



National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: August 25, 1995

In reply refer to: A-95-84 and -85

Honorable David R. Hinson
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On April 10, 1995, during a takeoff roll at Cairo, Egypt, an Egypt Air Airbus Industrie A300B4 airplane equipped with General Electric CF6-50C2 engines sustained an uncontained separation of the stage 3 through 9 high pressure compressor (HPC) rotor spool in the No. 1 engine, serial number (S/N) 528-305 (see illustration). The crew rejected the takeoff, stopped the airplane on the runway, and ordered an emergency evacuation of passengers. A small fire along the underside of the HPC in the left engine was reported to the crew of the A300B4 by the crew of another aircraft. Although there was no fire warning indication in the cockpit, the crew executed ground fire procedures, which included discharging of a fire bottle into the No. 1 engine. The small fire under the left wing was subsequently extinguished by ground personnel. One passenger sustained a minor injury in the course of exiting the aircraft via the emergency slide. The remainder of the 264 passengers, 9 flight attendants, and 3 pilots reported no injuries.

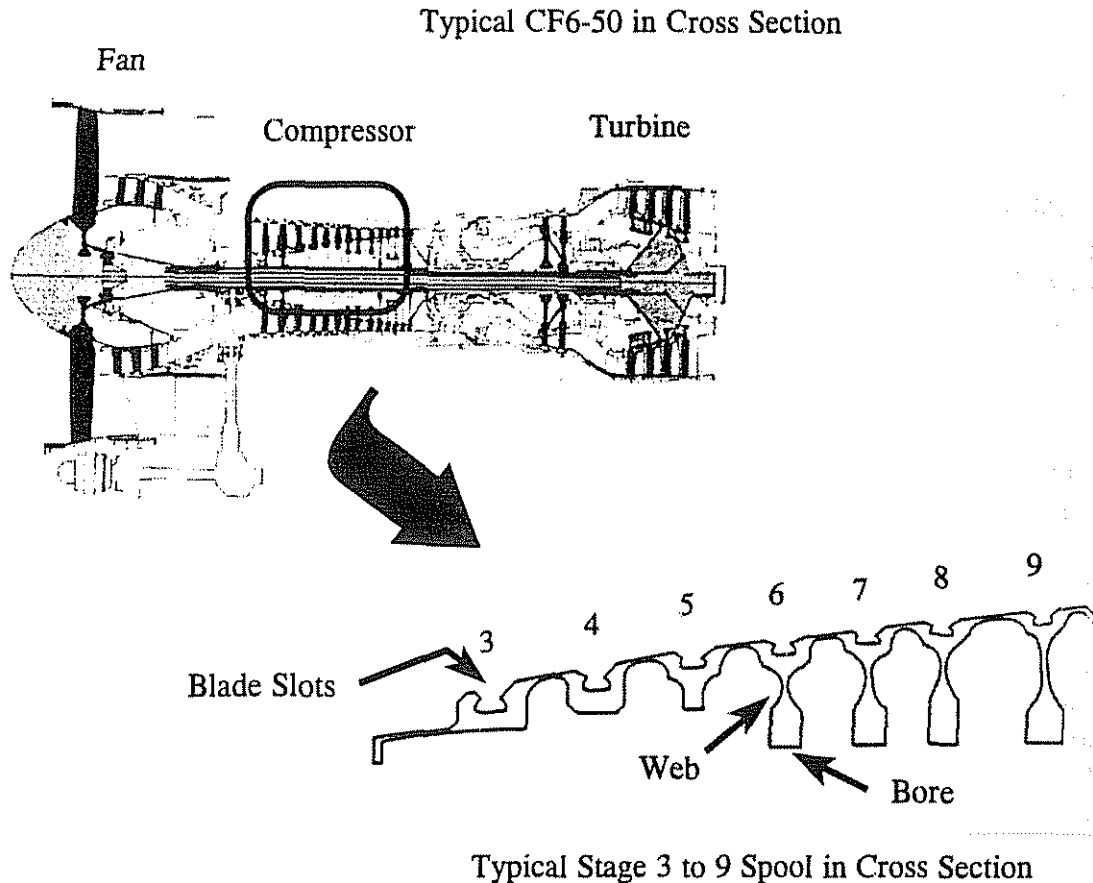
Postaccident investigation revealed substantial engine damage in the area of the HPC. Numerous pieces of the compressor were scattered along the runway. In accordance with the provision of Annex 13 to the Convention on International Civil Aviation, the accident investigation branch of the Egyptian Civil Aviation Authority requested the assistance of the National Transportation Safety Board with the investigation of the accident. The recovered pieces of the HPC stage 3 through 9 rotor spool and the compressor case were sent to the Safety Board for metallurgical examination.

The HPC stage 3-9 spool, P/N 9136M89G08, S/N MPON 2479, is a one-piece machined forging containing stage 3 through 9 compressor disks. It is made of Ti-6242 titanium alloy¹ and, according to General Electric, was manufactured in 1982 from a 13-inch-diameter billet.² Records indicate that since 1982, the spool had accumulated a total of 15,544 hours and 8,264 flight cycles. Maintenance records show that in March 1992, at 6,745 cycles (1,519 cycles prior to the

¹Titanium-based alloy containing 6 percent aluminum, 2 percent tin, 4 percent zirconium, and 2 percent molybdenum.

²A semifinished round product that has been hot worked by forging prior to machining of the spool.

accident), the HPC stage 3-9 spool was subjected to a fluorescent penetrant inspection³ when the compressor section was overhauled.



The metallurgical examination revealed that the failure of the HPC rotor spool was caused by a fatigue fracture in the stage 6 disk. The fatigue cracking initiated from a nitrogen stabilized "hard alpha"⁴ inclusion located on the aft side of the disk web. After initiation, the crack propagated on a radial plane forward through the web thickness in both inboard (towards the disk bore) and outboard (towards the rim) directions until it had reached a critical size of about 1.54 inches. The estimated number of fatigue striations on the fracture is approximately equal to the number of flight cycles on the spool. Assuming that each striation represents one flight cycle, the

³During fluorescent penetrant inspection, a dye is applied to the surface of the part. The dye penetrates cracks and leaves a surface indication detectable with fluorescent light.

⁴Nitrogen stabilized hard alpha inclusions are anomalies in titanium alloys. They usually form during initial melting of raw materials and are caused by localized excess amounts of nitrogen that have been introduced through atmospheric reaction with titanium in the molten state.

crack began propagating very early in the service life, perhaps with the application of the first cycle of stress.

General Electric records indicate that there have been three additional separations of the HPC stage 3-9 spool in CF6 series engines caused by fatigue cracking from hard alpha inclusions. These separations occurred in 1974, 1979, and 1983, and the spools had respectively accumulated 483 cycles, 2,854 cycles, and 3,233 cycles since new. Fatigue cracks from hard alpha inclusions have been detected during inspection of two other stage 3-9 spools. These spools had accumulated 8,918 cycles and 8,051 cycles since new.

Each time the compressor section is overhauled, the stage 3-9 spool is subjected to a fluorescent penetrant inspection per standard maintenance procedures. However, the Safety Board has learned that many operators do not use optimum inspection procedures and that portions of the spool that are not easily viewed, such as the web areas, may not have received an adequate inspection. On August 10, 1995, General Electric addressed this issue in a wire to all CF6 operators (Message Numbers 95-6-13, 95-50-25, 95-80A-14, 95-80C-16, and 95-80E-14). This wire suggests specific procedures to be used during the fluorescent penetrant inspection of the stage 3-9 spool. The Safety Board believes that the expeditious implementation of these procedures is necessary to ensure the detection of cracks of the type that caused the Cairo accident.

The Safety Board is aware that HPC stage 3-9 spools have also separated for a reason not related to hard alpha inclusions. On May 11, 1995, a McDonnell Douglas DC-10 airplane experienced an uncontained separation of the HPC 3-9 spool on the tail-mounted General Electric CF6-50C2B engine during takeoff from Bangkok, Thailand. The engine debris penetrated the right inboard elevator, damaging three ribs. No systems were damaged, and there was no loss of flight control. The airplane returned to the airport without further incident, and no injuries were reported. The spool was manufactured from a 13-inch-diameter billet, and at the time of the separation had accumulated 8,438 cycles since new.

Investigation of the Thai incident revealed that the stage 8 disk in the HPC rotor stage 3-9 spool contained a fatigue fracture in the forward face of the disk bore. The fatigue crack extended 0.80 inch in the radial direction and 0.57 inch in the axial direction. Fractographic features were typical of a phenomenon known as "dwell time" fatigue. Dwell time fatigue is a type of fatigue cracking that occurs when the peak cyclic load is sustained at a relatively low temperature. According to General Electric, dwell time fatigue occurs in colonies of alpha grains with a specific crystallographic orientation and is limited to only a few titanium alloys. The Ti-6242 alloy used for the stage 3-9 spool was selected because of its creep resistance. However, it has been found that this alloy is susceptible to dwell time fatigue when an aligned alpha colony is present.

The fractographic features in dwell time fatigue zones do not contain crack arrest positions. Therefore, the exact location of the fatigue origin area of the spool from the Thai accident could not be determined. According to General Electric, the spool had been inspected by ultrasonic and fluorescent penetrant methods in April 1991, at 7,107 cycles since new (1,331 cycles before the incident). During the inspection, an indication of a defect was found at the location of the fatigue crack. According to information obtained by General Electric, the disk was reworked, the spool

passed an inspection, and it was returned to service. General Electric indicated that the size of the ultrasonic indication found during the initial inspection is consistent with a crack length of about 0.24 inch.

General Electric has identified two other spools that separated as a result of dwell time fatigue. The first of these occurred in 1985, in Dakar, Senegal, on a spool that was made from a 16-inch-diameter billet and that had accumulated 4,075 cycles since new. This uncontained spool failure occurred in the tail engine of a McDonnell Douglas DC-10-30 airplane during takeoff climb, when the stage 9 disk in the spool ruptured. The other separation was in 1991 on a spool with 10,564 cycles since new.

The Safety Board investigated an additional incident involving the uncontained separation of the HPC rotor stage 3-9 spool from a CF6-80C2 engine. In October 1993, an Airbus A300-605R operated by American Airlines was climbing out from Los Angeles International Airport when the spool separated. The pilot declared an emergency and returned to the airport. No injuries were reported. Examination of the airplane revealed that the stage 6 disk in the stage 3-9 spool had fragmented and ruptured the engine case. The spool was manufactured from a 13-inch-diameter billet. At the time of the event, the stage 3-9 spool had accumulated 4,403 cycles since new, and had received no in-service inspections.

The pieces of the stage 6 disk were not recovered. Metallurgical evaluation of stages 3-5 and 7-9 of the spool was conducted at the facilities of General Electric. No defects that could have caused the separation of the stage 6 disk were found. However, the microstructure of the spool material contained features that made the spool susceptible to dwell time fatigue. Later analysis indicated that the spool microstructure was typical for spools of that vintage, and the cause of the disk separation has not yet been determined. The Safety Board believes that the separation of the stage 6 disk likely was caused either by dwell time fatigue or fatigue stemming from a hard alpha inclusion.

The HPC stage 3-9 spool was first manufactured in 1971 (for the CF6-50 model engine). Originally the spool was forged from a 16-inch-diameter billet. Beginning in 1980, the billet diameter for CF6-50 spools was reduced to 13 inches to provide for enhanced inspectability and for more working of the material during forging. Also in the same time frame, General Electric began to produce two-piece spools from 12-inch and 13-inch-diameter billets. In the two-piece configuration, the two forged and machined pieces of the spool are inertial welded together and then heat treated. Production of the one-piece spools continued until 1988. Currently only two-piece spools from 8-inch-diameter billets are produced. Until very recently, all two-piece spools received a post-weld solution heat treatment followed by slow cooling. General Electric tests have shown that the slow cooling caused excessive growth of alpha grains and, therefore, an increased susceptibility to dwell time fatigue. Recent changes in the process specifications have replaced the solution heat treatment with a post-weld stress relief process, thereby eliminating the slow cooling from high temperature and the propensity for grain growth.

General Electric reported that it has manufactured a total of 650 HPC stage 3-9 spools from 16-inch-diameter billets. Of these, 638 spools are installed in CF6-50 model engines, and 12 spools are installed in CF6-80A model engines. A total of 2,700 spools have been produced from 13-inch-diameter billets. Of these, 1,844 are installed in -50 models, 441 are installed in -80A models, and 415 are installed in -80C2 models. A total of 2,241 two-piece spools have been produced. Of these, 612 are installed in the CF6-50 model, 30 are installed in the -80A model, and 1,599 are installed in the -80C2 model.

Prior to the 1993 incident at Los Angeles International Airport, all reported failures and crack indications were in the bore areas of stage 3-9 spools made from 16-inch-diameter billets. General Electric believed that these spools were susceptible to dwell time fatigue because of insufficient working during forging. As a result of the history of failures and detected cracks, spools from 16-inch-diameter billets were subject to several service bulletins that defined and improved ultrasonic and eddy current inspection techniques applicable to the bore of the spool during shop visits. On October 25, 1991, the Federal Aviation Administration (FAA) issued Airworthiness Directive 91-20-1, requiring, within 3,500 cycles, one-time ultrasonic and eddy current inspections of spools produced from 16-inch-diameter billets. On February 16, 1995, the FAA issued AD 95-03-01, specifying that spools made from 16-inch-diameter billets be repeatedly inspected at an interval not to exceed 4,000 cycles.

A large percentage of the stage 3-9 one-piece spools have already been inspected under the inspection program described in the service bulletins and airworthiness directives. These inspections detected dwell time fatigue cracks in 15 spools, all made from 16-inch-diameter billets. Of the inspected spools made from 13-inch-diameter billets, one spool has been found with dwell time fatigue cracks. The cycles on the spools with cracks ranged between 3,275 and 10,540. Only a few two-piece spools have been inspected, and no crack indications have been found. Because they have been manufactured more recently, the two-piece spools generally have accumulated fewer cycles and less in-service time.

Similarly manufactured stage 3-9 spools are used in the CF6-50, -80A, -80C2 and -80E model engines. These engines are installed on Airbus A-300, A310, and A330 airplanes, Boeing 747 and 767 airplanes, and McDonnell Douglas DC-10 and MD-11 airplanes. The failure and crack detection history of spools made from both 16-inch-diameter and 13-inch diameter billets indicates that all one-piece spools are susceptible to dwell time fatigue. Also, two-piece spools made before the elimination of the solution heat treatment step could contain microstructural characteristics that are susceptible to dwell time fatigue. The Safety Board believes that HPC stage 3-9 spools made before the recent elimination of the post-weld solution heat treatment should be subjected to mandatory inspections to detect possible cracks. Because the earliest dwell time fatigue failure occurred at 4,075 cycles since new (the Dakar incident), the inspections should be performed at an interval substantially less than 4,000 cycles. Although the separations of the stage 3-9 spool have not caused a serious or catastrophic accident, the Safety Board believes that the potential for such an accident exists and that action should be taken immediately.

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

Issue an Airworthiness Directive to require that the fluorescent penetrant inspection procedure described in a wire to all General Electric Aircraft Engine CF6 operators (Message Numbers 95-6-13, 95-50-25, 95-80A-14, 95-80C-16, and 95-80E-14) be immediately incorporated by operators into the maintenance programs of the CF6 engines. (Class I, Urgent Action) (A-95-84)

Revise Airworthiness Directive 95-03-01, applicable to General Electric CF6-50, -80A, and -80C2 model engines, to require repeated inspections of all high pressure compressor rotor stage 3 to 9 spools, except for the two-piece spools that have not been solution heat treated after welding. The maximum interval between inspections should be appropriately less than 4,000 cycles. (Class I, Urgent Action) (A-95-85)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT and GOGLIA concurred in these recommendations.



By: Jim Hall
Chairman