



Aviation Investigation Final Report

Location:	Chicago, Illinois	Incident Number:	ENG171A028
Date & Time:	June 10, 2017, 17:50 Local	Registration:	N715SK
Aircraft:	BOMBARDIER INC CL 600 2C10	Aircraft Damage:	Minor
Defining Event:	Powerplant sys/comp malf/fail	Injuries:	64 None
Flight Conducted Under:	Part 121: Air carrier - Scheduled		

Analysis

The No. 1 engine failure was caused by combustion outer liner buckling due to low cycle (thermal) fatigue. An axial crack that was about 2.5 inches long in the outer panel connected with a circumferential crack that was about 12 inches long between the 10 o'clock and 12:30 positions. At the junction of the two cracks, the outer liner was displaced (buckled) about 1.5 inches inward toward the engine centerline. The liner deformation caused an airflow disruption that prevented complete combustion of fuel in the combustion chamber and decreased engine performance margin. In response to the decrease in performance, the engine control system increased fuel flow in an attempt to compensate. The combination of increased fuel flow and incomplete combustion of the fuel injected into the combustion chamber led to delayed ignition of unconsumed fuel downstream of the combustion chamber (flame holder). The delayed ignition resulted in thermal damage to the high pressure turbine (HPT) hardware. The first stage HPT blades and vanes receive a high volume of cooling airflow and remained intact, but the HPT 2nd stage nozzle was thermally damaged and a nozzle vane segment at the 10 o'clock position eventually separated. After separation of the HPT 2nd stage nozzle vane segment, all four stages of the LPT experienced severe impact damage as separated fragments moved through the gaspath. The HPT 2nd stage nozzle separation also resulted in LPT case burn through at the 10 o'clock position that allowed hot gases to escape and contact the engine fire detection loop, which triggered a fire warning. There was no evidence that high energy fragments exited the LPT case.

Combustion liner cracks are a normal occurrence on high time parts. The engine line maintenance manual (LMM) includes inspection criteria with limits based on crack length and location.

SkyWest received a total of four GE customer notification reports (CNRs) for the incident engine related to reduced hot day performance margin. SkyWest complied with the CNR recommendation to perform a core engine water wash after receipt of each CNR. Although the first water wash was effective, the third (April 1, 2017) and fourth (May 6, 2017) attempts did not improve engine performance margin. The CNRs all also included a recommendation to perform a borescope inspection (BSI) of the HPC and HPT (recommendations 3 and 4). SkyWest performed a HPC BSI on June 6, 2017

and no anomalies were reported. They then elected to cease further maintenance on the engine and instead scheduled it for removal and replacement. The HPT 2nd stage nozzle thermal damage would likely have been visible if an HPT BSI had been performed.

Reduced engine margin and the two ITT exceedances were both strong indicators of a potential core engine issue, but SkyWest did comply with all AMM inspection requirements leading up to the engine failure. GE CNRs are non-mandatory diagnostic tools, so both the completion of the recommended maintenance actions and the order the maintenance actions are completed are at the discretion of the operator.

Probable Cause and Findings

The National Transportation Safety Board determines the probable cause(s) of this incident to be: A Bombardier CRJ700 No. 1 engine failure caused by buckling of the combustion outer liner due to fatigue cracks. The liner buckling resulted in airflow disruption and reduced engine performance. The engine fuel control unit attempted to compensate for the decrease in engine performance by increasing the fuel flow rate. The combustion liner damage and increased fuel flow led to incomplete combustion of the fuel injected into the combustion chamber. Unconsumed fuel then ignited downstream of the combustion chamber (delayed ignition) and resulted in high pressure turbine thermal damage, and the eventual separation of a high pressure turbine 2nd stage nozzle vane segment. The separated vane segment subsequently caused low pressure turbine case burn through and catastrophic impact damage to the high and low pressure turbine stages.

Findings

Aircraft	Combustion section - Fatigue/wear/corrosion
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Factual Information

History of Flight

Takeoff	Powerplant sys/comp malf/fail (Defining event)
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HISTORY OF FLIGHT

On June 10, 2017, at about 1750 central daylight time (CDT), a SkyWest Airlines, Bombardier CRJ700, N715SK, equipped with two General Electric CF34-8C5B1 turbofan engines, experienced a No. 1 (left) engine failure during takeoff from Chicago O'Hare International Airport (ORD), Chicago, Illinois. The crew reported hearing a loud bang, followed by a reduction in engine power, and a No. 1 (left) engine fire warning. The crew declared an emergency, shutdown the No. 1 engine, and returned to ORD for an uneventful single engine landing. Aircraft Rescue and Firefighting (ARFF) crews met the airplane on the runway and did not observe fire or smoke coming from the No. 1 engine, so the airplane was cleared to taxi to the gate. There were no passenger or crew injuries reported. The flight was being operated in accordance with 14 *Code of Federal Regulations* Part 121 as a regularly scheduled flight from ORD to Bishop International Airport (FNT), Flint, Michigan.

DAMAGE TO THE AIRPLANE

The airplane fuselage had multiple small impact marks aft of the No.1 engine. The impacts did not penetrate the fuselage skin and were repairable in accordance with the Bombardier structural repair manual (SRM). The No. 1 engine aft core cowl had a hole at the 10 o'clock position, four inches aft of the cowl forward flange, that was approximately 7.5 inches circumferentially by four inches axially.

TEST AND RESEARCH

Engine Examination and Disassembly

A visual examination of the engine was conducted by maintenance crews at ORD who reported: a hole in the engine cowl, damage to the visible low pressure turbine (LPT) blades, and several small impacts on the fuselage, aft of the No. 1 engine. The No. 1 engine was removed from the airplane at ORD and shipped to the SkyWest maintenance facility at Salt Lake City International Airport (SLC), Salt Lake City, Utah for quick engine change component removal and a preliminary engine borescope. The engine was then shipped to StandardAero in Winnipeg, Manitoba, Canada for examination and disassembly. Party members from SkyWest Airlines, General Electric Aviation (GE), Bombardier, the Federal Aviation Administration (FAA), and the National Transportation Safety Board (NTSB) met at StandardAero from July 11-13, 2017.

The No. 1 engine LPT case had a hole at the 10 o'clock position, near the forward flange that was approximately six inches circumferentially by four inches axially. The high pressure turbine (HPT) 2nd stage nozzle assembly was missing a vane segment at the 10 o'clock position and the HPT inner case assembly had a burn through hole in the same location as the missing vane segment. The HPT 2nd stage

rotor blades exhibited thermal and impact damage. All four LPT stages exhibited severe impact damage and missing material. The combustion outer liner had a 2.5 inch axial crack that ran from aft flange (interface with the HPT 1st stage nozzle, panel P4) forward. The axial crack was connected to a 12 inch long circumferential crack from the 10 o'clock to 12:30 positions that ran between the cooling air holes. At the intersection of the circumferential and axial cracks, the liner surface was displaced about 1.5 inches radially in towards the engine centerline.

Fuel Nozzle Testing

All 18 fuel nozzles were shipped to the Woodward facility in Zeeland, Michigan for flow testing in the as received "dirty condition". There were no anomalies noted in spray pressure or spray angle, but 16 of the 18 nozzles failed spray quality testing due to minor streaking. The pass/fail criteria were based on new or repaired nozzles, and according to Woodward engineering, the nozzle spray patterns were consistent with what is expected for high time service run hardware.

Main Fuel Pump Testing

The main fuel pump (MFP) was shipped to Triumph Accessory Services in Grand Prairie, Texas for testing. The fuel pump met testing specifications and no faults were recorded.

Fuel Meter Unit Testing

The fuel metering unit (FMU) was shipped to the Woodward facility in Rockford, Illinois for testing. Multiple fuel flow test points recorded below minimum specification for a new unit but were within the expected range for a high time service run component according to Woodward and GE engineering.

ADDITIONAL INFORMATION

Customer Notification Reports and Maintenance

GE performs engine trending/health monitoring for SkyWest Airlines. SkyWest provides GE flight data and GE provides engine operational and maintenance recommendations based on that information. According to GE records, four high priority engine customer notification reports (CNR) were sent to SkyWest Airlines due to low or decreasing takeoff exhaust gas temperature hot day margin (EGTHDM) in combination with low or decreasing delta core speed (increasing physical core speed). The notifications were sent in February 2016, October 2016, March 2017, and May 2017. The probable cause listed on all four CNRs was compressor efficiency. The CNRs first recommended maintenance action was a review of maintenance records for recent changes that could affect engine performance. The second recommendation was to perform a core engine water wash in accordance with the GE line maintenance manual (LMM) procedures. SkyWest completed core engine water washes on March 7, 2016, November 2, 2016, April 1, 2017, and May 6, 2017. The first water wash was effective in restoring engine margin, the second water wash was had minimally effective, and the third and fourth water washes were ineffective. On June 6, 2017, SkyWest performed a high pressure compressor (HPC) borescope inspection (third recommendation on the CNRs) and no anomalies were reported. On June 9, 2017, SkyWest scheduled the engine to be removed and replaced on June 14, 2017; however, the event engine failure occurred June 10, 2017, prior to its scheduled removal.

Interturbine Temperature Exceedances

The electronic engine control (EEC) and digital flight data recorder (DFDR) recorded interturbine temperature (ITT) exceedances during the seventh and fifth flights (June 8th and 9th, 2017) prior to the incident. The maximum temperature and time duration of both ITT exceedances were within "Area A" according to the Bombardier CRJ700/900/1000 aircraft maintenance manual (AMM), Maintenance/Inspection Actions for ITT Overtemperature Events (Takeoff). An "Area A" exceedance requires maintenance operators to visually inspect the cases and visible blades through the exhaust nozzle for anomalies. No anomalies were noted following either of the two ITT exceedances, so the airplane was returned to service. Only one of the two exceedances (June 8, 2017) was recorded in the SkyWest aircraft maintenance log.

Combustion Liner Failure History

The NTSB is aware of five other similar combustion outer liner buckling occurrences. Two of these occurrences resulted in in-flight events, one of which caused an engine fire warning indication, engine shutdown, and air turn back. The cracks/buckling on the other liners were discovered during engine inspection or repair. A combustion outer liner failure has not occurred on a liner with fewer than 18,000 hours and/or 12,000 cycles.

The NTSB investigated a CF34-8C combustion inner liner burn through failure that resulted in LPT case burn through. The report for this investigation is available in the NTSB docket management system under NTSB investigation number ENG14IA029.

Corrective Actions

GE released service bulletins (SB), SB 72-A0326 (CF34-8C engines) and SB 72-A0211 (CF34-8E engines) on October 17, 2018, recommending a one-time borescope inspection of the combustion outer liner aft most panel (P4) on liners with more than 15,000 flight hours time since new or time since repair. Both bulletins are category 2 with recommended compliance as soon as possible without effecting revenue service but before 1,000 flight hours from issue date.

Following the incident event, GE developed a new CNR monitoring parameter for combustor distress. Engine trend data is monitored for sharp decreases in takeoff EGTHDM with corresponding shifts in takeoff delta fuel flow. These shifts are both most relatable to hot section distress, more precisely combustor distress. The following engine core related CNR parameters were also modified to add a recommendation to perform a borescope inspection on the combustion liner as part of the corrective actions: CNR HPC Efficiency, CNR Core Deterioration, CNR Low Engine Performance, CNR exhaust gas temperature (EGT) Indication, and CNR HPC-HPT Distress.

A new Core Health Indicator (CHI) parameter was developed in April 2018. The CHI algorithm uses core speed, fuel flow, and compressor discharge pressure measurements during takeoff to calculate a predicted EGTHDM. CHI is designed to provide a supplemental trend data point to the existing EGTHDM parameter. CHI does not factor EGT or ITT as part of the algorithm and GE believes agreement and/or variation between the two parameters will help maintainers perform more targeted troubleshooting of engine issues.

Information

Certificate:	Age:
Airplane Rating(s):	Seat Occupied:
Other Aircraft Rating(s):	Restraint Used:
Instrument Rating(s):	Second Pilot Present:
Instructor Rating(s):	Toxicology Performed:
Medical Certification:	Last FAA Medical Exam:
Occupational Pilot:	Last Flight Review or Equivalent:
Flight Time:	

Aircraft and Owner/Operator Information

Aircraft Make:	BOMBARDIER INC	Registration:	N715SK
Model/Series:	CL 600 2C10 700C	Aircraft Category:	Airplane
Year of Manufacture:	2004	Amateur Built:	
Airworthiness Certificate:	Transport	Serial Number:	10179
Landing Gear Type:	Retractable - Tricycle	Seats:	
Date/Type of Last Inspection:		Certified Max Gross Wt.:	
Time Since Last Inspection:		Engines:	2 Turbo fan
Airframe Total Time:		Engine Manufacturer:	GE
ELT:	Installed, not activated	Engine Model/Series:	CF34 SERIES
Registered Owner:		Rated Power:	9140 Horsepower
Operator:		Operating Certificate(s) Held:	Flag carrier (121)

Meteorological Information and Flight Plan

Conditions at Accident Site:	Unknown	Condition of Light:	Day
Observation Facility, Elevation:	KORD,674 ft msl	Distance from Accident Site:	1 Nautical Miles
Observation Time:	17:50 Local	Direction from Accident Site:	282°
Lowest Cloud Condition:		Visibility	
Lowest Ceiling:		Visibility (RVR):	
Wind Speed/Gusts:	20 knots / 27 knots	Turbulence Type Forecast/Actual:	/
Wind Direction:		Turbulence Severity Forecast/Actual:	/
Altimeter Setting:	29.1 inches Hg	Temperature/Dew Point:	32°C / 8°C
Precipitation and Obscuration:			
Departure Point:	Chicago, IL (ORD)	Type of Flight Plan Filed:	Unknown
Destination:	Flint, MI (FNT)	Type of Clearance:	Unknown
Departure Time:		Type of Airspace:	Unknown

Airport Information

Airport:	Chicago O'Hare Intl ORD	Runway Surface Type:	
Airport Elevation:	680 ft msl	Runway Surface Condition:	Unknown
Runway Used:		IFR Approach:	Unknown
Runway Length/Width:		VFR Approach/Landing:	Unknown

Wreckage and Impact Information

Crew Injuries:	4 None	Aircraft Damage:	Minor
Passenger Injuries:	60 None	Aircraft Fire:	None
Ground Injuries:	N/A	Aircraft Explosion:	None
Total Injuries:	64 None	Latitude, Longitude:	41.990276,-87.904724

Administrative Information

Investigator In Charge (IIC):	Hunsberger, Robert
Additional Participating Persons:	Carl Wager; SkyWest Airlines; St. George, UT David Zigan; GE Aviation; Cincinnati, OH Eugene Shingin; Bombardier; Montreal Earl Chapman; Transportation Safety Board of Canada; Ottawa John Frost; Federal Aviation Administration; Burlington, MA
Original Publish Date:	May 3, 2019
Note:	The NTSB did not travel to the scene of this incident.
Investigation Docket:	https://data.nts.gov/Docket?ProjectID=95345

The National Transportation Safety Board (NTSB), established in 1967, is an independent federal agency mandated by Congress through the Independent Safety Board Act of 1974 to investigate transportation accidents, determine the probable causes of the accidents, issue safety recommendations, study transportation safety issues, and evaluate the safety effectiveness of government agencies involved in transportation. The NTSB makes public its actions and decisions through accident reports, safety studies, special investigation reports, safety recommendations, and statistical reviews.

The Independent Safety Board Act, as codified at 49 U.S.C. Section 1154(b), precludes the admission into evidence or use of any part of an NTSB report related to an incident or accident in a civil action for damages resulting from a matter mentioned in the report. A factual report that may be admissible under 49 U.S.C. § 1154(b) is available [here](#).