety Board is therefore classifying Recommendations A-89-95, A-89-96, and A-89-97 as "Closed - Superseded".

KOLSTAD, Chairman, COUGHLIN, Acting Vice Chairman, LAUBER and BURNETT, Members, concurred in thse recommendations.

By: James L. Kolstad
Chairman