National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: December 14, 2006

In reply refer to: A-06-85 through -87

Honorable Marion C. Blakey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On October 5, 2003, an Edelweiss Air Airbus Industrie A330-200 airplane, Swiss registration HB-IQZ, operating as flight EDW 565, experienced an uncontained turbine blade release from the No. 1 (left) Rolls-Royce Trent 772-60/16 turbofan engine[1] while climbing through flight level 230 (approximately 23,000 feet) after departing from Miami International Airport, Miami, Florida. The flight crewmembers reported that the No. 1 engine fire warning activated and that they discharged both fire bottles before the fire warning extinguished. The flight crew declared an emergency and returned to Miami, where the pilots successfully landed the airplane. No injuries to the 12 crewmembers or 171 passengers were reported. The flight was operating on an instrument flight rules flight plan under the provisions of 14 *Code of Federal Regulations* Part 129 and was en route to Zurich, Switzerland, on an extended twin-engine operation (ETOPS)[2] route at the time of the event.[3]

The airplane sustained impact damage and holes in the left wing and in the fuselage (the airplane's pressure vessel was not breached). Both thrust reverser halves of the No. 1 engine experienced ballistic impact damage and large pieces of the reversers departed the airplane. Examination of the No. 1 engine revealed that the intermediate pressure (IP) turbine case was ruptured 360° circumferentially and that the IP turbine disk had fractured from its drive arm and had liberated all of its blades. Further inspection revealed that the high pressure/intermediate pressure (HP/IP) turbine bearing chamber external vent tube had two burn-through holes.

Disassembly of the No. 1 engine revealed evidence of heat damage and distress in the HP/IP turbine bearing chamber consistent with the presence of an oil fire. Microstructure

[1] Both engines were Rolls-Royce Trent 700-60/16 turbofan engines and were installed on the airplane when it was delivered new from Airbus on November 21, 2000; neither engine had been removed or overhauled since installation. Both engines had accumulated 15,169 hours time since new and 2,348 cycles since new.

[2] ETOPS is an International Civil Aviation designation for certain twin-engine airplanes that are permitted to fly routes that, at some points, are further than a distance of 1-hour flying time at the normal one-engine inoperative cruise speed (in still air) from an adequate airport. ETOPS operations must satisfy additional requirements that exceed those required for non-ETOPS operations to receive the designation.

[3] The description of this incident, DCA04IA002, can be found on the National Transportation Safety Board's Web site at <http://www.ntsb.gov>.

examination of the fracture surfaces on the IP turbine disk drive arm revealed damage consistent with a localized fire that caused the drive arm to eventually fail and separate, allowing the IP turbine disk to overspeed. The overspeed condition resulted in the liberation of all IP turbine disk blades through the IP turbine case, with some blades striking the airplane. Because thermal damage within the HP/IP turbine bearing chamber and associated hardware prevented identifying the exact cause of the fire based solely on the physical evidence from the No. 1 engine, the No. 2 engine was examined to help establish possible causes or contributors to the bearing chamber fire in the No. 1 engine.

A borescope inspection of the No. 2 engine revealed that the HP/IP turbine bearing chamber internal vent tube was obstructed with a black substance. An airflow check of the vent tube revealed that the air passage was not completely blocked. A nondestructive three-dimensional neutron tomography analysis revealed that the substance was not solid and was characterized by nodules of carbon deposits (also known as coke) with areas of voids. Although coke formations within oil tubes are not uncommon, the morphology, amount, and location of the carbon deposits found in the vent tube of the No. 2 engine were unusual and inconsistent with coke formation seen on other Trent engines or from other service experiences.[4]

At the time of the event, the No. 1 and No. 2 engines on the accident airplane were operated using Mobil Jet Oil (MJO) 291. Edelweiss representatives indicated that the airline switched to MJO 291 after using MJO II during the first 2 months of the airplane's in-service operation. According to Rolls-Royce, at the time of the Edelweiss event, MJO II had accumulated millions of operational hours in service on the Trent 700 engine without any incidence of coke formation leading to an in-flight problem, and Edelweiss was the only Trent 700 operator that used MJO 291 in its engines.[5]

Extensive autoignition[6] studies, coke formation tests, and oil analysis tests conducted by Rolls-Royce on oil removed from the No. 2 engine revealed that conditions within the engine and the obstructed vent tube not only supported autoignition of the carbon/oil mixture but could also support and sustain a fire once the flame was initiated.[7] Because both engines had the same service life history and operating environment, investigators considered it likely that the HP/IP turbine chamber internal vent tube of the No. 1 engine had been obstructed with the same unusual carbon formation found on the No. 2 engine. Thus, the National Transportation Safety Board's investigation determined that the fire in the No. 1 engine was caused by carbon buildup in the internal vent tube of the HP/IP turbine bearing compartment, which led to the liberation of

[4] Typically, coke is hard, nonporous, and without voids and is distributed uniformly along the interior circumference of the tube wall without any sudden discontinuity or abrupt changes in area. These features typically result in the relatively uniform reduction of the airflow cross-section area.

[5] On November 16, 2004, ExxonMobil issued a letter to customers that, effective December 31, 2004, ExxonMobil Aviation Lubricants would discontinue marketing MJO 291.

[6] Autoignition can occur under a variety of pressures, temperatures, air/oil mixtures, and air/oil mixture residence times. Under normal engine operation, conditions required for autoignition and sustained combustion do not occur. With vent tubes exhibiting more typical coke formation, autoignition does not occur because the relatively uniform reduction of the airflow cross-section area increases the local air velocities, which virtually eliminates the likelihood of autoignition.

[7] The porous carbon formation found in the No. 2 engine supports the anchoring and stabilizing of an autoignition-produced flame because air flow is forced to take a circuitous route through the obstruction, which restricts the air flow and reduces local velocities.

the IP turbine blades. Contributing to the cause of the uncontained engine failure was the absence of measures to adequately monitor the in-service performance of a new engine/oil combination.

Coke formation tests conducted on oil samples taken from both engines of HB-IQZ and on new production MJO 291 confirmed that MJO 291 conformed to industry standards. In compliance with guidance provided by the Federal Aviation Administration (FAA) in Advisory Circular (AC) 20-24B, "Qualification of Fuels, Lubricants, and Additives for Aircraft Engines,"[8] MJO 291 oil had successfully passed qualification testing in accordance with the industry lubricating oil performance standard, MIL-PRF-23699F[9] (superceding MIL-L-23699E), before Edelweiss began using the oil in its Trent 700 engines. The approval process outlined in AC 20-24B provides physical, chemical, and performance standards and requests that engine manufacturers provide data substantiating that fuels, lubricants, or additive combinations have undergone sufficient testing and development under the conditions in which they will be used to demonstrate compatibility with a particular engine. The standard for lubricating oil qualification includes testing for carbon formation. Based on the circumstances of this incident, the Safety Board is concerned about the adequacy of the current oil test protocol to identify an oil's tendency to form coke deposits and the procedures used to introduce new engine/oil combinations[10] into fleet service.

The Safety Board notes that although the FAA has accepted the 150-hour endurance test specified in the MIL-PRF-23699F standard as a means of qualifying oils for use in aircraft engines, it took several thousand flight hours of operation with MJO 291 oil in the accident engine before the hazardous condition manifested itself. As a result, the Board is concerned that the qualification tests outlined in military standard MIL-PRF-23699F and approved by the FAA in AC 20-24B were not adequate for evaluating the long-term safe operation of the Trent 700/MJO 291 combination and may not be adequate for other combinations as well. Although the Safety Board is aware that industry groups such as the Society of Automotive Engineers International Propulsion Lubricant Committee have been working to improve lubricant qualification test standards, the development and implementation of these improvements will take several years, and the Board is concerned that more immediate action is required to ensure safety in light of the findings in this investigation.

Because successful completion of the existing test protocol for engine/oil combinations may not ensure safe long-term operation, periodic engine inspections are needed to detect potentially hazardous conditions before they affect safety of flight. However, AC 20-24B does not provide guidance promoting the establishment of a long-term inspection program as part of the approval process. Accordingly, at the time of the incident, Edelweiss did not have an

[8] The approval process followed by Rolls-Royce to qualify MJO 291 for use in Trent 700 engines was the applicable United Kingdom Civil Aviation Authority procedure contained in Joint Aviation Regulation (JAR) E570 (a)(8). Although it is a non-U.S. regulatory agency procedure, JAR E570 (a)(8) is consistent with guidance provided in AC 20-24B.

[9] The full-scale performance test specified in MIL-PRF-23699F is an evaluation of candidate lubricants consisting of an engine test cell run. The test duration, determined on an individual basis, is typically in the order of a few hundred hours.

[10] "New engine/oil combination" refers to any engine/oil combination for which in-service data has not validated that coke formation does not adversely affect the oil system or the engine's behavior throughout its anticipated on-wing time.

established long-term engine oil system inspection program to periodically monitor levels and types of acceptable coke formation in its Trent 700 engine fleet after the MJO 291 oil was introduced. The Safety Board is concerned that the guidance provided by AC 20-24B for monitoring the condition and performance of engines following the introduction of new oil types does not provide for frequent, comprehensive inspections over long-term engine operation to detect undesirable oil behavior before it can result in a hazard to safety of flight. Therefore, the Board believes that the FAA should revise AC 20-24B to include guidance to ensure that each time a new engine/oil combination is introduced, procedures are developed and implemented to inspect, at appropriate intervals, those areas within the engine where testing or in-service experience has indicated porous carbon formation is likely and has the potential to result in hazardous oil system or engine behavior. AC 20-24B should also provide criteria for evaluating the results of those engine inspections to aid operators in determining whether continued operation is safe or whether the engine/oil combination should be discontinued.

The Safety Board also recognizes that engine/oil combinations other than the Trent 700/MJO 291 combination may currently be in use that similarly do not have extensive time in-service or an established inspection and data collection program to monitor the long-term effects of the combinations on in-service oil system operation. The Board is particularly concerned that ETOPS-approved airplanes, such as the one involved in the Edelweiss incident, may be operating with engine/oil combinations that could eventually exhibit levels of porous coking or other effects that could compromise flight safety. Therefore, the Safety Board believes that the FAA should review the maintenance programs for all engine/oil combinations currently in-service, with particular emphasis on the evaluation of ETOPS-approved airplanes, to determine that operators have gathered and evaluated sufficient data, including operational experience and engine hardware disassembly inspection findings, to ensure that these combinations are not at risk of producing potentially hazardous porous-coke conditions. If such data do not exist or are insufficient, require operators to implement appropriate measures, including periodic inspections, to collect and evaluate the necessary data until the safety risk associated with the presence of porous coke is either ruled out or properly controlled.

The investigation team[11] evaluated all requirements in place at the time of the event, including those used by non-U.S. regulatory agencies, for the qualification of new engine/oil combinations and found that they are consistent with those permitted by the FAA. With this in mind and because the safety risk of porous carbon buildup outlined in this letter can potentially apply to U.S. and non-U.S. certificated, turbine-engine designs, the recommendations discussed in this letter would equally benefit all engines flown worldwide. Therefore, the Safety Board believes that the FAA should coordinate with international regulatory agencies to inform them of the circumstances of the event involving Edelweiss Air flight EDW 565 and to encourage them to develop and adopt comprehensive standards and procedures regarding the introduction of new engine/oil combinations, including the inspection at appropriate intervals of those areas within the engine where testing or in-service experience has indicated porous carbon formation is likely and has the potential to result in a hazardous engine condition. This coordination effort should

[11] In accordance with Annex 13 to the International Convention on Civil Aviation, representatives of the French Inspection Generale de L'Aviation Civile (which certificated the Airbus aircraft), the United Kingdom Civil Aviation Authority (which certificated the Roll-Royce engines), the Switzerland Federal Office for Civil Aviation (which certificated Edelweiss), the United Kingdom Air Accidents Investigation Branch, the French Bureau d'Enquêtes et d'Analyses, and the FAA participated in the Safety Board's investigation of the Edelweiss accident.

also ensure that sufficient data, including operational experience and engine hardware disassembly inspection findings, have been gathered and analyzed, with particular emphasis on ETOPS-approved airplanes, to support continued operation of engine/oil combinations.

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

> Revise Advisory Circular (AC) 20-24B to include guidance to ensure that each time a new engine/oil combination is introduced, procedures are developed and implemented to inspect, at appropriate intervals, those areas within the engine where testing or in-service experience has indicated porous carbon formation is likely and has the potential to result in hazardous oil system or engine behavior. AC 20-24B should also provide criteria for evaluating the results of these engine inspections to aid operators in determining whether continued operation is safe or whether the engine/oil combination should be discontinued. (A-06-85)
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> Review the maintenance programs for all engine and oil combinations currently in service, with particular emphasis on the evaluation of airplanes approved for extended-range operation with two engines, to determine that operators have gathered and evaluated sufficient data, including operational experience and engine hardware disassembly inspection findings, to ensure that these combinations are not at risk of producing potentially hazardous porous-coke conditions. If such data do not exist or are insufficient, require operators to implement appropriate measures, including periodic inspections, to collect and evaluate the necessary data until the safety risk associated with the presence of porous coke is either ruled out or properly controlled. (A-06-86)
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> Coordinate with international regulatory agencies to inform them of the circumstances of the event involving Edelweiss Air flight EDW 565 and to encourage them to develop and adopt comprehensive standards and procedures regarding the introduction of new engine/oil combinations, including the inspection at appropriate intervals of those areas within the engine where testing or in-service experience has indicated porous carbon formation is likely and has the potential to result in a hazardous engine condition. This coordination effort should also ensure that sufficient data, including operational experience and engine hardware disassembly inspection findings, have been gathered and analyzed, with particular emphasis on airplanes approved for extended-range operation with two engines, to support continued operation of engine/oil combinations. (A-06-87)

Chairman ROSENKER, Vice Chairman SUMWALT, and Members HERSMAN and HIGGINS concurred with these recommendations.

[*Original Signed*]

By: Mark V. Rosenker
Chairman