National Transportation Safety Board
Aviation Incident Final Report

Location:	Atlanta, GA	**Incident Number:**	ENG09IA002
Date & Time:	01/02/2009, 1028 EST	**Registration:**	N864DA
Aircraft:	BOEING 777	**Aircraft Damage:**	Minor
Defining Event:	Powerplant sys/comp malf/fail	**Injuries:**	257 None
Flight Conducted Under:	Part 121: Air Carrier - Scheduled		

Analysis

The Boeing 777 airplane experienced a contained fan blade fracture in the No. 2, right, engine, a Rolls-Royce plc RB.211 Trent 895-17 turbofan, during the takeoff roll at the Hartsfield Jackson Atlanta International Aiport. The examination of the fan blade revealed it had fractured from a fatigue crack that had initiated at the intersection of the convex side aft corner of the shear key slot and bedding flank. The examination of the fan blade also revealed the plasma spray coating was deteriorated and the dry film lubricant was almost completely gone. A survey by the engine manufacturer of the operator's 777 engine usage indicated that because of the loads and lengths of the flights, the operator was operating their Trent 895-17 engines at higher thrust levels with correspondingly high fan rotational speeds, which were still within the engine's operating limits, than any other operator. The survey also indicated the operator was operating its 777 and Trent engines significantly more hours per cycle than any other Trent 895 operator. An analysis by the engine manufacturer indicated that the blade fracture was caused by a combination of the breakdown of the lubrication system and residual fatigue life usage in the blade root following the last overhaul coupled with the high operating stresses in the fan blade from the high thrust settings.

Probable Cause and Findings

The National Transportation Safety Board determines the probable cause(s) of this incident to be: The fan blade fractured due to a fatigue crack that was the result of the combination of the breakdown of the fan blade lubrication system and residual fatigue life usage following the last overhaul of the fan blade. Contributing to the fracture was the inadequate lubrication schedule established by the engine manufacturer that was not reflective of the operator’s use of the engine.

Findings

Aircraft	Compressor section - Fatigue/wear/corrosion (Cause)
Organizational issues	Task design - Manufacturer (Factor) Oversight of maintenance - Manufacturer (Factor)

Factual Information

History of Flight

On January 2, 2009, about 1028 eastern standard time, a Boeing 777-232ER airplane, N864DA, operating as Delta Air Lines flight 55, experienced a contained fan blade separation in the No. 2, right, engine during the takeoff roll at the Hartsfield-Jackson Atlanta International Airport (ATL), Atlanta, Georgia. The pilots reported that, during the takeoff roll at about the 80-knots callout, they felt the airplane shudder and observed the No. 2 engine's exhaust gas temperature (EGT) go to redline. The pilots rejected the takeoff and taxied the airplane clear of the runway and stopped on an adjacent taxiway where they shutdown the No. 2 engine. Airport fire department equipment and personnel were dispatched to the airplane to check the engine for any indications of a fire, but no fire was detected. The airplane then taxied back to the gate under its own power where the passengers and crew deplaned normally. There were no reported injuries to the 4 pilots, 11 flight attendants, and 242 passengers on board. The airplane was operating on an instrument flight rules flight plan under the provisions of 14 Code of Federal Regulations Part 121 as a regularly scheduled international flight from ATL to Narita International Airport, Tokyo, Japan.

Damage to Engine and Airplane

The on-scene examination of the No. 2 engine revealed one fan blade was fractured transversely across the root shank adjacent to the dove tail bedding flank. The aft inner end of the fractured fan blade root, which was approximately 7-inches long, remained in the fan disc's blade slot. The fracture surface on the fractured fan blade root had an elliptical-shaped pattern radiating from the convex side of the blade root. A broken piece of the fan blade root shank that was recovered from the runway had a corresponding elliptical-shaped pattern on the mating fracture surface. All of the remaining fan blades remained in their respective slots in the fan disc, but all of the fan blades had large nicks and tears in the leading edges. There were several fan blades that were missing the outer portions of the airfoil with the remaining inner portion being delaminated. The fan blades did not have any evidence of a bird strike.

The fractured fan blade was contained within the fan case and Kevlar wrap. The fan case and Kevlar wrap were bulged out on the right side of the engine, but there were no through-holes in the Kevlar wrap. The fan blade rub strip was rubbed completely down to the metal of the fan case. Although there were numerous cuts and gouges through the case around the circumference, there were no through-holes in the fan case.

The examination of the engine's inlet duct revealed numerous through-holes in the upper part of the duct. The trajectory analysis of the holes in the inlet duct indicated the debris that went through those holes would not have struck the airplane. The examination of the airplane revealed four approximately 0.06-inch deep closely spaced parallel gouges at the bottom of an approximately 3-inch diameter, 0.4-inch deep dent in the fuselage skin above the window belt about midway between the 1R and 2R doors. The trajectory analysis indicated the debris that caused the gouges and dent came out through the front of the engine inlet. The examination of the remainder of the airplane revealed numerous gouges and dents, but no holes, to the underside of the right wing and to the flap jackscrew fairings downstream from the engine.

Engine Information

The airplane was equipped with two Rolls-Royce plc (Rolls-Royce) RB211-Trent 895-17

turbofans. The Trent 895-17 engine is a three-spool, axial flow, fully-ducted turbofan that features a one-stage fan that is driven by a five-stage low pressure turbine, an eight- stage intermediate pressure compressor driven by a one-stage intermediate pressure turbine, a six-stage high pressure compressor driven by a one-stage high pressure turbine, an annular combustor, and a full authority digital electronic control. According to the Federal Aviation Administration's (FAA) type certificate data sheet, the RB211-Trent 895-17 engine has a takeoff thrust rating of 92,940 pounds flat-rated to 77 degrees F (25 degrees C).

The No. 2 engine, serial number (SN) 51191, had accumulated 35,206.3 hours and 4,867 cycles since new at the time of the incident. The engine had accumulated 18,036.8 hours and 1,914 cycles since it was last overhauled in May 2005, and 7,050 hours and 591 cycles since it was installed on the airplane in September 2007. The engine had originally been delivered to Delta as an RB211 Trent 892-17 engine, which has a takeoff thrust rating of 91,450 pounds, but was upgraded to the higher Trent 895-17 thrust rating at the time of the last overhaul.

Fan Blade History

The fractured fan blade, part number (PN) FW22129 ASSY, SN RGG16701, had accumulated 33,499 hours and 4,657 cycles since new. The fan blade has a published life limit of 10,000 cycles. Markings on the fan blade indicated that it had originally been manufactured as a PN FK30842ASSY fan blade. The fractured fan blade's maintenance records show that at 2,742 cycles since new, the fan blade had been reworked in accordance with Rolls-Royce Service Bulletin RB.211-72-D672 and then reidentified. In accordance with the service bulletin, the blade root bedding flanks were grit blasted, laser shock peened (LSP), shot peened, and then plasma sprayed.

FLIGHT RECORDERS

The flight data recorder (FDR) data show that No. 1 engine followed by the No. 2 engine were started at about 0949. The FDR data show that after both engines had been started and stabilized at idle, their N1 and N3 rpms were about 20 and 50 percent, respectively. The FDR data show that the N1 and N3 rpms were matched following engine start except around 0954 when the No. 2 engine's N1 and N3 rpms increased from about 20 to 35 percent and from about 50 to 70 percent respectively, until about 1000 when the No. 2 engine was shutdown. (The pilots stated that they shutdown the No. 2 engine during the taxi out to the runway because of the lengthy air traffic delays.) The FDR data shows the No. 2 engine was restarted about 1021and again, the No. 2 engine's rpms matched those for the No. 1 engine. During the taxi out to the runway after the initial engine start and the subsequent start of the No. 2 engine, there were no exceedances or warnings for either engine. At 1027:52, the N1 indication for both engines began to increase at the same rate and after briefly stabilizing for about 4 seconds, both continued to increase at the same rate until they both stabilized at about 95 percent N1 at 1028:04. The FDR data show at 1028:20, the No. 2 engine's N1 and N3 indications dropped to zero and remained at that level for the remainder of the recording. Concurrent with the increase in engine power, the No. 1 engine's N1, N2, and N3 vibration levels increased and then dropped back to zero after the N1 and N3 rpm had dropped to zero. The FDR data shows that concurrent to when the No. 2 engine's N1 and N3 rpm had dropped to zero, there were momentary warnings for the No. 2 engine EGT exceedance and failure warning.

The cockpit voice recorder (CVR) was auditioned in the Safety Board's Recorder Laboratory.

The incident was captured on the CVR. The audition of the CVR did not reveal any issues with the flight crew's performance and handling of the incident.

RESEARCH AND TESTING

The fractured fan blade root pieces were initially sent to the NTSB's Materials Laboratory, Washington, D.C., for metallurgical examination. Subsequently, the fractured root pieces were sent to the Rolls-Royce Materials Laboratory, Derby, England, for further testing and metallurgical examination with an NTSB metallurgist present. The metallurgical examination of the fractured fan blade root revealed an elliptical-shaped fatigue crack that had originated on the convex side aft corner shear key slot corner radius. The fatigue crack had progressed about 1.4 inches across the shank to the concave side and about 5.2 inches rearward from the point of origin. The metallurgical examination confirmed that the fan blade's titanium alloy conformed to the material requirements. The metallurgical examination at the origin of the fatigue did not reveal any material anomalies or preexisting defects. A computerized axial tomography (CAT) scan of the area of the shear key slot corner radius in comparison to a CAT scan of an exemplar fan blade root confirmed the geometry conformed to the engineering drawing requirements. Additionally, the metallurgical examination confirmed the accomplishment of the LSP and shot peening.

The metallurgical examination of the fan blade root confirmed the presence of the required metal spray material and dry film lubricant (DFL) on the blade root's bedding flank. However, the examination of the blade root revealed the metal spray coating was significantly worn. According to Rolls-Royce, prior to this fan blade separation incident, the metal spray coating had a soft life limit of 4,000 cycles and the fan blade roots should be relubricated with the DFL every 1,200 cycles. According to Rolls-Royce, that schedule for the restoration of the metal spray coating and the relubrication with the DFL was consistent with what it recommended for the fan blades in their other high bypass fan engines. Delta's maintenance records also showed that the metal spray coating had been reapplied to the fan blade's roots at 1,915 cycles before the incident and the fan blade's roots had been relubricated at 250, 390, 680, and 1,480 cycles before the incident. Following this fan blade separation incident, Rolls-Royce advised that it had revised and reduced the intervals for the restoration of the metal spray coating and the relubrication of the fan blades' roots.

Following the fan blade separation incident, Rolls-Royce conducted a review of operational data of all Trent 895 fleet operators including Delta. The review revealed that Delta was making more high thrust level takeoffs, with correspondingly higher N1 speeds, more often than any other Trent 895 operator, although they Delta never exceeded the engines' thrust rating level or EGT and rpm limitations. Additionally, Delta's 777 airplane hours-per-flight cycle ratio was also considerably higher than that for any of the other Trent 895 operators.

In an analysis presented to investigators, Rolls-Royce stated that Delta's higher than typical Trent 895 thrust levels and N1 speeds would have increased the operating stresses in the fan blade bedding flanks in comparison to the stress levels in the fan blades' bedding flanks of other Trent 895 operators. The higher stress levels in the bedding flanks would have contributed to the deterioration of the plasma spray coating that would have then resulted in the loss of the DFL. However, Rolls-Royce further stated that the high stress levels, deterioration of the plasma spray coating, and loss of the DFL were insufficient to have initiated the crack from which the blade fractured. Rolls-Royce stated that their analysis indicated that even though the fractured fan blade's bedding flanks had undergone the LSP, it

was likely that there was residual fatigue life usage in the bedding flanks that in conjunction with the high stress levels, worn plasma spray coating, and loss of the DFL caused the crack and subsequent fracture.

OTHER

The Rolls-Royce RB211 Trent 895-17 engine is certificated in the United Kingdom. In accordance with Annex 13 to the International Convention on Civil Aviation, the Air Accidents Investigation Branch (AAIB) was notified of this incident. The AAIB appointed an accredited representative to the investigation.

History of Flight

Takeoff-rejected takeoff	Powerplant sys/comp malf/fail (Defining event)

Aircraft and Owner/Operator Information

Aircraft Manufacturer:	BOEING	**Registration:**	N864DA
Model/Series:	777 232	**Aircraft Category:**	Airplane
Year of Manufacture:		**Amateur Built:**	
Airworthiness Certificate:	Transport	**Serial Number:**	
Landing Gear Type:	Tricycle	**Seats:**	
Date/Type of Last Inspection:		**Certified Max Gross Wt.:**	
Time Since Last Inspection:		**Engines:**	2 Turbo Fan
Airframe Total Time:		**Engine Manufacturer:**	Rolls-Royce
ELT:	Not installed	**Engine Model/Series:**	Trent 895-17
Registered Owner:	Delta Air Lines	**Rated Power:**	
Operator:	Delta Air Lines	**Air Carrier Operating Certificate:**	Flag carrier (121)

Meteorological Information and Flight Plan

Observation Facility, Elevation:		**Observation Time:**	
Distance from Accident Site:		**Condition of Light:**	
Direction from Accident Site:		**Conditions at Accident Site:**	
Lowest Cloud Condition:		**Temperature/Dew Point:**	
Lowest Ceiling:		**Visibility**	
Wind Speed/Gusts, Direction:		**Visibility (RVR):**	
Altimeter Setting:		**Visibility (RVV):**	
Precipitation and Obscuration:			
Departure Point:	Atlanta, GA (KATL)	**Type of Flight Plan Filed:**	IFR
Destination:	Tokyo Narita (NRT)	**Type of Clearance:**	IFR
Departure Time:	EST	**Type of Airspace:**	

Airport Information

Airport:	Atlanta International Airport (KATL)	**Runway Surface Type:**	Asphalt
Airport Elevation:		**Runway Surface Condition:**	Dry
Runway Used:		**IFR Approach:**	None
Runway Length/Width:		**VFR Approach/Landing:**	None

Wreckage and Impact Information

Crew Injuries:	15 None	**Aircraft Damage:**	Minor
Passenger Injuries:	242 None	**Aircraft Fire:**	None
Ground Injuries:	N/A	**Aircraft Explosion:**	None
Total Injuries:	257 None		

Administrative Information

Investigator In Charge (IIC):	Gordon J Hookey	**Adopted Date:**	10/09/2012
Additional Participating Persons:	Shannon Masters; Delta Air LInes; Atlanta, GA Pamela Banas; Delta Air Lines; Atlanta, GA Tony James; FAA; Washington, DC Ken Cox; Rolls-Royce; Atlanta, GA Frank Piasecki; Boeing; Atlanta, GA Peter Frey; Air Line Pilots Association; Danbury, CT		
Publish Date:	10/09/2012		
Investigation Docket:	NTSB accident and incident dockets serve as permanent archival information for the NTSB's investigations. Dockets released prior to June 1, 2009 are publicly available from the NTSB's Record Management Division at pubinq@ntsb.gov, or at 800-877-6799. Dockets released after this date are available at http://dms.ntsb.gov/pubdms/.		

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