National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

CORRECTED COPY

Date February 13, 1998

In reply refer to: A-98-8

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

On April 23, 1996, a Delta Air Lines McDonnell Douglas MD-88 airplane, N985DL, operating as flight 1593, experienced an uncontained low pressure turbine (LPT) failure[1] in the No. 2 (right) engine during a regularly scheduled Title 14 Code of Federal Regulations (CFR) Part 121 passenger flight from Washington, D.C., to Atlanta, Georgia. The flightcrew reported that while cruising at flight level (FL) 310, they heard a "loud bang" from the No. 2 engine, a Pratt & Whitney (P&W) JT8D-219, serial number (SN) 725978. The engine lost power, followed by a loss of oil pressure and quantity. The pilot shut down the engine, declared an emergency, and diverted to the Raleigh-Durham International Airport without further incident.

Inspection of the aircraft revealed a 3-foot by 1-foot hole in the upper cowling of the No. 2 engine nacelle with no other noted aircraft damage. Examination of the engine revealed that the bolts securing the rear turbine case rear flange to the turbine exhaust case (TEC) front flange had fractured, allowing the two flanges to separate, creating an opening approximately 1-inch wide. Considerable impact damage was observed on the inner diameter of both cases; however, neither case was penetrated. The 4th stage blades exited the engine through the opening between the cases before damaging the engine cowling.

Examination of the LPT revealed that all the 4th stage turbine blades, part number (PN) 798404, were fractured transversely across the airfoil just above the blade root platform, and that the blade roots were retained in the disk. Metallurgical examination of one blade root revealed high cycle fatigue (HCF)[2] that initiated on the convex airfoil side and propagated from 75 to 80 percent through the airfoil before failing in overload. No defects were observed in the fracture

[1] This is the only documented case of an uncontained low pressure turbine blade event occurring in a JT8D-200 engine.

[2] HCF is the mechanism in which cracks propagate an incremental amount from the bending stresses associated with resonant frequency vibration. The vibration can cause rapid crack progression through a component. The failure can occur under normal operational stress after the crack progresses through sufficient cross section of the component.

origin area. Examination of the 4th stage LPT blade shroud notches[3] that were recovered from the exhaust case revealed evidence of extreme notch wear estimated at 0.030 to 0.050 inch in depth.

In response to reports of numerous rear turbine case/TEC attachment bolts fracturing during LPT blade fracture events, P&W issued Service Bulletin (SB) 6149 on January 19, 1994, to provide bolts made of a stronger material. The original bolts, made of Tinidur, a steel alloy, lacked the strength needed to prevent the flanges from separating during an LPT blade failure. The stronger bolt, made of Inconel 718, a nickel alloy, improves the containment capability of the flange. Tinidur bolts were involved in this event.

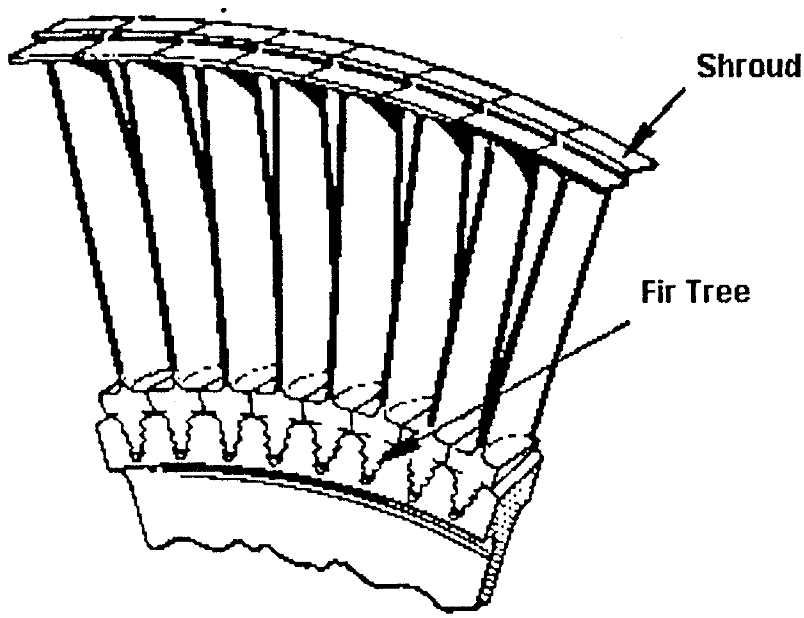
Two days after this event, on April 25, 1996, another Delta Air Lines, McDonnell Douglas MD-88 airplane, N959DL, operating as flight 591, experienced a contained No. 1 (left) engine LPT failure while climbing from FL 310 to FL 330. The flightcrew reported hearing a "loud bang" from the No. 1 engine, a P&W JT8D-219, SN 725977. The pilot shut down the engine and diverted to Shreveport, Louisiana, where the landing was uneventful and no injuries occurred.

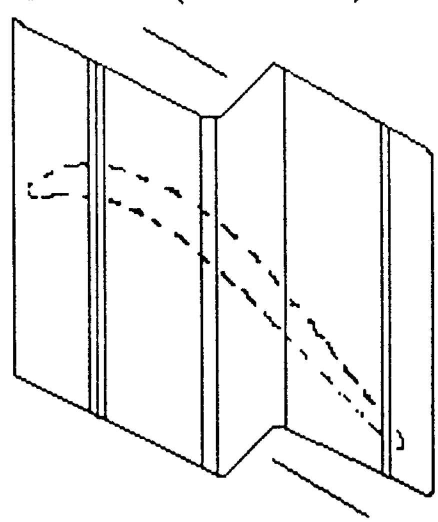
Examination of the LPT revealed that all of the 3rd and 4th stage turbine blades were fractured transversely across the airfoil just above the blade root platform. As in the first incident, metallurgical examination of a 4th stage LPT blade, PN 798404, revealed HCF cracking that originated on the airfoil convex side. No defects were noted at the fatigue origin. No evidence of fatigue was observed on the 3rd stage LPT blades, nor were any 3rd or 4th stage blade shrouds recovered to determine the extent of the shroud notch wear.

Along with the HCF on the 4th stage LPT blades, there were other similarities to indicate a connection between the two events and possible causes. The engine serial numbers were consecutive (725977 and 725978); both engines had approximately the same number of cycles (10,833 and 10,862) at the time of failure; both LPT modules were essentially in the same condition as when they were delivered from P&W, with no repairs performed to the internal components; and both 4th stage LPT blades were PN 789404, which has a thin shroud notch configuration.

The JT8D LPT blade design incorporates a blade tip shroud for structural support and vibration dampening. The blade shrouds interlock to provide stiffness so that they function as a single ring to reduce blade flexing caused by thermal, aerodynamic and centrifugal loads. The shroud notches (contact areas) are coated with PWA 694, which is a cobalt alloy that is a hard temperature and wear resistant material, to help reduce wearing. Worn shroud notch surfaces reduce blade damping and drop the blades' resonance frequency into the engine operating range. This increases the vibratory stresses to levels that can initiate fatigue cracking.

[3] The blade is a casting. The shroud is an integral part of the blade and it is located outboard on the airfoil.





Typical Top View of Blade

According to P&W, the JT8D-200 series engine has experienced 180 3rd and 4th stage LPT blade failures resulting from two different failure modes. The first is excessively worn LPT blade notches that can result in HCF fractures occurring at the root of the 3rd and 4th stage blades. P&W indicated that approximately 95 percent of all 3rd and 4th stage blade failures are the result of worn shroud notches. The second is a low cycle fatigue (LCF)[4] crack initiating in the 4th stage blade shroud fillet resulting in a cross-notch failure.

P&W addressed the wear problem by increasing the blade's shroud notch contact area. The objective was to reduce the notch wear rate and thereby reduce blade failures. Three SBs were issued to introduce new 3rd and 4th stage LPT blade designs. SB 5867[5] was issued on September 22, 1989, to replace the 3rd stage thin shroud notch blade configuration with a blade featuring an increased contact area. There have been only two documented 3rd stage LPT blade failures of this new blade. SBs 6029[6] and 6090[7] were issued on June 18, 1991, and August 6, 1992, respectively, to introduce 4th stage blades with a similar larger contact area. There have been 18 recorded blade failures since the introduction of the two new blades. At a briefing conducted for the FAA and the Safety Board on October 11, 1997, P&W stated that the increased failure rate is due to the addition of more shroud material used for the thick notch. This extra material increased the LCF stresses in the shroud fillet radius resulting in thick notch shroud failures. The blade design was upgraded to reduce the fillet radius stresses so that the shrouds would no longer fracture, but kept the thick notch configuration to address the fractures due to excessive notch wear. P&W issued SB JT8D-6308 on October 10, 1997, to introduce this upgraded 4th stage LPT blade and made it available to the operators in early November 1997. Thus far, there is not yet any operational experience with this current design.

On March 7, 1996, an American Airlines McDonnell Douglas MD-82 airplane, N73444, operating as flight 1853, experienced a contained No. 2 engine failure en route to Orlando, Florida. The flightcrew reported hearing a "loud bang" and experienced a subsequent loss of power in the No. 2 engine, a P&W JT8D-217C, SN 718479. The airplane returned to Chicago, Illinois, without further incident. Engine disassembly revealed that all of the 3rd and 4th stage LPT blades were fractured near the airfoil root. The engine was equipped with the 4th stage LPT blade, PN 808904, that was introduced by SB 6090. The increased blade shroud notch surface on this blade was designed to have eliminated the HCF fractures at the blade root platform that occurred in this event.

From 1973 through 1989, there were 527[8] documented cases of 3rd and 4th stage LPT blade HCF fractures occurring in JT8D-1 through -17AR series engines.[9] The LPT blade failures

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[4] LCF is the mechanism in which cracks propagate an incremental amount from the increased pressure, temperature, and centrifugal stresses associated with starting an engine and increasing the thrust to takeoff power.

[5] SB 5867 replaced blade PN 772203 with PN 804303. The change is applicable to -209, -217 and -217A series. There have been 88 documented LPT blade, PN 772203, fractures. This accounted for 85 percent of all 3rd stage -200 blade failures. Approximately 65 percent of the current -200 series engine fleet has PN 804303 blades installed.

[6] SB 6029 replaced blade PN 775404 with PN 804304. The change is applicable to -209, -217 and -217A series. There have been 32 documented LPT blade, PN 775404, fractures. This accounted for 31 percent of all 4th stage -200 series blade failures. Approximately 72 percent of the current -200 series engine fleet has PN 804304 blades installed.

[7] SB 6090 replaced or modified PNs 798404 and 810504 with PN 808904. The change is applicable to -217C and -219 series engines. There have been 27 documented LPT blade, PN 798404, fractures. This accounted for 26 percent of all the 4th stage -200 series blade failures. Approximately 75 percent of the current -200 series engine fleet has PN 808904 blades installed.

[8] This is the number of documented blade failures at the time of the issuance of ASB A5913 on April 2, 1990.

were caused by excessively worn shrouds resulting in 21 uncontained turbine events. To manage the problem, P&W issued an alert service bulletin (ASB), A5913, on April 2, 1990, to perform recurrent inspections for wear on the blade notches for installed 3rd and 4th stage LPT blades. The FAA mandated this action with the issuance of Airworthiness Directives (AD) 94-20-08 and 94-20-09, on November 14, 1994. The inspection uses a mechanical tool made up of a torque screwdriver and notch gauge. The tool is inserted through the exhaust duct and placed between two adjacent 3rd or 4th stage LPT blades. The tool is then rotated to separate the blades, and the amount of torque to do so is recorded. This gives an indication of the amount of wear present on the blade notches. Blades that have worn shrouds require less torque to separate and vice versa. Analysis of the torque check data indicated that the inspection was effective in identifying worn notches before blade failures in JT8D-1 through -17AR series engines.

P&W determined that the same failure mechanism that had occurred in the JT8D-1 through -17AR series was also occurring in the -200 series. Based on the success of the torque check on -1 through -17AR series engines, P&W issued SB 6224 on October 12, 1995, to address the -200 series engines just as ASB A5913 had for the -1 through -17AR series. However, because of differences in blade geometry and operating environment for the -200 series engines, the inspection interval and torque limits were varied. The notch gauges were redesigned, and the number of inspection locations within the 3rd and 4th stage LPT were modified. P&W recommended that the time intervals listed in SB 6224 not be considered hard requirements because the times were based on limited service data and those operators, who had established inspection intervals based on their own experience, are continuing to use their own criteria until operational data results in revised limits. Thus far, there is no information available from the operators that verifies whether the torque check on the -200 series is effective and the proposed inspection interval is appropriate.

Several operators, including American Airlines, Trans World Airlines and Continental Airlines, are using an isotope inspection (x-ray) to determine the amount of wear on the blade shrouds, instead of the torque check. From the x-ray, the blade offset and shroud gap are measured to determine the notch wear. P&W is currently reviewing this technique and the operators' proposed limits, and is collecting data to determine the inspection's effectiveness. Other operators are using shims to measure the gap between blades and to define acceptable wear limits. Each of the techniques mentioned may be effective, but the torque check remains the only P&W-approved procedure for determining the amount of blade notch wear. The lack of operational data on any of these inspection techniques makes determining the appropriate method(s) for measuring the wear difficult.

Worn LPT blade shrouds can result in blade failures causing considerable engine and aircraft damage on JT8D-200 series engines even with the incorporation of the redesigned blades with the thicker shroud notch. The Safety Board concludes that recurrent inspection of the 3rd and 4th stage LPT blades for notch wear is needed to prevent future failures. Therefore, the Safety Board believes that the FAA should determine the effectiveness of inspection techniques used to measure the amount of shroud wear on installed 3rd and 4th stage low pressure turbine

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[9] Of the 527 LPT events, 456 were 3rd stage and the remaining 71 were 4th stage. Thirteen of the uncontained events were 3rd stage LPT failures with the remaining 8 4th stage.

blades on P&W JT8D-200 series turbofan engines, and mandate inspection techniques determined to be most effective based on an interval derived from failure and operational data.

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

> Determine the effectiveness of inspection techniques used to measure the amount of shroud wear on installed 3rd and 4th stage low pressure turbine blades on Pratt & Whitney JT8D-200 series turbofan engines, and mandate inspection techniques determined to be most effective based on an interval derived from failure and operational data. (A-98-8)

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

By: Jim Hall
Chairman