National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date:

In reply refer to: A-99-12 through -15

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

On March 30, 1998, Royal Airlines flight 311, a Boeing 727-212 airplane, registered in Canada as C-FRYS, experienced an uncontained failure[1] of the low pressure turbine (LPT) in the No. 2 engine, a Pratt & Whitney (P&W) JT8D-17A, during the takeoff roll at the Fort Lauderdale-Hollywood International Airport, Fort Lauderdale, Florida. The flightcrew reported that at approximately 100 knots, they felt a thud, and the engine fail light in the cockpit illuminated. The takeoff was rejected, and the No. 2 engine fire warning light illuminated. The flightcrew discharged both fire extinguishing bottles into the No. 2 engine nacelle, stopped the airplane on an adjacent taxiway, and initiated an evacuation of the airplane. Of the 186 revenue passengers, 2 infants, and 8 flight crewmembers on board, 10 passengers sustained injuries during the evacuation. The airplane was operating on an instrument flight rules flight plan under the provisions of 14 Code of Federal Regulations Part 129 as an international charter passenger flight from Fort Lauderdale to Toronto, Canada.

Because the airplane was operated by a Canadian-certificated air carrier, the Transportation Safety Board of Canada assisted in the National Transportation Safety Board's investigation under the provisions of Annex 13 to the International Convention on Civil Aviation. Because the engine had been previously repaired by Volvo Flygmotor AB,[2] Trollhättan, Sweden, the Safety Board was also assisted by the Swedish Board of Accident Investigation during the review of the failed engine's repair records.

The examination of the airplane revealed that the No. 2 engine's left and right aft cowl doors had numerous penetrations and fire-blistered paint just aft of the LPT; however, the airplane sustained no other damage. The fire was caused by fuel and oil from several severed lines in the aft section of the engine.

[1] An uncontained engine failure occurs when an internal part of the engine fails and is ejected through the cowling or causes other pieces of the engine to be ejected through the cowling.
[2] Volvo Flygmotor AB has since changed its name to Volvo Aero Corporation.

The JT8D engine's low pressure rotor system is made up of a two-stage fan, which consists of the 1st and 2nd stage fan rotors,[3] and a four-stage low pressure compressor (LPC), which consists of the 3rd, 4th, 5th, and 6th stage compressor rotors. The two-stage fan and four-stage compressor are joined to the three-stage LPT, which consists of the 2nd, 3rd, and 4th stage turbine rotors, by a drive shaft, all of which rotate as one unit under normal conditions (see figure 1). The examination of the incident engine revealed that the 1st and 2nd stage fan rotors and the 3rd stage compressor rotor rotated together but independently from the remainder of the low pressure rotor system from the 4th stage compressor rotor rearward. The examination also showed that the 2nd, 3rd, and 4th stage LPT disks were intact but that all of the LPT blades were fractured adjacent to the blade root platforms, and most of the LPT vanes were missing. Although the engine was outfitted with an LPT containment shield, as required by Airworthiness Directive (AD) 94-20-09, the containment shield was broken into three pieces, and the engine was cut in two just aft of the LPT by liberated LPT blades.[4]

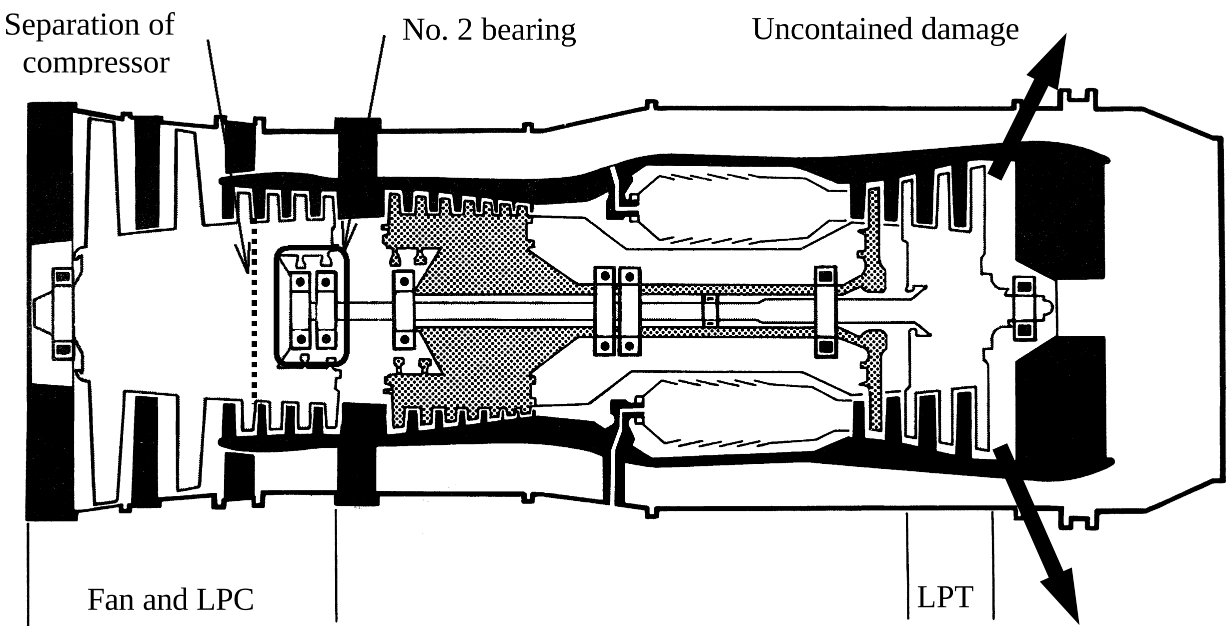

Figure 1. JT8D engine

The 4 stages of the JT8D engine's LPC are held together by 12 long bolts, called LPC rear tierods, that pass through alternating disks and spacers (see figure 2). The disassembly of the Royal Airlines LPC revealed that one LPC rear tierod, part number (PN) 789550, was fractured transversely across the tierod's 4th stage compressor disk land.[5] The entire fracture face on the

[3] A rotor stage refers to the compressor or turbine disk or hub and the respective installed blades.
[4] The aft section of the engine and thrust reverser assembly remained attached to the airplane by the aft engine mount cone bolt.
[5] A tierod compressor disk land is a larger diameter section of the tierod that passes through the compressor disk's tierod hole. The diameter of the tierod compressor disk land is about 0.010 inch less than the diameter of the compressor disk's tierod hole.

tierod had surface corrosion, suggesting that the tierod had been broken for some time. Because of overstress, the 11 remaining LPC rear tierods were fractured at their forward ends between the 3rd stage compressor disk lands and the tierod nut threads. All six of the recovered tierod nuts and ends had numerous pockmarks on one side, and the tierod ends were bent away from the pockmarks. The pockmarks and bending damage suggest that after the initial tierod fractured and was liberated from the compressor, it tumbled around in the cavity at the front of the LPC and impacted the other tierod nuts and ends until they eventually fractured, causing the compressor to separate between the 3rd and 4th stage rotors and the engine to fail. Eleven equally spaced fan exit vanes had the imprints of the tierod nuts on the leading edge, indicating that the 11 remaining tierods fractured simultaneously when the engine failed.

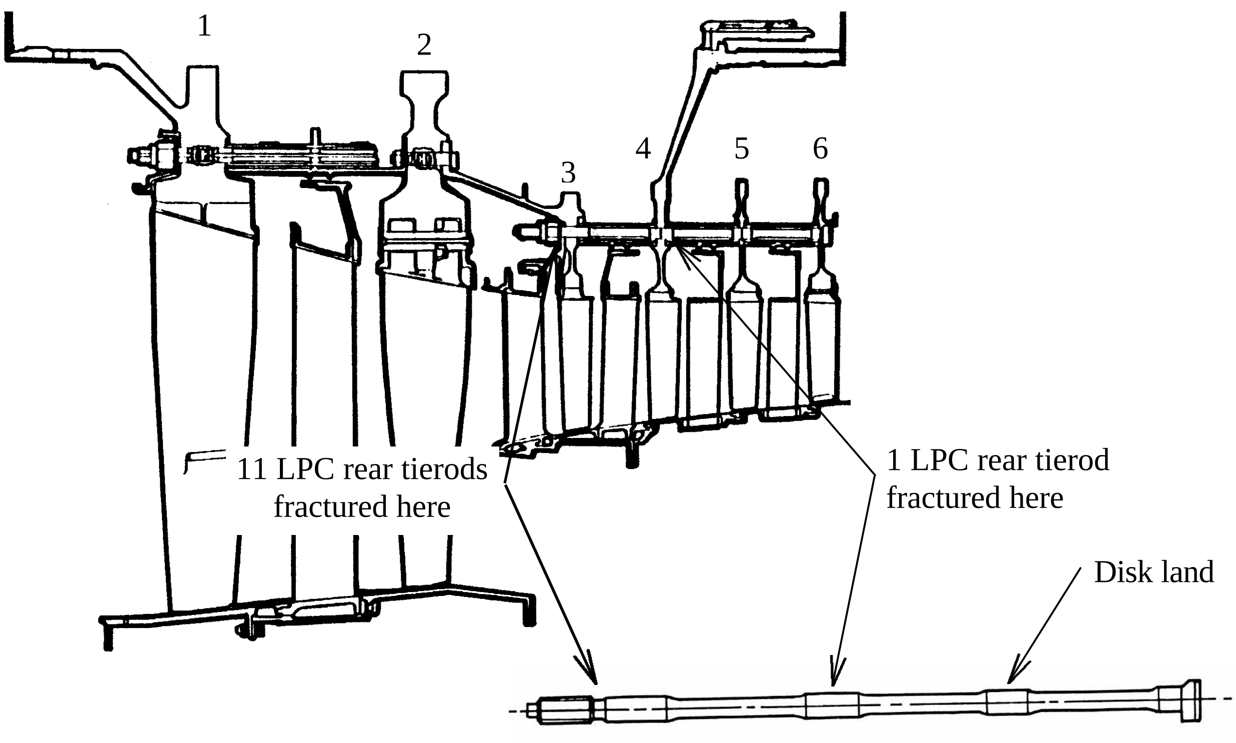

Figure 2. Cross-section of the JT8D fan and LPC and view of an LPC rear tierod

The Safety Board's examination of the LPC rear tierod with the corroded fracture face revealed that a fatigue fracture originated from a small area of galling[6] on the 4th stage compressor disk land. On July 7, 1982, as a result of 33 LPC rear tierod fractures at the 3rd and 4th stage disk land locations that caused damage in JT8D engines, P&W issued Service Bulletin (SB) 5407.[7]

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[6] Galling is a condition whereby excessive friction between high spots results in localized welding with the subsequent tearing and flaking away of material that further roughens one or both of the rubbing surfaces.

[7] Although a review of Federal Aviation Administration service difficulty reports identified only 1 event of an LPC rear tierod fracture, P&W advised that as of September 17, 1998, it had received reports of 133 events of LPC rear tierod fractures in JT8D-1 through -17AR engines.

SB 5407 introduced into the JT8D-9 through -17AR engines, the PN 789550 LPC rear tierod, which differs from the old part only in that it is required to have an antigalling coating applied to the tierod's compressor disk lands. SB 5407 also introduced PN 789552 and 789553 LPC rear tierods into the JT8D-1 through -7B engines and PN 789774 LPC rear tierods into the JT8D-9 through -17 engines. All of these new parts are also required to have the antigalling coating applied to the tierod's compressor disk lands. For newly manufactured tierods, the antigalling coating is required to be applied to the compressor disk lands at the time of manufacture; but, for previously operated tierods, the antigalling coating can be applied when the parts are being repaired and the part is then reidentified with the appropriate part number. P&W indicated that the SB should be complied with when the LPC rotor module was disassembled sufficiently to afford access to the tierods. However, no AD was issued to mandate the installation of the tierods with the antigalling coating.

The accident engine's maintenance records show that the engine, including the LPC, had been repaired by Volvo Flygmotor AB, on November 26, 1987, and on April 18, 1991.[8] The records for the 1987 repair show that SB 5407 had been complied with by the installation of 12 new PN 789550 LPC rear tierods in the engine. The records for the 1991 repair show that the LPC rear tierods were removed, visually inspected in accordance with the JT8D engine manual,[9] and after being found serviceable, reinstalled in the LPC. The postaccident energy dispersive x-ray spectroscopy examination of the compressor disk lands on the initially fractured tierod and the other 11 LPC rear tierods in the engine's LPC did not detect any trace of the primary constituents of the antigalling coating specified in the SB. Therefore, the Safety Board concludes that the antigalling coating was not applied to the new LPC rear tierods by P&W at the time of manufacture. P&W stated that the Royal Airlines engine failure has been the only one that involved the fracture of an LPC tierod that was supposed to have been coated with the antigallant. The lack of the antigalling coating on all 12 of the LPC rear tierods in the Royal Airlines engine suggests the problem may be widespread since it is unlikely that if only 12 tierods were manufactured without the antigalling coating, that all of them would be installed in the same engine. Therefore, the Safety Board believes that the Federal Aviation Administration (FAA) should require that all P&W JT8D-1 through -17AR engines be disassembled at the next shop visit and that the LPC rear tierods be removed, cleaned, stripped of any antigallant and nickel cadmium (nicad),[10] non-destructively inspected, replated with nicad, coated with the antigallant, and reinstalled or that new tierods coated with the antigallant be installed.

The Safety Board notes that the JT8D engine manual requires a fluorescent penetrant inspection (FPI)[11] for the high pressure turbine (HPT) tierods[12] and that the JT8D-200 engine

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[8] At the time of both repairs, the engine was owned and operated by Sterling Airways, a Danish supplemental air carrier that subsequently ceased operations. The engine also received a hot section inspection by Gas Turbine Corporation, East Granby, Connecticut, on August 24, 1995, but the LPC was not disassembled at that time.

[9] JT8D Engine Manual Task 72-33-13 Insp-01.

[10] Nicad is a two-step plating process of cadmium over nickel and is used as a corrosion preventative.

[11] FPI is a non-destructive inspection (NDI) method of detecting cracks and other surface anomalies. The inspection consists of applying to or immersing a part in a low-viscosity penetrating fluid containing fluorescent dyes and allowing the fluid to penetrate into any surface defects. Excess penetrant is removed and a developer is applied that acts as a blotter to draw the penetrant out from any surface defects, which will then luminesce when viewed under a blacklight.

manual[13] requires a magnetic particle inspection (MPI)[14] for that engine's LPC tierods[15] and an FPI for the high pressure compressor and HPT tierods.[16] However, the JT8D engine manual requires only a visual examination for the LPC rear tierods. The Safety Board is concerned that a visual inspection may not adequately determine the serviceability of these parts. Therefore, the Safety Board believes the FAA should require P&W to revise its JT8D engine manual to require that the LPC rear tierods be inspected with an appropriate non-destructive inspection (NDI) method.

Although the engine was equipped with an LPT containment shield, as required by AD 94-20-09, turbine blade fragments were still liberated through the engine cases and nacelle when the engine failed. A dimensional inspection of the LPC and LPT disks revealed that the 6th stage LPC disk and the 2nd, 3rd, and 4th stage LPT disks had grown diametrically. When a compressor or turbine disk exceeds its rotational speed limit, the extreme centrifugal loads that occur from the overspeed cause plastic deformation of the part, increasing its diametrical dimensions.

In a letter to the Safety Board, P&W stated that its analysis of the disks' growth indicated that the low pressure rotor had experienced a 140 percent overspeed of the rotor's rotational speed limit. In its letter, P&W further stated that the JT8D engine's LPT containment shield had been designed and demonstrated to withstand the impacts from fractured blade pieces at speeds of up to 120 percent of the rotor's rotational speed limit. (In the JT8D engine, a 120 percent overspeed of the LPT rotor can occur during an LPT shaft fracture event.) In the JT8D engine, a significant amount of the rotational energy produced by the LPT is required to drive the two fan stages compressing the air entering the engine. When the limiting force of the fan stages is suddenly removed from the LPT, as might occur in an LPT shaft fracture or as occurred in the Royal Airlines engine separation, the LPT rotor rapidly accelerates and exceeds its rotational speed limit. However, in an LPT shaft fracture event, the LPT rotor, as it accelerates, will also translate rearward rapidly and the blades will mesh[17] with the LPT vanes to break up the airfoils into small fragments and limit the rotor speed to about 120 percent of the rotational speed limit.

In the Royal Airlines event, the separation of the fan stages and 3rd stage compressor rotor from the rest of the LPC was in front of the No. 2 bearing, which is the thrust bearing for the LPC

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[12] JT8D Engine Manual Task 72-52-05 Insp-01.

[13] The JT8D and JT8D-200 engines are separately type certificated and are treated separately with regard to engine manuals and maintenance.

[14] MPI is an NDI method of detecting cracks and other defects in ferromagnetic materials such as iron or steel. The inspection consists of magnetizing a part with high amperage, direct current electricity, thus creating magnetic lines of flux, then applying or immersing the part in a liquid containing ferromagnetic particles in suspension. The ferromagnetic particles align themselves with the magnetic lines of flux on the surface of the part forming a pattern. If a discontinuity is present in the material on or near the surface, opposing magnetic poles form on either side of the discontinuity and the pattern is disrupted, forming an indication of a crack. An indication assumes the approximate size and shape of the surface projection of the discontinuity; however, indications are more visible when defects are approximately perpendicular to the magnetic lines of flux.

[15] JT8D-200 Engine Manual Task 72-33-13.

[16] JT8D-200 Engine Manual Tasks 72-36-20 and 72-52-05, respectively.

[17] Meshing is the desired clashing of the turbine blades and vanes following a turbine rotor shaft fracture that is intended to decelerate the rotor and to break the blades into small particles, thus reducing the likelihood of blades penetrating an engine casing.

in the JT8D engine. Because the thrust bearing is designed to absorb the axial loads of the low pressure rotor, it prevented the rearward movement of the LPT. Consequently, the LPT rotor in the Royal Airlines engine was able to accelerate to about 140 percent of the rotational speed limit before the LPT blades fractured because the desired meshing action was not able to occur. When the LPT blades did fracture, they were likely full or almost full length in comparison to the small fragments that would have resulted if the blades and vanes had meshed. As a result of the larger mass of the airfoils at the 140 percent overspeed, the fractured LPT blades were able to penetrate the containment shield, engine cases, and nacelle.

The Safety Board is concerned that an LPC rear tierod fracture can lead to an uncontained engine failure because it is likely that there are other LPC rear tierods in service without the antigalling coating that may be subject to fracture. Further, because of the size of the JT8D-1 through -17AR operating fleet and the length of time between shop visits, it will likely be several years before all affected engines will be disassembled to permit an NDI of the LPC rear tierods. Therefore, the Safety Board believes the FAA should require a repetitive borescope inspection of P&W JT8D-1 through -17AR engines to check for fractured LPC rear tierods and, if found, require the removal of those engines from service for repair. Periodic reinspections should continue until an NDI of the LPC rear tierods is performed or the tierods are replaced.

A visual inspection of several new PN 789550 JT8D LPC rear tierods with the antigalling coating applied showed only a subtle color difference between the nicad plating and antigalling coating. It was possible, with a focused inspection in optimal lighting conditions, to discern the light gray color of the antigalling coating from the light greenish-silver background color of the nicad plating. However, the Safety Board is concerned that if lighting conditions are less than optimal, if the inspection is not focused on the subtle color difference between the nicad and antigalling coatings, or if the tierods have discolored slightly in service, a shop technician may not be able to readily detect the presence or absence of the antigalling coating on these tierods. The shop technician who installed the LPC rear tierods on the accident engine could have reasonably assumed that the tierods were coated with antigallant at manufacture, as required, and therefore, might not have examined the parts closely to check for its presence. However, if the antigallant were readily observable, the technician would likely have noticed its absence.

The Safety Board is aware that many special coatings are applied to parts used throughout the aviation industry and that these special coatings are not generally visually distinct so as to be readily detectable. Thus, the problem of being able to identify whether a part has the appropriate coating applied is not just limited to JT8D LPC rear tierods, but exists for many coated parts used in aviation. Therefore, the Safety Board believes that the FAA should evaluate, and if feasible, implement the use of dyes and other means to ensure coatings and surface treatments are easily detectable so that shop technicians can determine if the necessary coatings have been applied to a part before installation in an engine or airplane.

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

> Require that all Pratt & Whitney JT8D-1 through -17AR engines be disassembled at the next shop visit and that the low pressure compressor rear tierods be removed, cleaned, stripped of any antigallant and nickel cadmium (nicad), non-destructively inspected, replated with nicad, coated with the antigallant, and reinstalled or that new tierods coated with the antigallant be installed. (A-99-12)
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> Require Pratt & Whitney to revise its JT8D engine manual to require that the low pressure compressor rear tierods be inspected with an appropriate non-destructive inspection method. (A-99-13)
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> Require a repetitive borescope inspection of Pratt & Whitney JT8D-1 through -17AR engines to check for fractured low pressure compressor (LPC) rear tierods and, if found, require the removal of those engines from service for repair. Periodic reinspections should continue until a non-destructive inspection of the LPC rear tierods is performed or the tierods are replaced. (A-99-14)
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> Evaluate, and if feasible, implement the use of dyes and other means to ensure coatings and surface treatments are easily detectable so that shop technicians can determine if the necessary coatings have been applied to a part before installation in an engine or airplane. (A-99-15)

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

[original signed]

By: Jim Hall
Chairman