National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: June 28, 2000

In reply to refer to: A-00-61 and -62

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On October 7, 1998, at 0710 eastern daylight time, a Continental Airlines (Continental) Boeing 727-224 airplane, N66734, operating as flight 1521, experienced an uncontained failure of its No. 2 (center), Pratt & Whitney (P&W) JT8D-9A engine during the takeoff roll at Miami International Airport, Florida. Flight 1521 was a regularly scheduled domestic passenger flight from Miami to Houston, Texas, operating under the provisions of 14 Code of Federal Regulations Part 121. The captain reported that while he was advancing the engine power levers, he heard a loud bang and immediately retarded the power levers, rejecting the takeoff. After the airplane was stopped, the flight crew discharged one fire bottle, and all crewmembers and passengers deplaned using a portable airstair. There were no reported injuries.

The National Transportation Safety Board's investigation revealed that fragments of the engine's 8^{th}-stage high pressure compressor (HPC) hub penetrated the engine, passed through the cowlings, and penetrated the airplane's vertical stabilizer. Investigators determined that the trajectory of the liberated hub fragments had come within inches of the rudder control cables. Pieces of the engine and cowling were recovered from the runway and surrounding areas.

Continental maintenance records indicated that the 8^{th}-stage hub, part number 787008, serial number N33354, had accumulated 176 cycles since its last overhaul and 15,539 total cycles at the time of the accident; the hub has a published life limit of 20,000 cycles. The maintenance records indicated that, during its last overhaul, the 8^{th}-stage hub had been nickel-cadmium (NiCd) plated[1] by Wings Aviation Services, Inc. (Wings), Miami, Florida, in April 1996 before installation into the accident engine by Greenwich Air Services, Miami (now GE Engine Services) in February

[1] Steel rotating engine parts, such as hubs and disks, undergo a NiCd plating process at manufacture and overhaul to protect them from corrosion and pitting.

1998. According to the P&W JT8D Engine Manual and the Overhaul Standard Practices Manual, the NiCd plating process is accomplished by applying a 0.0004- to 0.0007-inch layer of nickel on the base material (steel), followed by a 0.0001- to 0.0002-inch layer of cadmium on top of the nickel. The P&W JT8D Engine Manual indicates that the nickel thickness should be measured using an approved coating thickness gage before the process is continued. The process then calls for the hub to be baked[2] for 60 minutes at about 630° F.

Metallurgical examination of the 8th-stage hub at the Safety Board's materials laboratory revealed that the primary hub fracture stemmed from a crack that extended inboard from the rim radius partially into the bore. The fracture initiation site contained a significant amount of cadmium in contact with the base material and on the fracture surface, indicating that the hub failed because of cadmium embrittlement.[3] The source of the cadmium was the NiCd plating on the exterior surface of the hub. Analysis of the plating on multiple cross sections through the hub revealed primarily a single layer of diffused NiCd ranging from 0.00008 to 0.00019 inches thick and no pure nickel layer adjacent to the steel surface. The exact thickness of the initial nickel layer that was applied to the accident hub could not be determined because the diffusion process reduces it to create the NiCd layer. However, it became clear during the investigation that insufficient nickel was applied to the hub during the plating process because all measurements of the diffused NiCd layer were less than the 0.0004- to 0.0007-inch specification for the initial pure nickel layer. This deficiency suggests that the nickel thickness inspection specified in the maintenance manual was either omitted or performed incorrectly.

During its investigation of this accident, the Safety Board learned that an October 12, 1995, customer audit of Wings revealed that the facility had not been measuring the nickel thickness as required but was performing only a visual inspection. In addition, during a November 24, 1998, visit at the Wings facility, Safety Board staff witnessed an electrical malfunction of a nickel plating tank while a disk was being NiCd plated. This malfunction caused a circuit breaker to trip, which terminated the plating process before sufficient nickel was applied. No audible or visual alarms alerted the operator that the tank had malfunctioned and shut down before the process had been completed.

An uncontained engine failure similar to the Continental failure occurred on April 28, 1997, and also involved an improperly NiCd plated part. United Airlines (United) flight 1210, a Boeing 737-222 equipped with P&W JT8D-7B engines, experienced an uncontained failure of the No. 2 (right) engine's 10th-stage HPC disk during takeoff from O'Hare International Airport, Chicago, Illinois. The captain rejected the takeoff following the engine failure, stopped the airplane, discharged one fire bottle, and ordered an evacuation of the airplane. There was no secondary airframe damage, and two passengers sustained minor injuries during the evacuation.

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[2] The baking process causes the cadmium to diffuse into the nickel. Thus, when the prescribed thickness of nickel and cadmium has been applied, baking creates two distinct layers—a pure nickel layer next to the surface of the hub and a diffused NiCd layer on top of the nickel layer. The nickel acts as a barrier coating between the cadmium and the base material to prevent the cadmium from migrating into the steel.

[3] Cadmium embrittlement is a brittle cracking phenomenon in a normally ductile material that is caused by diffusion of cadmium into the material when it is subsequently stressed in tension. When a sufficient cross section of the part is cracked, the part separates under normal applied loads.

Metallurgical examination of the United 10^{th}-stage disk revealed fractures that stemmed from large intergranular areas in the steel surface where solidified molten cadmium was present; no pure nickel layer was observed adjacent to the steel. The Safety Board determined that the 10^{th}-stage disk failed because of cadmium embrittlement as a result of an inadequate nickel coating. Investigation of United's NiCd plating process revealed that United used deposition rates for determining plating thickness instead of using gages to measure each part as specified in the engine manual. The Safety Board's findings prompted Safety Recommendation A-97-83, which asked the FAA to review and revise, in conjunction with engine manufacturers, air carriers, and certificated repair stations, the published plating guidance, plating equipment, inspection procedures, inspector training, including any electronic and visual aids, and supervision currently in place for performing NiCd plate, and other plating processes that could lead to cadmium embrittlement of steel rotating engine parts.

The FAA responded to the recommendation by evaluating NiCd plating practices, procedures, equipment, training, and inspection standards at two repair stations. The review revealed that improper processing during maintenance and overhaul was the root cause of failure of steel rotating parts. The FAA also issued Flight Standards Information Bulletin for Airworthiness (FSAW) 98-11, which provides information to all FAA inspectors involved in the certification and surveillance of repair stations and operators authorized to perform NiCd plating operations. FSAW 98-11 directs maintenance inspectors to perform repair station audits during normal surveillance to ensure that proper plating procedures are being followed and to provide background information on cadmium embrittlement, recent failures in service, and repair station audit findings. On March 12, 1999, on the basis of the FAA's response, the Safety Board classified Safety Recommendation A-97-83 "Closed—Acceptable Alternate Action." Although FSAW 98-11 appears to provide inspectors who are visiting overhaul shops with adequate information to detect deficiencies in the NiCd plating process, it does not appear to be sufficient in preventing engine parts from being improperly plated during routine operations when an inspector is not present or if the process is momentarily left unattended.

Although the Continental and United uncontained HPC failures did not cause a loss of life or catastrophic airplane damage,[4] the Safety Board notes that the failure of steel rotating engine parts, such as an HPC disk or hub, can have more critical consequences, especially if it occurs at maximum power or if fragments penetrate fuel lines, fuel cells, critical control system components, or hydraulic systems. For instance, on May 3, 1991, during the takeoff roll, a Ryan International Airlines Boeing 727-100QC, departing from Windsor Locks, Connecticut, experienced a P&W JT8D HPC disk failure (burst) that resulted from a fatigue crack. Engine debris was ejected and severed an engine fuel supply line. The fuel ignited, burned through the fuselage, and ignited the cargo. The flight crew aborted the takeoff but was unable to extinguish the fire before it destroyed the entire airplane.[5] In addition, on June 8, 1995, also during the takeoff roll, a ValuJet Douglas DC-9-32, departing from Atlanta, Georgia, experienced a P&W

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[4] As noted previously, in the Continental accident, liberated hub fragments came within inches of the rudder control cables. If those cables had been severed, the consequences of that incident could have been much more severe.

[5] For more information, see Brief of Accident NYC91FA125.

JT8D HPC disk burst that resulted from a fatigue crack. As a result, shrapnel penetrated the fuselage and punctured an engine fuel supply line, causing a cabin fire that destroyed the airplane. A flight attendant sustained serious injury when she was struck by hot engine debris, and another flight attendant and five passengers received minor injuries.[6]

The Continental and United events demonstrate that failure to properly perform all steps of the NiCd plating procedure on steel rotating engine parts can lead to catastrophic failure of the parts. After reviewing the circumstances of these events and considering Safety Board staff's observations at Wings, the Board is concerned about the continued NiCd plating of steel rotating engine parts. The Board is aware that there are FAA-approved corrosion protection coating alternatives to NiCd plating that have been used successfully for many years to resist oxidation and corrosion in commercial and military gas turbine engines. These coatings are aluminum-based paints that do not diffuse into and embrittle steel like cadmium; therefore, no protective layer is needed between these coatings and the steel. The Safety Board is not aware of any failures of steel parts related specifically to problems with aluminum-based paints.

The Safety Board is also aware that before the April 1997 incident, United solicited and gained approval from P&W to use Sermetel (one of the approved aluminum-based paints) instead of NiCd plating on P&W steel HPC disks.[7] United informed the Safety Board that it had voluntarily discontinued NiCd plating of HPC disks because United believed Sermetel has better corrosion and erosion protection. The Board considers the use of such alternative corrosion protection methods important in the effort to prevent failures of steel rotating parts in turbine engines. Therefore, the Board believes that the FAA should require the use of alternative corrosion protection methods instead of NiCd plating on steel rotating engine parts to eliminate the hazards introduced by improper NiCd plating.

Further, the events discussed in this letter suggest that such improper NiCd plating techniques may continue to be performed in industry and that maintenance personnel may not be receiving adequate initial and recurrent training in the NiCd plating process. Therefore, the Board believes that the FAA should issue a flight standards information bulletin requiring principal maintenance inspectors to ensure that facilities performing plating operations have a specific training program for the NiCd plating process and that maintenance personnel receive this training on a recurring basis.

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

> Require the use of alternative corrosion protection methods instead of nickel-cadmium (NiCd) plating on steel rotating engine parts to eliminate the hazards introduced by improper NiCd plating. (A-00-61)

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[6] National Transportation Safety Board. 1996. *Uncontained Engine Failure/Fire Valujet Airlines Flight 597 Douglas DC-9-32, N908VJ, Atlanta, Georgia, June 8, 1995*. Aircraft Accident Report NTSB/AAR-96/03. Washington, D.C.

[7] United began sending disks through the Sermetel process in March 1997.

Issue a flight standards information bulletin requiring principal maintenance inspectors to ensure that facilities performing plating operations have a specific training program for the nickel-cadmium plating process and that maintenance personnel receive this training on a recurring basis. (A-00-62)

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

Original Signed

By: Jim Hall
Chairman