



AVIATION



HIGHWAY



MARINE



RAILROAD



PIPELINE

# Aviation Investigation Final Report

<b>Location:</b>	Washington, District of Columbia	<b>Incident Number:</b>	ENG171A027
<b>Date &amp; Time:</b>	June 3, 2017, 08:55 Local	<b>Registration:</b>	N765SW
<b>Aircraft:</b>	Boeing 737 7H4	<b>Aircraft Damage:</b>	Minor
<b>Defining Event:</b>	Uncontained engine failure	<b>Injuries:</b>	67 None
<b>Flight Conducted Under:</b>	Part 121: Air carrier - Scheduled		

## Analysis

The alternator control gearshaft (L3 gearshaft) failed due to high cycle fatigue intergranular corrosion cracking. High cycle fatigue is normally vibration driven where fatigue striations are hard to resolve (count) and where the number of cycles far exceeds the flight cycles. No indications of any abnormal vibration were noted during the event flight and a review of fan and core vibration diagnostic data from the last shop visit in 2017 (the AGB was overhauled at that time) showed all the vibration levels to be within acceptable limits.

A review of the manufacturing records showed that the failed L3 gearshaft was 1 of 32 initially produced from the same production batch. Due to corrosion issues during the initial manufacturing process, all the gearshafts were subjected to additional manufacturing operations; only 8 were deemed serviceable and put into service, one of which was the event gearshaft.

To understand the impact of the additional manufacturing processing steps performed on the failure L3 gearshaft, a series of chemical etch and black oxide treatments were performed on a sample of the same material. This sample was compared with the failed L3 gearshaft and revealed that the intergranular attack observed on the failed L3 gearshaft could not be replicated; the sample material showed no intergranular attack even after 5 chemical etchings. CFMI concluded that the chemical etching alone could not account for the intergranular attack observed on the event L3 gearshaft; instead it is thought that the additional machining process stress combined with the chemical etching needed to remove the corrosion caused the increase in quantity and density of the microcracks along with the grain boundary consumption. However, this still did not fully account for why the gearshaft failed in high cycle fatigue, which is normally a vibration driven failure mode.

Since the event L3 gearshaft was introduced into service, it had operated almost 20 years; accumulated 63,711 hours time since new and 37,433 cycles since new; and was subjected to in-service inspections at

the piece part level on two occasions; once in 2007 and then again in 2017 with no anomalies reported. Had the additional manufacturing processing been the solely cause of the failure, the L3 gearshaft most likely could not have operated as long as it had, and it would most likely not have failed in a vibratory mode. Instead the additional manufacturing operations most likely affected the high cycle fatigue capability of the gearshaft, but it wasn't until a change in the vibratory stress that the part was exposed did it fail. Unfortunately, the engine is not equipped with any vibration sensors on the AGB so detecting any changing vibratory response in the AGB was not possible. The engine is however equipped with a No. 1 bearing sensor and fan frame compressor case vertical sensor. Review of the flight data recorder data showed no aircraft vibration monitoring alerts prior to, or after the engine failure event. Also, a review of fan and core vibration diagnostic data from the last shop visit in 2017, the AGB was overhauled at that time, to the event date showed all the vibration levels to be within acceptable limits.

The transfer shaft locking nut was found loose but was still engaged with the 47 tooth gearshaft and the transfer gearbox. Review of the maintenance records showed locking nut was last torqued in accordance with the approved procedures during the engine's last shop visit. The locking nut threads and mating threads on the L3 gearshaft were in good condition, the lock nut retaining ring was present, properly installed, and in good condition, and the transfer shaft was found fully engaged. CFMI's experience with locking nuts becoming untorqued during operation is that the transfer shaft disengages resulting in a subsequent in-flight shutdown; in this case the transfer shaft remained fully engaged. Therefore, the loose transfer nut did not cause nor a contributing factor to the failure of the L3 gearshaft and was an artifact of the initial failure event.

## **Probable Cause and Findings**

The National Transportation Safety Board determines the probable cause(s) of this incident to be:

The failure the control alternator gearshaft, which disconnected the accessory gearbox from the rest of the engine and resulted in an uncommanded in-flight shutdown of the left engine and subsequent flight diversion. The control alternator gearshaft failed because of high cycle fatigue intergranular corrosion cracking. Contributing to the failure of the control alternator gearshaft were additional manufacturing processing steps to address part non-conformances that reduced its high cycle fatigue capability and potential change in vibratory environment since the last shop visit.

## Findings

Aircraft	Accessory drives - Failure
Aircraft	Accessory drives - Fatigue/wear/corrosion

# Factual Information

## History of Flight

Enroute	Uncontained engine failure (Defining event)
Enroute	Loss of engine power (total)
Enroute	Engine shutdown
Enroute	Powerplant sys/comp malf/fail

## HISTORY OF FLIGHT

On June 3, 2017, at 0820 eastern daylight time, a Boeing 737-7H4 airplane, registration number N765SW, powered by two CFMI CFM56-7B24 turbofan engines, operated by Southwest Airlines (SWA) as flight number 4635, experienced a right-hand (No. 2) engine failure while enroute from Tampa Florida to Rochester New York. The airplane was diverted to Washington Dulles International Airport (IAD) where an uneventful single engine landing was performed, and no injuries were reported to any of the occupants. The incident flight was conducted under instrument flight rules (IFR) under 14 *Code of Federal Regulations* (CFR) Part 121 as a regularly scheduled flight from the Tampa International Airport (TPA) to the Greater Rochester International Airport (ROC). There were 62 passengers and 5 crewmembers on board the incident flight.

## ENGINE DAMAGE EXAMINATION

On-scene damage documentation and subsequent engine removal was conducted by SWA with the approval of the NTSB; NTSB personnel were not in attendance. The fan cowls and thrust reversers were latched and secured. The right-hand engine inboard fan cowl exhibited an 8.75-inch circumferential (long) by 3.75-inch axial (wide) impact rip/tear/slice at about the 9:00 o'clock position. When the fan cowls were opened, loose debris was collected; a piece of gear teeth rim had a part number marked on it that corresponded with the accessory gearbox 47-tooth gearshaft assembly, also known as the control alternator gearshaft, line 3 (L3) gearshaft, or L3 gear train. Along with the part of the L3 gearshaft were parts consistent with the accessory gearbox housing and one of the accessory gearbox oil supply nozzles. Examination of the accessory gearbox housing revealed a 3-inch circumferentially (length) by 2-inch axially (wide) exit hole in-line with the control alternator gearshaft.

The engine was removed from the airplane and shipped to the SWA maintenance facility at Love Field, Dallas Texas for further evaluation. Prior to removing the accessory gearbox, an alignment check was performed as well as an examination of the accessory mounting hardware. To perform the alignment check, the transfer gearbox was disengaged from the accessory gearbox. In doing so, the horizontal drive shaft locking nut was found loose; essentially finger tight. This locking nut was last torqued in accordance with the approved procedures during the engine's last shop visit that occurred in January 2017 at the GE Celma facility. The locking nut threads and mating threads on the L3 gearshaft were in good condition with slight signs of fretting; the lock nut retaining ring was present, properly installed, and in good condition. The results of the alignment check showed that the accessory gearbox met the installation

requirements. No anomalies were noted on any of the accessory gearbox mounting hardware; the dampers were all installed and in good condition, and mount links appeared straight and were easy to remove.

The transfer gearbox, horizontal drive shaft, and accessory gearbox were removed from the engine and retained for examination. No anomalies were found with the transfer gearbox that related to the incident.

## TEST AND RESEARCH

The accessory gearbox was shipped to CFMI in France for examination; disassembly and visual examination of the housing and the internal gearshafts found that: 1) the accessory gearbox housing L3 gearshaft bore was heavily damaged/scored and exhibited a 3-inch x 2-inch exit hole, 2) all the gear teeth of the L3 gearshaft had separated from the gear web and what remained of the gear web was distorted, and 3) gear teeth of the handcranking gearshaft (L4 gearshaft) – this gearshaft meshes with the L3 gearshaft – were damaged but all present. Binocular examination of the web of the L3 gearshaft revealed that the primary crack initiation site was located at the interface radius of the gear web-to-centerline shaft on the roller bearing side of the gear web. Fine secondary circumferential fatigue cracks were observed on both sides of the web near the interface of the web-to-centerline shaft; secondary cracks were located about 90° from the primary crack initiation. Cracks were also visible at the bottom land of several gear teeth.

High resolution images taken of the L3 gearshaft fracture surface revealed features consistent with high cycle fatigue (HCF) with multiple arrest lines along the initial propagation path. The primary crack initiation site was more precisely located between microstructure grain boundaries where chemical etching and black oxide surface treatment of the part was performed during manufacturing and was consistent with intergranular corrosion; no embrittlement was noted around the fracture initiation site. The secondary web cracks also initiated on the microstructure grain boundaries and the crack had features consistent with HCF. Chemical analysis and hardness checks confirmed the part was manufactured of the specified material and to the required hardnesses.

## ADDITIONAL INFORMATION

Review of the manufacturing history of the failed L3 gearshaft revealed that it was 1 of 32 initially produced from the same production batch. Due to corrosion issues during the manufacturing process, only 8 of the 32, including the event gearshaft, were ever put into service. The 8 gearshafts that were put into service had additional manufacturing operations performed on them such as corrosion removal, etching, deoxidation, and additional machining to address the corrosion issue before they were deemed serviceable. At that time, shot-peening was not required on any of the AGB gears and gearshafts. Soon after, CFMI changed the manufacturing specifications requiring all new manufactured gears and gearshafts to be shot-peened. A total of approximately 600 non-shot peened L3 gearshafts were produced and went into service.

Review of the maintenance records showed that the failed L3 gearshaft was installed on the same accessory gearbox for its entire in-service life and that it was visually, non-destructively, and dimensionally inspected in May 2007 and again in January 2017 with no anomalies reported. At the time of the failure, the event L3 gearshaft (and accessory gearbox) had accumulated 63,711 hours time since new; 37,433 cycles since new; 668 hours since last shop visit; and 415 cycles since last shop visit.

After multiple attempts to replicate the condition of the failed L3 gearshaft, CFMI concluded that the chemical etching alone could not account for the intergranular attack observed on the event L3 gearshaft;

instead it is thought that the additional machining process combined with the chemical etching needed to remove the corrosion caused the increase in quantity and density of the microcracks along with the grain boundary consumption that ultimately led to the initiation of the primary crack/fracture.

## CORRECTIVE ACTION

Of the eight L3 gearshafts from the same production batch as the failed SWA gearshaft, two are no longer in service, and the remaining six have all been positively identified as installed in an AGB on an in-service engine. CFMI, as a preventative action, releases service bulletin CFM56-7B 72-1032-R00 on March 12, 2018 that recommends removal of the seven remaining L3 gearshafts (including one that is currently out-of-service) from the same production batch as the failed SWA L3 gearshaft at the next AGB overhaul.

Currently, Safran Transmission Systems limits the number of additional manufacturing operations to address non-conformances during production; for example, the number of acid etchings has been limited for the steel gears/gearshaft. This process has been in use for several years; however, considering this event, the process is being reviewed for improvements in process documentation.

## Information

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

## Aircraft and Owner/Operator Information

<b>Aircraft Make:</b>	Boeing	<b>Registration:</b>	N765SW
<b>Model/Series:</b>	737 7H4 7H4	<b>Aircraft Category:</b>	Airplane
<b>Year of Manufacture:</b>	2000	<b>Amateur Built:</b>	
<b>Airworthiness Certificate:</b>	Transport	<b>Serial Number:</b>	29805
<b>Landing Gear Type:</b>	Tricycle	<b>Seats:</b>	
<b>Date/Type of Last Inspection:</b>		<b>Certified Max Gross Wt.:</b>	154500 lbs
<b>Time Since Last Inspection:</b>		<b>Engines:</b>	2 Turbo fan
<b>Airframe Total Time:</b>		<b>Engine Manufacturer:</b>	CFM INTL.
<b>ELT:</b>		<b>Engine Model/Series:</b>	CFM56-7B24
<b>Registered Owner:</b>	SOUTHWEST AIRLINES CO	<b>Rated Power:</b>	
<b>Operator:</b>	SOUTHWEST AIRLINES CO	<b>Operating Certificate(s) Held:</b>	Flag carrier (121)
<b>Operator Does Business As:</b>		<b>Operator Designator Code:</b>	SWAA

## Meteorological Information and Flight Plan

<b>Conditions at Accident Site:</b>	Unknown	<b>Condition of Light:</b>	Day
<b>Observation Facility, Elevation:</b>		<b>Distance from Accident Site:</b>	
<b>Observation Time:</b>		<b>Direction from Accident Site:</b>	
<b>Lowest Cloud Condition:</b>		<b>Visibility</b>	
<b>Lowest Ceiling:</b>		<b>Visibility (RVR):</b>	
<b>Wind Speed/Gusts:</b>	/	<b>Turbulence Type Forecast/Actual:</b>	/
<b>Wind Direction:</b>		<b>Turbulence Severity Forecast/Actual:</b>	/
<b>Altimeter Setting:</b>		<b>Temperature/Dew Point:</b>	
<b>Precipitation and Obscuration:</b>			
<b>Departure Point:</b>	Tampa, FL (TPA )	<b>Type of Flight Plan Filed:</b>	IFR
<b>Destination:</b>	Rochester, NY (ROC )	<b>Type of Clearance:</b>	IFR
<b>Departure Time:</b>		<b>Type of Airspace:</b>	Class A

## Airport Information

<b>Airport:</b>	WASHINGTON DULLES INTL IAD	<b>Runway Surface Type:</b>	
<b>Airport Elevation:</b>	313 ft msl	<b>Runway Surface Condition:</b>	Unknown
<b>Runway Used:</b>		<b>IFR Approach:</b>	Unknown
<b>Runway Length/Width:</b>		<b>VFR Approach/Landing:</b>	

## Wreckage and Impact Information

<b>Crew Injuries:</b>	5 None	<b>Aircraft Damage:</b>	Minor
<b>Passenger Injuries:</b>	62 None	<b>Aircraft Fire:</b>	None
<b>Ground Injuries:</b>	N/A	<b>Aircraft Explosion:</b>	None
<b>Total Injuries:</b>	67 None	<b>Latitude, Longitude:</b>	38.948612,-77.450279



## Administrative Information

**Investigator In Charge (IIC):** Scarfo, Jean-pierre

**Additional Participating Persons:**

**Original Publish Date:** June 26, 2018

**Last Revision Date:**

**Investigation Class:** [Class](#)

**Note:** The NTSB did not travel to the scene of this incident.

**Investigation Docket:** <https://data.ntsb.gov/Docket?ProjectID=95321>

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