Log #2652

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: August 29, 1997

In reply to refer to: A-97-83

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

On April 28, 1997, United Airlines (United) flight 1210, a Boeing 737-222 equipped with Pratt & Whitney (P&W) JT8D-7B engines, experienced an uncontained failure of the No. 2 (right) engine high pressure compressor (HPC) 10th-stage disk during takeoff from O'Hare International Airport, Chicago, Illinois. Flight 1210 was a regularly scheduled passenger flight from Chicago to Philadelphia, Pennsylvania, operating under the provisions of Title 14 Code of Federal Regulations (CFR) Part 121. 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; two passengers sustained minor injuries during the evacuation. The investigation of this incident is continuing; however, information gathered thus far raises concerns that the National Transportation Safety Board believes require Federal Aviation Administration (FAA) action.

The investigation has determined that during the initial part of the takeoff roll, before the engines had achieved takeoff power, a failure occurred within the engine, which caused two disk fragments, compressor blades, and other pieces of the engine to be ejected through the engine nacelle structure. The components were recovered from the runway and surrounding area. Postincident examination of the engine revealed that two approximately 2- x 4-inch fragments separated from the 10th-stage HPC disk. Examination of the disk revealed a 4-inch, circumferential fracture around the snap diameter,[1] with three additional fractures emanating diagonally outward toward the rim. Also, cracks emanated radially outward from two tierod holes, one of which bisected the fracture at the snap diameter. No cracks were detected on any of the other HPC compressor disks in the engine.

[1] A snap is a feature that engages the inner and outer diameters of two adjacent components. The two diameters are machined to slightly different dimensions, typically between 0.005 to 0.010 inch, such that the tight (interference) fit aligns and locks the parts together

United maintenance records indicate that the 10th-stage HPC disk, part number 772510, serial number P51489, had 25,063 total hours and 16,198 total cycles since new.[2] However, the HPC, including the fractured 10th-stage disk had been overhauled 38 hours (33 cycles) before the failure at the United Maintenance Operations Center (MOC), in San Francisco, California.

The JT8D 10th-stage disk, which is made from steel, is similar in design to most axial-flow compressor[3] disk designs. A nickel-cadmium (NiCad) plate is applied to the steel disk at manufacture and overhaul as a corrosion prevention measure for the disk. According to the P&W Engine Manual, "Repair 03 for the 10th-stage Disk," nickel is first applied to the steel to a thickness between 0.0005 and 0.0006 inch. According to the P&W Overhaul Standard Practices Manual, cadmium is then plated onto the nickel layer to a thickness between 0.0001 and 0.0002 inch. This adds up to a total plating thickness of between 0.0006 and 0.0008 inch. The nickel is a barrier coating that keeps the cadmium from migrating into and embrittling the steel during high temperature operation. After these plating layers are applied, the disk is baked in an oven, causing the cadmium to diffuse into the nickel to form a single NiCad layer. Subsequent to the original type design, FAA approval was obtained for the steel disks to be coated with an aluminum-based paint, called Sermetel, a more effective corrosion prevention alternative.

Metallurgical examination of the disk at the Safety Board's materials laboratory showed that the fractures stemmed from large intergranular areas in the steel substrate. Solidified molten cadmium was detected along the grain boundaries of these intergranular areas indicative of liquid metal (cadmium) embrittlement.[4] A small area measuring less than 0.1 inch on the surface of the fillet radius of the forward snap diameter adjacent to the 4-inch circumferential fracture contained no visible evidence of plating; however, elemental analysis of this area indicated a trace of nickel and cadmium. The remaining surface of the disk was found to have one layer of plating that measured between 0.00006 and 0.00015 inch thick, with the exception that the thickness of the plating layer in certain areas on the forward and aft face of the outer web measured as much as 0.00025 inch; all of these were far below the NiCad plating thickness (0.0006-0.0008 inch) specified in the P&W Engine and Overhaul Standard Practices Manuals. Trace amounts of nickel and cadmium in nearly equal amounts were detected throughout the thickness of the diffused NiCad layer. No nickel-rich layer was found adjacent to the steel surface. Although the thickness of the first-applied nickel layer could not and need not be determined in the investigation, it likely was insufficient because, during high temperature operation of the engine, the cadmium migrated into the steel causing cadmium embrittlement of the steel.

[2] One cycle is equivalent to one takeoff and landing.

[3] An axial-flow compressor incorporates numerous, alternating stages of blades and stators that increase air pressure in incremental amounts across each stage. The air pressure and temperature rises when the speed of the air is increased across the rotating blades then decreased across the nonrotating stators. Each stage of rotating blades is retained within a disk. The disks are intermixed with spacers and clamped with tierods to form a rotor that rotates about a horizontal axis.

[4] Liquid metal embrittlement is a phenomenon in which, under conditions of high temperature and stress, the molten metal (cadmium) diffuses into the steel disk along the grain boundaries. The cadmium diffuses into the highly stressed areas causing liquid metal embrittlement cracks. When a sufficient cross section of the disk is cracked, the disk separates under normal applied loads.

The failed disk had been plated at the United MOC on February 10, 1997. The Safety Board learned that the plating of the incident disk coincided with the training period of an employee (from February 4 through February 28, 1997) who was new to the NiCad plating line.[5] Interviews with the trainee revealed that during his training period he was not sure how to operate the 1,000 ampere rectifier[6] used to plate the nickel.[7] Also, there were deficiencies in United's plating equipment. For example, on February 5, the trainer discovered an anomaly with the 1,000 ampere rectifier on the nickel plating tank used to plate the incident disk. A 4-volt output from the rectifier was discovered with the rectifier set to zero volts. The 4 volts reduced to zero volts if a disk or other component made electrical contact with the 1,000 ampere rectifier bus bar in the plating cell. The disk is normally plated with 4 volts while immersed in the plating tank. Poor electrical connection would still produce a 4-volt reading and even though little plating occurs the reading may indicate to the operator that the plating is normal.

During the investigation, United identified 37 critical rotating components (hubs, disks, and shafts) that had been NiCad plated by the trainer and trainee from February 4 through February 28, 1997. United also identified four critical rotating components that had been NiCad plated by the trainee from April 1 through April 18. The trainee was not assigned to the NiCad plating line from March 1 to March 31. Consequently, United removed from service four spare engines, 13 engines on operating airplanes, and additional parts from its spare part inventory or that were undergoing rework.

Based on findings from the Safety Board's materials laboratory regarding the incident disk, United's MOC examined the plating thickness of several of the disks from the population of critical components that were NiCad plated by the trainer and the trainee. United's examination found that the typical thickness of the diffused NiCad plating of these disks was 0.00012 inch, which is below P&W's specified thickness of 0.0006 to 0.0008 inch. The investigation found that although the NiCad process in the United Engine Manual 72-36-44/AR01 specified measurement of the nickel and cadmium plating for appropriate thickness, United's MOC was using deposition rates for determining plating thickness. Also, there were differences between P&W's and United's specifications for nickel plating thickness. For example, the United General Processes Manual GN/MM 5-0-2-7 indicated that the plating thickness for nickel should be between 0.0002 to 0.0004 inch, which falls short of the 0.0005 and 0.0006 inch thickness specified in the P&W Engine Manual, "Repair 03 for the 10th-stage Disk."

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[5] The NiCad plating line consists of a series of tanks (approximately 20) where, depending on the plating requirements (component size, parent material, plating thickness, etc.), components are immersed in some or all of the tanks in rapid succession. Certain tanks incorporate electrical power supplies and various electrolytic, cleansing, and neutralizing solutions. As the plating operator immerses the component in a plating tank, the component makes electrical contact with a bus bar. The operator then adjusts the amperage to the component with the power supply and nickel, cadmium, or other electrolytes are deposited in thin layers on the surface of the part.

[6] A rectifier is an electrical device that permits electron flow in only one direction. In this application, the 1,000 ampere rectifier converts alternating current into direct current.

[7] The electrical power supply for the nickel plating tank has a 50 ampere, two 100 ampere, and a 1,000 ampere rectifier that provides the electrical current to the component. Depending on the size of the component (surface area), the plating operator selects the proper rectifier and adjusts the current by varying the applied voltage.

The NiCad plating procedures at United have been reviewed and corrective actions[8] are being taken. Further, on March 7, 1997, United discontinued routing P&W steel HPC disks to the NiCad line for plating and has substituted Sermetel for the NiCad plating process. However, NiCad plating continues to be used throughout the industry to protect aircraft engine parts from corrosion.

This incident, as well as past engine failure experience,[9] has shown that inadequate nickel plating can cause catastrophic failure of major rotating components. The Safety Board is concerned that inspector procedures, training, and supervision may not be fully adequate to ensure reliable plating of critical rotating engine parts in other repair stations. Therefore, the Safety Board believes that the FAA should review and revise, in conjunction with engine manufacturers, air carriers, and certified 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 NiCad plate and other plating processes that could lead to liquid metal embrittlement of high energy rotating engine parts.

Therefore, as a result of its ongoing investigation of this accident, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Review and revise, in conjunction with engine manufacturers, air carriers, and certified 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 NiCad plate and other plating processes that could lead to liquid metal embrittlement of high energy rotating engine parts. (A-97-83)

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[8] United reported in a July 1, 1997, letter to the FAA's Manager, San Francisco Certificate Management Office, the following corrective actions to the NiCad plating line:

a. The NiCad plating process was shutdown pending a review of all significant documents controlling the process.
b. A revision to the General Processes Manual (GN/MM) procedure 5-0-2-7 had been made to define the plating process in a step-by-step method creating a more user-friendly process.
c. All NiCad plating job planning cards have been revised to add a requirement to measure and record the nickel plating thickness prior to applying the cadmium. Coating measurement instrument tool model EMX-D was purchased to accomplish this task.
d. The plating shop training manual has been revised to reflect the new NiCad plating process.
e. All NiCad platers are in the process of being qualified under the new NiCad plating training program.
f. The NiCad process has been recertified by Quality Assurance and was reviewed with the FAA Certificate Management Office.
g. A plate shop alert bulletin was distributed and reviewed with all plate shop personnel. The alert bulletin outlined the corrective actions to be taken by the plate shop.
h. Load sheets have been implemented for local use to record all items processed in the NiCad line.
i. Training procedures have been revised to include mathematical formulas to determine process parameters. Additionally, rectifier set-up procedures have also been added to the training curriculum.
j. Job hint sheets were made illustrating the part as well as containing specific details to be used in the plating process.

[9] On July 23, 1990, the crew of a JT8D-9 equipped Boeing 737-100, reported that during climb they heard a muffled explosion followed by a loss of rpm of the No. 1 engine. The crew returned to Houston, Texas, without incident. Engine examination revealed a failure of the 8th-to 9th-stage HPC disk spacer due to liquid metal embrittlement.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation

By: Jim Hall
Chairman