A. INCIDENT

Location: Dulles, Virginia
Date: June 3, 2017
Time: 0820 eastern daylight time
Aircraft: Southwest Airlines, Boeing 737-7H4, Registration N765SW, Flight No. 4635

B. POWERPLANT GROUP

Safety Board Powerplant Group Chairman: Jean-Pierre Scarfo
Powerplant Lead Engineer
Washington D.C.

CFMI Members: Ken Wolski
Flight Safety Investigator
Cincinnati, Ohio
Valerie Gros
Accident Investigator
Villaroche, France

Federal Aviation Administration Members: Kasra Sharifi
Aerospace Engineer
Burlington, Massachusetts
Philip Haberlen
Aerospace Engineer
Burlington, Massachusetts
Southwest Airlines Members:

- Sara Gons
  Air Safety Investigator
  Dallas, Texas
- Cory Boese
  Manager, Powerplants Programs
  Dallas, Texas
- Mark Babb
  Senior Engineer, Powerplants Programs
  Dallas, Texas

Bureau d’Enquêtes et d’Analyses pour la sécurité de l’aviation civile (BEA) Members:

- Adrien Vidal
  Safety Investigator
  Investigations Department Aéroport du Bourget, Paris France
- Stéphane Otin
  Safety Investigator
  Technical Department Aéroport du Bourget, Paris France

Boeing Members:

- Richard Anderson
  Air Safety Investigator
  Seattle, Washington
- Michael Germani
  Propulsion Safety
  Seattle, Washington
C. SUMMARY

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.

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 or line 3 (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; the transfer gearbox housing was scrapped due to issues with a bushing that had been previously installed.

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 hardmesses.

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 eight 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. 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, released 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, in light of this event, the process is being reviewed for improvements in process documentation.
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| % | PERCENT | JAA | JOINT AVIATION AUTHORITIES |
| %C | TEMPERATURE IN DEGREES CELSIUS | JAR | JOINT AVIATION REQUIREMENTS |
| μm | MICROMETER | Lbs. | POUNDS |
| AC | ADVISORY CIRCULAR | LPC | LOW PRESSURE COMPRESSOR |
| AGB | ACCESSORY GEARBOX | LPT | LOW PRESSURE TURBINE |
| ALF | AFT LOOKING FORWARD | MCD | MAGNETIC CHIP DETECTOR |
| AMM | AIRCRAFT MAINTENANCE MANUAL | MIN | MINUTE |
| AMS | AEROSPACE MATERIAL STANDARD | Mm | MILLIMETERS |
| ASB | ALERT SERVICE BULLETIN | Mn | MAGNESIUM |
| AOW | ALL OPERATORS WIRE | Mo | MOLYBDENUM |
| APU | AUXILIARY POWER UNIT | MPa | MEGAPASCALS |
| BEA | BUREAU D’ENQUÊTES ET D’ANALYSES POUR LA SÉCURITÉ DE L’AVIATION CIVILE | N1 | FAN/LOW ROTOR SPEED IN PERCENT RPM |
| BSI | BORESCOPE INSPECTION | N2 | HIGH ROTOR SPEED IN PERCENT RPM |
| C | CARBON | Ni | NICKEL |
| CMM | COMPONENT MAINTENANCE MANUAL | NTSB | NATIONAL TRANSPORTATION SAFETY BOARD |
| Cr | CHROME | NVM | NON-VOLATILE MEMORY |
| CSLSV | CYCLES SINCE LAST SHOP VISIT | OEM | ORIGINAL EQUIPMENT MANUFACTURER |
| CSN | CYCLES SINCE NEW PART | PN | PART NUMBER |
| CSO | CYCLES SINCE OVERHAUL | POE | REFERS TO ENGINE OIL PRESSURE |
| DGAC | DIRECTION GÉNÉRALE DE L’AVIATION CIVILE | PPH | POUNDS PER HOUR |
| ECI | EDDY CURRENT INSPECTION | PSI | POUNDS PER SQUARE INCH |
| ECU | ELECTRONIC CONTROL UNIT | QAD | QUICK ATTACH-DETACH |
| EDS | ENERGY DISPERSIVE X-RAY SPECTROSCOPY | RPM | REVOLUTION PER MINUTE |
| EEC | ELECTRONIC ENGINE CONTROL | SAE | SOCIETY OF AUTOMOTIVE ENGINEERS |
| EGT | EXHAUST GAS TEMPERATURE | SB | SERVICE BULLETIN |
| ESM | ENGINE SHOP MANUAL | SEC | SECOND |
| ESN | ENGINE SERIAL NUMBER | SEM | SCAN ELECTRON MICROSCOPE |
| FAA | FEDERAL AVIATION ADMINISTRATION | Si | SILICON |
| FDR | FLIGHT DATA RECORDER | SN | SERIAL NUMBER |
| Fe | IRON | Sncema | SOCIÉTÉ NATIONALE D'ÉTUDE ET DE CONSTRUCTION DE MOTEURS D'AVIATION |
| FE | FINITE ELEMENT | SO | SERVICE ORDER |
| FF | FUEL FLOW | SPM | STANDARD PRACTICES MANUAL |
| FMC | FLIGHT MANAGEMENT COMPUTER | TBV | TRANSIENT BLEED VALVE |
| FPI | FLUORESCENT-PENETRANT INSPECTION | TC | TYPE CERTIFICATE |
| FWD | FORWARD | TCDS | TYPE CERTIFICATE DATA SHEET |
| G | GRAMS | TE | TRAILING EDGE |
| GMT | GREENWICH MEAN TIME | TGB | TRANSFER GEARBOX |
| GMT | GREENWICH MEAN TIME | TLA | THRUST LEVER ANGLE |
| H | HOUR(S) | TR | THRUST REVERSER |
| HCF | HIGH CYCLE FATIGUE | TRF | TURBINE REAR FRAME |
| HP | HIGH PRESSURE | TSLSV | TIME SINCE LAST SHOP VISIT |
| HPC | HIGH PRESSURE COMPRESSOR | TSN | TIME SINCE NEW |
| HPT | HIGH PRESSURE TURBINE | TSO | TIME SINCE OVERHAUL |
| IDG | INTEGRATED DRIVE GENERATOR | UTI | ULTRASONIC INSPECTION |
| IFSD | IN-FLIGHT SHUTDOWN | VBV | VARIABLE BLEED VALVE |
| IGB | INLET GEARBOX | VSV | VARIABLE STATOR VANE |
| WO | WORK ORDER | | |
D. DETAILS OF THE INVESTIGATION

1.0 ENGINE AND AIRPLANE INFORMATION

1.1 ENGINE DESCRIPTION

The CFM56-7B24 is a high bypass, dual-rotor, axial flow turbofan engine. A single-stage high pressure turbine (HPT) drives the 9-stage high-pressure compressor (HPC). The integrated fan and low-pressure compressor (booster) are driven by a 4-stage low pressure turbine (LPT). The annular designed combustion chamber increases the HPC discharge air velocity to drive the high and low-pressure turbines. An accessory drive system provides drive requirements for engine mounted aircraft accessories. The engine consists of 3 major assemblies: fan, core engine, and LPT. It also includes the following components which are removed or installed at engine level: 2 modules (accessory gearbox (AGB) and transfer gearbox (TGB)), spinner front cone, LPT shaft plug and coupling nut, aft rotating air/oil separator, and oil inlet cover (FIGURE 1). According to the engine’s Federal Aviation Administration (FAA) Type Certificate Data Sheet (TCDS) E00056EN, Revision 10, dated August 9, 2016, the CFM56-7B24 has a maximum takeoff thrust rating of 24,200 pounds flat-rated\(^1\) to 86°F (30°C) and a maximum continuous thrust rating of 22,800 pounds flat-rated to 77°F (25°C). The CFM56 engine is a dual certificated engine – certificated by the United States FAA and French Direction Générale de l’Aviation Civile (DGAC). The FAA issued the type certificate for the CFM56-7B24 on December 17, 1996. The FAA certificate basis is 14 CFR §33 effective February 1, 1965 with Amendments 33-1 through 33-15. Since the CFM56 engine is a dual certificated engine, Joint Aviation Requirements (JAR) required by the European Joint Aviation Authorities (JAA) were also complied with. The DGAC originally certificated the engine model under DGAC certificate de Type Moteur M21 and the FAA validated the product under type certificate (TC) number E00056EN.

\(^{1}\) Flat-rated to a specific temperature indicates that the engine will attain the rated thrust level up to the specified inlet temperature.
CFMI is a partnership between General Electric in the USA and Safran Aircraft Engines (formerly Snecma of France). CFM is not an acronym; however, the company (CFM International) and product line (CFM56) receive their names by a combination of the two parent companies’ commercial engine designations: GE’s CF6 and Snecma’s M56. Snecma changed its name to Safran Aircraft Engines, a subsidiary of the Safran Group, in May 2016. The division of labor is such that Safran Aircraft Engines is responsible for the fan and LPT modules while GE is responsible for the remainder of the engine – HPC, combustion, and HPT.

According to the type certificate E00056EN, engines that are produced by GE are identified by an even number serial number prefix (i.e., “874”, “876”, “890”, “892”, or “654”) and by Safran are identified by odd number prefix; therefore, the event engine serial number (ESN) 874267 was produced by GE.

All directional references to front and rear; right and left; top and bottom; and clockwise and counterclockwise are made aft looking forward (ALF) as is the convention. All numbering is in the circumferential direction starting with the No. 1 position at the 12:00 o’clock position, or immediately clockwise from the 12:00 o’clock position, and progressing sequentially clockwise ALF. The direction of rotation of the engine is clockwise ALF.

1.2 ENGINE HISTORY

The right-hand engine installed on the incident airplane, N765SW, was a CFM56-7B24 turbofan engine, ESN 874267 (PHOTO 1). According to SWA, at the time of the gearbox failure incident, ESN 874267 had accumulated 63,711 hours time since new (TSN); 37,433 cycles since new (CSN); 668 hours time since last shop visit (TSLSV); and 415 cycles since last shop visit (CSLSV). In January 2017, SWA removed ESN 874267 from the right-hand side of airplane N241WN due to life limited parts and sent it to the GE Celma facility in Petrópolis, Brazil for repair; the engine repair also included repair of the AGB. The engine was repaired and returned to SWA on March 16, 2017. Then on March 26, 2017, SWA installed ESN 874267 on the right-hand side of airplane N765SW where it remained until the gearbox failure event. For pre-2017 engine history, see Section 1.4 - ACCESSORY GEARBOX ASSEMBLY HISTORY.
1.3 TRANSFER GEARBOX AND ACCESSORY GEARBOX ASSEMBLY DESCRIPTION

The transfer gearbox (TGB) assembly provides power transmission between the inlet gearbox (IGB), located internal to the engine and driven by the high pressure (HP) rotor system, and the AGB and consists of three major assemblies: outer radial drive shaft, TGB, horizontal drive shaft (Figure 2). The TGB is mounted on the left-hand side of the fan frame at the 9:00 o’clock position and consists of a housing and two bevel gears; the input bevel gear (31-tooth gearshaft) and the horizontal bevel gear (32-tooth gearshaft). A pair of roller and ball bearings support the input bevel gear and the horizontal bevel gear. The gearshafts are identified by nomenclature and number of teeth while the shafts are identified by line number; line numbers 1 and 2 refer to the outer radial drive shaft and 31-tooth gearshaft (L1) and the horizontal drive shaft and 32-tooth gearshaft (L2), respectively. The radial drive shaft is also commonly referred to as the input shaft and the horizontal drive shaft is commonly referred to as the transfer shaft. For consistency and simplify, the horizontal drive shaft will be referred to as simply the transfer shaft.

The AGB assembly is mounted on the left-hand side of the fan frame at the 9:00 o’clock position by 4 clevis mounts (2 lateral, one upper, one lower) (Figure 3). A fifth lateral outer mount enables AGB adjustment according to the X-axis (longitudinal) for the coupling of AGB and TGB. The AGB assembly consists of the AGB housing and gear train. The AGB housing is an aluminum alloy casting where some of the accessories are installed using Quick Attach/Detach (QAD) rings. The front face of the AGB housing has installation pads for the hydraulic pump, integrated drive generator (IDG) starter, handcranking drive, control alternator (provided power supply to the electronic engine control (EEC)\textsuperscript{2}, and N2 speed sensor while the rear face connects to the TGB assembly and has installation pads for the lubrication unit, intermediate oil filter, intermediate gear, and fuel pump and hydromechanical unit (HMU)\textsuperscript{3} (Figure 4). The gear train is contained within the AGB housing and consists of gears that reduce or increase the rotational speed to meet the specific drive requirements of each accessory. Each gear and its respective bearings and bearing support is a plug-in type assembly and sealing is accomplished by either carbon magnetic or sealol-type seal\textsuperscript{4}. The various gear train gearshafts are identified by nomenclature, number of teeth, and line number (Figure 5). The accessory mount pads on the AGB housing are identified by nomenclature and by line number.

For engine start or restart, the air-driven starter drives the AGB through the L5 gearshaft to accelerate the engine core (HP) rotor system) to a speed where fuel and ignition can be introduced until

\textsuperscript{2} The EEC is sometimes referred to as the engine control unit (ECU).
\textsuperscript{3} The fuel pump is mounted directly to the AGB and the HMU is mounted on the fuel pump. Also mounted to the fuel pump is the oil-fuel heat exchanger and the fuel heater is mounted to the oil-fuel heat exchanger.
\textsuperscript{4} The magnetic seal consists of a non-magnetic seal housing which houses a magnetized mating ring with a polished face and a retaining ring a rotating seal, which has a carbon seal held in a rotating ring. The sealol seal is made of a carbon packing and a rotating mating ring with a polished face. The rotating mating ring has 4 lugs that engage in 4 corresponding slots in the gearshaft on bearing. A housing containing a spring-loaded carbon seal ensures constant contact between the polished face of the rotating mating ring and the carbon seal element.
the engine becomes self-sustaining. After the engine reaches a speed that it can sustain itself, the starter is disengaged, and the HP rotor system drives the AGB.
1.4 ACCESSORY GEARBOX ASSEMBLY HISTORY

The event AGB was identified as serial number (SN) WQ1196 and review of the maintenance records revealed: 1) AGB SN WQ1196 was installed on ESN 874267 for its entire service history and 2) the failed L3 gearshaft, SN UN00086, was installed in AGB SN WQ1196 for its entire service history (See Section 1.5 – L3 GEARSHAFT SN UN00086 HISTORY for details). Therefore, times and cycles since new or since last shop visit listed for the engine also apply to the AGB and the L3 gearshaft.

In July 1998, SWA received ESN 874267 new with AGB SN WQ1196 installed; this engine was installed on airplane N717SA, position 1 (FIGURE 6). In June 1999, SWA removed the engine due to vibration focused on the fan section and shipped it to the GE Strother engine facility in Strother Kansas for repair. The engine had accumulated 3,213 hours TSN and 2,180 CSN. The AGB was not removed from the engine at this shop visit, instead Level 1 maintenance was performed. According to SWA, Level 1 maintenance for the AGB is a visual inspection of the AGB, ATB turnbuckles, and the TGB in-situ for obvious damage; no anomalies were reported. ESN 874267 was repaired and in December 1999 SWA installed it on airplane N737JW, position 2 where it remained until May 2003.

In May 2003, SWA removed the engine due to cracked HPT blades and shipped it to the GE Strother engine facility for repair. The engine had accumulated 16,038 hours TSN and 9,726 CSN at the time of removal. The AGB was not removed from the engine at this shop visit, instead Level 1 maintenance was performed. According to GE Strother’s maintenance records, the AGB gear pad seals were replaced and the AGB link and turnbuckle at the 6:00 o’clock position was repaired. ESN 874267 was repaired and in September 2003 SWA installed it on airplane N790SW, position 1 where it remained until May 2007.
In May 2007, SWA removed ESN 874267 due to life limited parts and shipped it to the GE Celma facility for overhaul. The engine had accumulated 29,952 hours TSN; 17,573 CSN; 13,914 hours TSLSV; and 7,847 CSLSV at the time of removal. The AGB was removed from the engine and Level 3 maintenance was performed. According to SWA, Level 3 for the AGB requires disassembly to piece-part level for inspection and is considered an overhaul of the AGB. The AGB was inspected and repaired per the CF56-7B engine shop manual ESM repairs 001 and 002, and RD 15-93753 and RD 15-93815. Alert Service Bulletin (ASB) 72-A0140 Revision 1 was also incorporated before the AGB was reassembled and reinstalled on ESN 874267; the engine was shipped to SWA where in August 2007 they installed it on airplane N429WN, position 1 where it remained until October 2007.

In October 2007, SWA removed ESN 874267 for a potential configuration issue (not connected to the AGB) related to a SB incorporation. The engine had accumulated 30,695 hours TSN; 18,010 CSN at the time of removal. An inspection was performed and the engine was deemed serviceable; no maintenance was performed on the AGB and the engine was preserved and stored until November 2007 when SWA installed it on airplane N241SW, position 2 where it remained until January 2017.

In January 2017, SWA removed ESN 874267 due to life limited parts and shipped it to the GE Celma facility for overhaul. The engine had accumulated 63,043 hours TSN; 37,018 CSN; 33,091 hours TSLSV; and 19,445 CSLSV at the time of removal. The AGB was removed from the engine and Level 3 maintenance was performed. According to January 2017 shop records, the AGB assembly installed on ESN 874267 was PN 340-046-509-0, SN WQ1196. The incoming inspection at the engine level found that the AGB was nicked, rear mount link dampers were worn, cover and fuel pump quick attach-detach (QAD) had impact marks, and control alternator had carbon build-up. According to CFMI about 90% of all dampers are replaced at shop visit. At this shop visit, GE Celma incorporated Category 6 CFM56-7B service bulletin (SB) 72-0879 titled ENGINE - GENERAL (72-00-00) - INTRODUCTION OF A NEW ACCESSORY GEARBOX ASSEMBLY (AGB) WITH NEW HOUSING ASSEMBLY AND NEW STARTER DRIVE PAD ASSEMBLY AND REWORK OF THE OLD AGB TO THE NEW ONE. SB 72-0879 was issued to address instances where studs fixing the control alternator line bearing outer race-to-AGB housing pulled out resulting in inflight shutdowns. With the incorporation of SB 72-0879, the old AGB assembly PN 340-046-503-0 was reidentified as PN 340-046-509-0 (PHOTO 2). The FAA issued Airworthiness Directive (AD) 2013-26-01 on December 30, 2013 with an effective date of February 3, 2014 requiring CFM56-3 and CFM56-7B series turbofan engines with certain AGBs not equipped with a handcranking pad "oil dynamic seal" assembly to be subjected to an independent inspection to verify re-installation of the handcranking pad cover after removal of the pad cover for maintenance. The intent of the AD was to address instances where the handcrank pad was inadvertently left off resulting in loss of engine oil while in flight in AGBs

5 Category 6: Do when the part is routed for repair
6 The European Aviation Safety Agency (EASA) issued an AD 2012-0209 dated October 08, 2012.
without a dynamic seal. Although SB 72-0879 was issued to address stud pullouts, it did include the new handcranking "oil dynamic seal" assembly, PN 340-155-305-0, that satisfies a termination option for the inspection requirement by AD 2013-26-01; therefore, only the AD inspection requirement was applicable.

After the AGB was inspected, repaired, reassembled, and reinstalled (new dampers were installed) on ESN 874267; the engine was shipped to SWA were in March 2017 SWA installed it on airplane N765SW, position 2 where it remained until its failure on June 3, 2017. At the time of the AGB failure, the engine and AGB had accumulated 63,711 hours TSN; 37,433 CSN; 668 hours TLSSV; and 415 CSLSV; the last shop visit was also the last AGB overhaul, so 668 hours and 415 cycles since last shop visit also relate to 668 hours time since overhaul (TSO) and 415 cycles since overhaul (CSO).

FIGURE 6: ESN 874267, AGB SN WQ1196 AND GEARSHAFT SN UN00086 HISTORY TIMELINE

1.5 L3 GEARSHAFT SN UN00086 HISTORY

Review of the maintenance records revealed that the L3 gearshaft PN 340-051-801-0/SN UN00086 was installed in AGB SN WQ1196 for its entire service history. Therefore, times and cycles since new or since last shop visit listed for the engine and AGB apply to the L3 gearshaft as well (See Sections 1.4 - ACCESSORY GEARBOX ASSEMBLY HISTORY for AGB/L3 gearshaft times/cycles).

L3 gearshaft SN UN00086 was manufactured in 1997 by Hispano-Suiza (now Safran Transmission Systems). The event gearshafts was 1 of 32 L3 gearshafts initially produced from the same production batch; batch number DM042218. Due to corrosion issues during the manufacturing process, only 8 of the 32 from batch DM042218, including the event gearshaft, were ever put into service. The eight gearshafts that were put into service had additional manufacturing operations performed on them to
address the corrosion. These included corrosion removal, etching, deoxidation which is a chemical cleaning process, and machining. In March 1998, gearshaft SN UN00086 was installed new in AGB SN WQ1196 and the AGB was installed new on ESN 874267.

At that time the failed L3 gearshaft was manufactured, shot-peening was not required on any of the AGB gears and gearshafts. Later that same year (1998), 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.

The L3 gearshaft was removed and inspected twice in its service life; during the 2007 and 2017 AGB Level 3 maintenance repairs. According to the CFM56-7B ESM, ACCESSORY GEARBOX GEARSHAFTS – INSPECTION/CHECK, TASK 72-63-03, all the AGB gearshafts are subjected to an FPI, visual inspection, and dimensional inspection. The FPI is to be performed per standard practices manual (SPM) TASK 70-32-15-230-009; the FPI is a post-emulsifiable ultra high sensitivity Level 4 inspection process. No cracks are allowed, and any amount of black oxide missing is permissible and deemed serviceable. If no visible damage is noted to the gearshaft, then the only dimensional requirement is to inspect the bearing surface diameters “E” and “F”.

Review of the 2007 GE Celma work orders (WOs), 2007122246 (FPI) and 2007126953 (dimensional) showed that the gearshaft SN UN00086 was FPIed, visually inspected, and diameters “E” and “F” were dimensionally inspected per TASK 72-63-03. The gearshaft was determined to be serviceable and was reinstalled in AGB SN WQ1196. According to 2017 GE Celma maintenance records, OPERATION SEQUENCE RESULTS RECORDING INSPECTION – SERVICE ORDER, SO 2001690853, the control alternator gearshaft was FPIed with no findings reported. No discrepancies were noted for the visual inspection cracks, and visual inspection for damage/wear to the bearing journal, seal seat, teeth and splines; the only damage noted was the oil retaining ring located on the inner diameter gearshaft where it mates with the control alternator. The damaged oil retaining ring was repaired in accordance with ACCESSORY GEARBOX GEARSHAFT REPAIR 003 – REPLACEMENT OF THE OIL RETAINING RING ON THE 47-TOOTH GEARSHAFT ASSEMBLY (ROUTING OPERATIONS REPAIR - SO 6000313548). Since no visual damage was noted to the gearshaft, the only required dimensional inspections were for diameters “E” and “F”; these diameters are bearing journal diameters, and both were within serviceable limits. The gearshaft was determined to be serviceable and was reinstalled in AGB SN WQ1196.

At the time of the AGB failure, the 47-tooth gearshaft/AGB/engine had accumulated 63,711 hours TSN; 37,433 CSN; 668 hours TSLSV; and 415 CSLSV.

1.6 DESCRIPTION OF ENGINE NACELLE, AND ENGINE MOUNT HARDWARE

The engine inlet cowl, fan cowl, fan duct cowl & thrust reverser (TR) (subsequently referred to in the rest of the report as simply the thrust reverser (TR)), the primary exhaust nozzle, and exhaust plug, comprise the boundaries of the engine nacelle and consist of fixed and hinged components (FIGURES 7). The fixed components include the inlet cowl, primary exhaust nozzle, and exhaust plug; while the hinged components include the fan cowl and TR. The inlet cowl is bolted to the engine fan case, the primary exhaust nozzle is bolted to the outer portion of the turbine rear frame (TRF), and the exhaust plug (two-piece design) is bolted to the forward centerbody that is attached to the inner portion of the TRF. The fan cowl and the TR are each in two halves, hinged at either side of the strut, and joined by latch hooks on the bottom centerline – the fan cowl incorporates 3 latches while the TR incorporates 6 latches. All the nacelle hardware, including the TR, is provided by Boeing and the engine is supplied by
CFMI. The fan cowl, PN 314-2200-5, SN 2123001, was manufactured for Boeing by Rohr Industries, Inc. (currently known as UTAS\(^7\)) Chula Vista, California.

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\(^7\) Rohr Industries, Inc. originally designed, manufactured, and delivered the inlet cowl to Boeing. Subsequently, Rohr Industries, Inc. was acquired by Goodrich Aerospace and became Goodrich Aerostructures respectively before being acquired by UTAS. Though the company name at the time of the design and certification was Rohr Industries, Inc., for the remainder of this report, the inlet cowl manufacturer will be referred to as UTAS.
2.0 ON-SCENE EXAMINATION

A Powerplant Group did not convene at IAD to examine the airplane and engine. Instead, the NTSB granted permission for SWA to document the airplane and engine damage in-situ and report back their findings. The NTSB also granted permission for SWA, after the in-situ documentation was completed, to remove and transport ESN 874267 back to their maintenance facility at Love Field, Dallas Texas. The following on-scene and engine examination information was provided by SWA.

2.1 ENGINE COWLINGS EXAMINATION

The fan cowls and TRs 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. The damage was located: 37-inches from the trailing edge of the fan cowling to the trailing edge of the tear, 25-inches from the top of the fan cowl to the top of the tear, and 23.5 inches from bottom of the fan cowl to the bottom of the tear (PHOTO 3 and FIGURE 8). The outer skin was peeled/pushed outward about 1-inch and slightly curled in some areas. Some of the fan cowling DAPCO® 2900 red/orange-colored fire protection thermal coating8 on the inboard side of the peeled skin was missing and appeared to be scraped off; the underling bare skin did not exhibit any impact damage (red arrow). Imbedded in the crease of the tip/tear/slice was part of the oil pressure transmitter and alternator-A electrical wire bundle (yellow arrow). Some of the blue and white paint around the tear became disbonded and flaked/peeled off. From the outside of the fan cowl, it appears that all the outer skin was still present.
When the fan cowls were opened to exam the condition of the inside of the fan cowl and the engine; loose debris was collected. PHOTO 4 shows the gear teeth rim section with PN 340-051-801-0 marked on it. According to the CFM56-7B Illustrated Parts Catalog (IPC), reference 72-63-00, the piece of gear teeth rim is part of the L3 gearshaft. PHOTO 5 shows what appears to be a piece of the gearbox housing assembly (top) and an oil supply nozzle (bottom); the AGB has seven oil supply nozzles.

PHOTO 4: GEAR TOOTH RIM SECTION FROM L3 GEARSHAFT
PHOTO COURTESY OF SWA

PHOTO 5: PIECES OF THE AGB HOUSING ASSEMBLY HOUSING AND OIL NOZZLE
PHOTO COURTESY OF SWA

Examination of the inside of the right-hand engine inboard fan cowl revealed that the impact rip/tear/slice was in-line axially between the two fan cowl hold-OPEN rod attachment brackets (PHOTO 6). No other impact damage was noted on the fan cowl. No thermal damage or distress was noted to the fan cowling DAPCO® 2900 fire protection thermal coating.

PHOTO 6: RIGHT-HAND ENGINE INBOARD COWL DAMAGE VIEW FROM OUTSIDE
PHOTO COURTESY OF SWA
2.2 ENGINE EXAMINATION

Examination of the engine revealed an exit hole in the outboard side of the AGB in-line with the L3 gear train (PHOTO 7); line 3 gear train is the control alternator gearshaft (also referred to as the 47-tooth gearshaft or the L3 gearshaft). The exit hole was visually estimated to be 3-inches circumferentially (length) x 2-inches axially (wide). This bracket secures the J6, J7, and J8 harnesses (PHOTOS 7 and 8). The J7 wire harness assembly, which contains the EEC, N1 sensor, alternator-A, oil filter bypass warning, T12 sensor-A and oil pressure sensor-A, was severed (PHOTO 8).

[Photos 7 and 8 showing AGB exit hole and distorted wire bundle bracket, and severed J7 wire bundle harness.]

3.0 POST ON-SCENE ENGINE EXAMINATION

Following the in-situ airplane and engine exam at IAD, the right-hand engine and its associated fan cowls were shipped to the SWA facility in Dallas for further evaluation. The Powerplant Group did not convene at the SWA maintenance facility in Dallas to witness and oversee the follow-on engine examination and AGB removal. The NTSB authorized SWA to perform the following tasks: Perform a visual inspection of the engine and document any damage, performed a borescope inspection of the AGB while it was still installed on the engine, perform a AGB alignment check, and inspection the magnetic chip detectors and oil filter for debris. The results from SWA are below.

3.1 ACCESSORY GEARBOX BORESCOPE INSPECTION

A borescope probe was inserted into the exit hole in the side of the AGB while it was still installed on the engine; none of the accessories that were attached to AGB were removed to perform the inspection. No attempt to rotate any of the gearshafts was made. Examination of L3 gearshaft revealed that all the gear teeth were sheared at the web interface (PHOTO 9); remnants of what appear to be gear teeth from the L3 gearshaft were found within the AGB. The AGB housing exhibited impact damage in the size and shape consistent with gear teeth contact in the area were the L3 gearshaft gear teeth had been found. The oil nozzle that supplies oil to the L3 gearshaft and its bearing was missing; however, its
attachment bolt was still engaged with the AGB housing and the top of the bolt exhibited impact damage. The handcranking gearshaft (62-tooth gearshaft), also commonly referred to as the line 4 (L4) gearshaft, meshes with the L3 gearshaft. The ‘top lands’ of the L4 gearshaft teeth were smeared and exhibited loss of material; all the L4 gearshaft teeth that were visible appeared to be present and whole (Photo 10).

3.2 Accessory Gearbox Alignment Check

Before the AGB alignment check was performed, all the gearbox attached accessories were removed except for the control alternator; the TGB assembly was also disengaged from the AGB. Examination of the external driven splines for all the accessories and their mating gearshaft internal drive splines revealed that they were in good condition, intact, whole, wetted, and did not exhibit any fretting or damage.

To disengage the TGB, the V-clamp that secures the TGB sleeve to the TGB-to-AGB input drive mount pad flange was removed and the TGB sleeve was slid aft exposing the horizontal drive shaft and the horizontal drive shaft locking nut (Figure 9). The horizontal drive shaft locking nut (subsequently referred to as the locking nut) was found loose; essentially finger tight. The coupling of the TGB to the AGB requires full engagement of the horizontal drive shaft into the internal splines of the L3 gearshaft, the locking nut is threaded onto the external threads of control alternator gearshaft, and a nominal torque of 120 foot-pounds (1300-1600-inch-pounds or 145-180 newton-meter) is applied. According to the GE Celma OPERATION SEQUENCE RESULTS RECORDING ASSEMBLY SERVICE ORDER, (SO) 30184137, Operation number 310, performed on March 4, 2017, the recorded torque value for the horizontal shaft locking nut was 1600-inch-pounds.
Examination of the AGB-to-TGB joint revealed: 1) the locking nut threads appeared in good condition with slight signs of fretting or damage, 2) the locking nut engagement threads on the L3 gear shaft appeared in good condition with no signs of fretting or damage (PHOTO 11), 3) no damage to the engagements spline teeth on either the L3 gear shaft (internal splines) and mating the horizontal drive shaft spline teeth (external splines), 4) the retaining ring, also referred to as a C-clip, remained installed in the groove just forward of the lock nut engagement threads on the L3 gear shaft (FIGURE 8 and PHOTO 11) and 5) the C-clip appeared to be in good condition; not flattened or distorted (PHOTO 11). The C-clip prevents disengagement of the locking nut if the clamping torque is lost. Centrifugal force pushes the C-clip radially outward to engage the nut.

The gearbox alignment check was performed using the Boeing aircraft maintenance manual (AMM) TASK 72-63-00-400-804-F00 ACCESSORY GEARBOX INSTALLATION. GE engine services assisted SWA in performing the AGB alignment check. Alignment fixture, SPL-9148 was attached to the fan frame with three knurled buttons. In the AMM TASK 72-63-00 Section C Tools/Equipment section alignment fixture SPL-9148 is cross-referenced to tool PN 856A3709G01. Depth gage, PN 856A3709P06, was installed in the guide rail PN 856A3709P05, to measure the distance from the fixture to the IDG pad; measurements are taken on opposite sides of the IDG (FIGURE 10 and PHOTO 12). For correct alignment, the difference between the two measurements (difference between DIM A and DIM B) must be no greater than ±0.0020-inches (0.05-millimeters (mm)). According to SWA, the post event DIM A and DIM B measurements were 17.5455-inches and 17.5475-inches respectively; hence the difference between DIM A and DIM B was 0.0020-inches. This AGB alignment met the installation requirements.
The AGB alignment instructions are also located in the CFM56-7B ESM TASK 72-00-63-420-001-A ACCESSORY GEARBOX MODULE - INSTALLATION. These were the procedures that GE Celma used during the last engine shop visit. A comparison of the AMM and ESM revealed that the alignment fixtures/gages, procedures, and alignment limits were all identical. According to the GE Celma OPERATION SEQUENCE RESULTS RECORDING ASSEMBLY SERVICE ORDER, SO 30184137, Operation number 290, performed on March 4, 2017, DIM A and DIM B were recorded as 17.541-inches and 17.5405-inches, respectively; hence the difference was 0.0005-inches.

3.3 OIL SYSTEM INSPECTION - MAGNETIC PLUG, FILTER, AND OIL LINES

The oil lubrication unit is comprised of one supply and three scavenge pumps, a relief valve, four filters – one supply and three scavenge with magnetic chip detectors (MCD), and a red clogging indicator with a by-pass valve mounted in parallel with the supply filter. The red clogging indicator becomes visible when the supply filter is clogged and the by-pass valve opens. The indicator must be manually reset if triggered (PHOTO 13).

The supply pump draws oil from the tank and pressurizes it. Downstream of the pump, the oil passes through the supply oil filter, pressure relief valve, and out to the AGB and the forward and aft sumps. The three scavenge pumps draw the air/oil mixture in the sumps and AGB through external tubing to the oil lubrication unit where it passes through the individual scavenge filters and chip detectors before the scavenge oil is mixed and the oil is sent to the main scavenge filter (external to the oil lubrication unit), oil/fuel heat exchanger and then back to the oil tank.

Visual inspection of the oil lubrication unit revealed that the clogging indicator had not been triggered. The three scavenge filters with MCDs were removed from the oil lubrication unit and the forward chip detector was covered in ferrous material (PHOTOS 14 and 15); the other two filters were free of visible debris (PHOTO 14).
The oil supply filter and the main scavenge filter were removed and the main scavenge filter and filter bowl (Photo 16) had small bits of shiny silver material; the oil supply filter was free of visible debris. Removal of the AGB/TGB scavenge line revealed that the line was full of debris (Photo 17).

**Photo 16: Main Scavenger Filter Bowl with Silver Debris**  
*Photo Courtesy of SWA*

**Photo 17: AGB/TGB Scavenge Line-to-Oil Lubrication Unit Tube Full of Debris**  
*Photo Courtesy of SWA*

3.4 **Accessory Gearbox Removal**

The AGB assembly is mounted to the fan frame by four clevis mounts plus a fifth mount to adjust the AGB for coupling of the AGB and TGB (Figure 11). The top (Photo 18) and bottom of the AGB is mounted by using straight pin bolts with self-locking nuts at the upper and lower mount positions clevis. Two lateral fixed-length rear mount links, upper (Photo 19) and lower (Photo 20), connect the rear of the AGB assembly to the fan frame along with an adjustable lower turnbuckle rear mount (Photo 21). At either end of the rear mount links are dampers to minimize fretting and straight pin bolts with self-locking nuts and cotter pins are used to clamp the joint.

No anomalies were noted on any of the bolted joints; nuts were secured and torqued, cotter pins were in place, the dampers were all installed and in good condition, and the mount links appeared straight and were easy to remove.
4.0 ACCESSORY GEARBOX ASSEMBLY TEARDOWN/METALLURGICAL EVALUATION

The AGB, the TGB-to-AGB locking nut, horizontal drive shaft (commonly referred to as the transfer shaft), debris collected for all the oil filters, debris collected from the AGB/TGB scavenge line, and loose gearbox debris collected on-scene and at the AGB removal at SWA were shipped to the Safran facility in Colombes north of Paris, France for teardown, evaluation, and metallurgical examination. The AGB was disassembled and examined the week of July 24, 2017 with members from the BEA, SWA, and CFMI in attendance. CFMI provided a detailed report, reference number 17/1209 dated December 12, 2017, on the disassembly and examination of the accessory gearbox and the transfer gearshaft. The following is a synopsis of that report; for complete details see ATTACHMENT 1.

4.1 AGB MAIN HOUSING AND MOUNT PADS

The AGB housing, PN 340-046-602-0, SN U000233, is made from aluminum with a corrosion preventative anodized layer applied. Before the AGB was disassembled, a series of run out, drop, alignment, and concentricity dimensional checks were performed on the L3 gearshaft as well as on the AGB housing L3 mount pad (PHOTO 22). Due to damage of the gearshaft portion of the L3 gearshaft,
dimensional checks could not be performed where a reference datum was on the gearshaft. Of the dimensional checks performed, all were within specifications. The AGB housing exhibited an exit hole measured approximately 55 millimeters (mm) by 38 mm (2.2 x 1.5-inches) in line with the L3 gearshaft. The fragment of the housing recovered on-scene (See PHOTO 5) matched well with the hole found in housing. The recovered housing fragment was bulged outwards and on the inner surface exhibited circumferential scoring marks; thickness measurements revealed variations consistent with wear observed. With all the gearshafts removed, the housing line bore locations were examined. The AGB housing L3 bore was heavily damaged/scored and remnants of the L3 gearshaft gear teeth and gear web were found inside (PHOTO 23). Like the housing fragment recovered on-scene, thickness measurements of the L3 bore scoring revealed reduction in wall thickness consistent with the scoring observed. Dimensional inspection found that the main housing had become distorted, which CFMI concluded was due to the event. All the line bore covers were intact and some exhibited minor impact marks and fretting marks consistent with the failure event and post event operation.

4.2 L3 Gearshaft (47-Tooth Gearshaft) Assembly PN 340-051-801-0/SN UN00086

4.2.1 L3 Gearshaft Assembly Description

The L3 gearshaft is also commonly referred to as the control alternator gearshaft and listed in the IPC as the 47-tooth gearshaft assembly. All three names are used throughout the rest of the report interchangeably. The L3 gearshaft is supported within the AGB housing by two sets of bearings; a roller bearing on the front side of the AGB housing (control alternator drive side) and a ball bearing on the aft side of the AGB housing (the TGB horizontal drive shaft driven side). The L3 gearshaft installed in the failed AGB was PN 340-051-801-0 and SN UN00086. The L3 gearshaft is made of Safran DMD 180-20, a carburized steel similar to the Society of Automotive Engineers (SAE) International Aerospace Material Standard (AMS) 6263. DMD 180-20 is a low alloy carburizing case hardenable steel with trace amounts of Carbon (C), Magnesium (Mn), Silicon (Si), Nickel (Ni), Chrome (Cr) and Molybdenum (Mo). A black oxide surface treatment is applied to the part to provide some corrosion resistance. Black oxide is a chemical conversion coating; it is not a deposited layer, such as electroplating or brush coating.
Instead it is a chemical reaction between the iron (Fe) in the part material and the oxidizing salt solution applied causing a black oxide to form on the surface.

### 4.2.2 L3 Gearshaft Metallurgical Evaluation

Visual examination of the L3 gearshaft confirmed that all the gear teeth had separated from the gearshaft web and what remained of the gear web was distorted (Figure 12 and Photo 24). A dimensional check found that the L3 gearshaft was bowed longitudinally at either end; centerline was no longer concentric. Binocular examination of the web fracture surface 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 (Photo 25). Fine secondary circumferential fatigue cracks were observed on both the roller and ball bearing sides of the web near the interface of the web-to-centerline shaft (Photo 26). These secondary cracks encompassed about a quarter (90⁰ sector) of the web circumference and were located about 90⁰ circumferentially from the primary crack initiation site (See Photo 30). Cracks were also visible at the bottom land of several gear teeth (Photo 27).
A series of field emission secondary and backscatter scanning electron microscope (SEM) high resolution images were taken of the fracture surface (PHOTO 28) as well as the secondary web cracks. The primary crack propagation had features consistent with transgranular 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 (also referred to as intergranular attack)\(^9\). The L3 gearshaft eventually failed in ductile overload as evident by the tensile dimpling. Black oxide was observed on the surface of the gearshaft as well on the microstructure grain boundary; no embrittlement was noted around the fracture origin site. No secondary cracks were noted at the primary initiation site and no anomalies were noted at the origin. The secondary web cracks, similar to the primary crack/fracture, initiated on the microstructure grain boundaries and the cracks had features consistent with HCF. The cracks located at the tooth bottom land had features consistent with static overload. According to CFMI, the secondary cracks may have initiated due to the web oscillation following the primary crack propagation and the tooth cracks appeared later in the event as they meshed improperly with the L4 gearshaft (handcranking gearshaft, 62-tooth gearshaft).

\(^9\) During the manufacturing process, the gearshaft is subjected to chemical etching and black oxide. Chemical etching is a process by which a thin layer of material is removed, and this technique is often used to determine if any microstructure changes to the bulk material had occurred during the machining of the part by highlighting the grain boundaries. Black oxide surface treatment is not a simple deposited layer; instead it is a conversion layer formed by a chemical reaction of iron (Fe) in the part as it is immersed in an aqueous alkaline solution to produce an iron-oxide layer.
Five gear teeth fragments were recovered comprising 26 of the 47 gear teeth (Photo 29). A reconstruction of the recovered gear teeth fragments revealed that 21 of the missing gear teeth were in two separate sectors on opposite sides of the web; one section was visually much larger than the other (Photo 30). Examination of the gear teeth showed, according to CFMI, normal running/operational wear marks and no evidence of a misalignment. The crack initiation site also lined up radially with the smaller of the two teeth missing sectors.

All the collected AGB debris was weighed and categorized; the only AGB gearshaft assembly that was missing any material was the L3 gearshaft; therefore, any magnetic material collected (all the gearshaft material is magnetic while the AGB housing, nuts, etc. are non-magnetic) was attributed to the L3 gearshaft. The weight of the all the gearshaft debris was approximately 355.4 grams (g) (0.8 pounds(lbs.)) and the weight of the remaining damaged gearshaft was about 951.5 g (2.1 lbs.). Based on the weight of the collected debris, CFMI estimated that about 318.9 g (0.7 lbs.) or about 20% of L3 gearshaft material, comprised in part by the 21 missing teeth and portions of the gear web, was missing and not recovered.

Sections of the gearshaft near the web-to-shaft transition radius were cut for chemical and hardness analysis. Chemical analysis of the gearshaft using energy dispersive x-ray spectroscopy (EDS) produced an x-ray spectrum consistent with the specification for the core material and consistent with black oxide salt solution on the gear web faces as well as on primary/fracture origin and secondary web cracks. Evidence of grain boundary consumption measuring up to a depth of 20 micrometers (µm) (0.00079-inches) was observed near the primary crack initiation site and up to 50 µm (0.00197-inches) at the secondary crack locations. The black oxide layer was observed up to 1 µm (0.00004-inches) in depth.

The hardness of both the shaft radius and gear teeth were within specifications (the entire gearshaft is not carburized, just those areas needing additional wear resistance); since the gear teeth are carburized, there is a surface hardness, core hardness, and depth of carburization and all were within specifications. Carburizing is a process in which carbon is introduced into the gearshaft at a specified transformation temperature followed by quenching to produce a surface hardness (case hardness) layer that is substantially harder than the core material. The carburization process defines the surface hardness and the depth of the carburized layer.
No visual evidence of shot-peening was noted on the L3 gearshaft. This L3 gearshaft was produced before shot-peening was required; therefore, the lack of shot-peening was expected (See Section 1.5 – L3 GEARSHAFT SN UN00086 HISTORY for details). A residual stress (RS) analysis of the L3 gearshaft was performed. Measurements were taken at various depths through the part, was conducted on the gearshaft at three locations; two locations on the shaft, one of either side of the web, and one location on the web. Residual stress is defined as the stress that remains in the body that is not being subjected to external forces and is caused by processing operations where the surface is distorted, such as shot-peening, machining, forging, heat treat, etc., as well as by service/operating environment, such as operating in a high stress or high temperature application. Some amount of RS was observed at all three locations; however, the RS curves were consistent with a part that was not subjected to shot-peening and the low RS observed, according to CFMI, could either be an artifact of the event which distorted the gearshaft or left over from some of the manufacturing processes.

4.3 OTHER AGB GEARSHAFTS

Examination of the L5 through L11 gearshafts and their respective ball and roller bearings revealed that all the gearshafts were intact and in generally good condition. All the gear teeth were present, whole, and exhibited minor impact from small hard particles and the bearings were intact, rotated freely but were a bit rough. A fluorescent penetrant inspection (FPI) of all the other gearshafts (L4 through L11) revealed no evidence of any cracks.

Examination of the L4 gearshaft revealed that the dynamic seal mating ring tabs had rotated out from the ball bearing inner race locking slots (PHOTO 31). Visual examination of the mating ring tabs and the corresponding locking slots in the inner race revealed contact marks on both, consistent with the ring engaged properly while the gearbox was operating. The bearing was intact, in good condition, and rotated freely albeit roughly. Disassembly of both the L4 gearshaft ball and roller bearing revealed they were in good condition with no signs of spalling or skidding but did exhibit small particles between the cage and inner race. The carbon seal rotated smoothly and no visual damage to the carbon seal was noted. All the teeth of the L4 gearshaft were damaged (PHOTO 32) and exhibited gear teeth meshing patterns (contact marks from running position) on the face of the teeth consistent with proper alignment with the L3 and L5 gearshafts.

PHOTO 31: DISENGAGED DYNAMIC SEAL MATING RING TABS
PHOTO COURTESY OF CFMI

PHOTO 32: L4 GEARSHAFT TEETH DAMAGE
PHOTO COURTESY OF CFMI
4.4 Transfer Shaft

Since the locking nut that retains the transfer shaft to the L3 gearshaft assembly was found loose when disengaging the TGB was from the AGB to perform the post-event alignment check (See Section 3.2 - Accessory Gearbox Alignment Check), the locking nut, PN 335-306-301-0/SN 9708, the transfer shaft, PN 340-051-101-0/SN UP50206, and the internal splines of the L3 gearshaft were examined in greater detail. **Figure 13 (Figure 9 as well)** provides a cross-section of how the various parts engage.

![Figure 13: TGB-to-AGB Retention Hardware Configuration](image)

Slight fretting/contact marks were noted on: 1) the transfer shaft axial stop located in the inner diameter of the L3 gearshaft and the corresponding front face of the transfer shaft splines (**Photo 33**), 2) the transfer shaft locking nut engagement flange (**Photo 34**) and the corresponding locking nut rear flange, 3) the aft face of the ball bearing inner race where the locking nut makes contact and the corresponding locking nut front lip (**Photo 35**), 4) locking nut internal threads, and 5) the locking ring and the corresponding locking nut recess groove in the locking nut.
Examination of transfer shaft external splines (See Figures 8 and 12) revealed three distinctive gear meshing/running marks (patterns) on the face of the splines at both the AGB and TGB engagement splines (Photo 36). According to CFMI and SWA, the three distinctive gear meshing/running marks observed on the transfer shaft are considered a normal in-service condition. The darker center mark represents the normal stabilized operating position of the transfer shaft with the two lighter contacts marks at either end representing normal transient positions.
5.0 TRANSFER GEARBOX (PN 340-050-705-0/SN VQ1201) TEARDOWN & EVALUATION

The TGB was sent to Triumph Accessory Services, Grand Prairie Texas for teardown and examination; the teardown occurred on June 26, 2017 with persons from SWA in attendance. Triumph provided a report, Work Order (WO) 265695-17, dated June 27, 2017 of their findings. Results of the examination were as follows:

1) Both roller and the ball bearing that support the horizontal bevel gear (32-tooth gearshaft) failed inspection. Nicks were found greater than the allowable inspection limit on the ball bearings and the roller bearing cage was worn.
2) The ball bearing that supports the input bevel gear (31-tooth gearshaft) failed inspection due to nicks greater than the allowable inspection limit. The roller bearing passed.
3) The housing was scrapped due to the inability to repair a bushing that had been previously installed in the housing.
4) No other anomalies were noted.

6.0 L3 GEARSHAFT LOADING AND SURFACE ANALYSIS

CFMI performed a finite element (FE) analysis on the L3 gearshaft to access the stresses on the web near where the crack initiated. The FE analysis considered centrifugal as well as meshing loads and vibratory loads. The results of the analysis showed that the peak stress location was consistent with the crack initiation site location; the peak stress level was well below the tensile strength and there was no significant impact in this area due to a misalignment condition on the vibratory stress.

As mentioned in Section 1.5 – L3 GEARSHAFT SN UN00086 HISTORY, the failed L3 gearshaft was 1 of 32 manufactured from the same production batch. Due to corrosion issues additional processing steps were performed; only 8 were ultimately delivered into service. To access the effect of the additional process steps on the failed L3 gearshaft, CFMI performed a surface analysis comparing the failed L3 gearshaft with the L4 and L6 gearshafts from the event AGB; manufacturing and surface preparation are essentially the same for all three gearshafts. Examination of the L4 and L6 gearshafts revealed the presence of intergranular microcracks 40 μm (0.00157-inches) and 10 μm (0.00039-inches, respectively at the grain boundaries with black oxide inside the microcracks similar to what was found in the L3 gearshaft (See Section 4.2.2 - L3 GEARSHAFT METALLURGICAL EVALUATION for details). The second difference was the lack of manufacturing grinding marks on the L3 gearshaft; both L4 and L6 gearshaft had visible grinding channels. According to CFMI, the findings on the L4 and L6 gearshaft are within the production experience for density and length of the microcracks.

To better understand the impact of the additional processing steps performed on the failure L3 gearshaft to address the corrosion that had occurred during the initial manufacturing process, 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 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. CFMI has indicated
that they will evaluate and compare the findings from the event L3 gearshaft to those from the same event batch that are recommended to be removed by SB CFM56-7B 72-1032-R00.

7.0 TRANSFER SHAFT LOCKING NUT ANALYSIS

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 show that GE Celma torqued the locking nut during the last shop visit in January 2017 to the maximum allowable value – 1600-inch-pounds (See Section 3.2 - ACCESSORY GEARBOX ALIGNMENT CHECK for details). The maintenance records also show that once the locking nut was torqued, it was rechecked and found acceptable; both the initial and follow-on check were performed by the same mechanic. Furthermore, 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, CFMI’s hypothesized that the loose transfer nut was not the cause nor a contributing factor to the failure of the L3 gearshaft and was an artifact of the initial failure event.

8.0 CORRECTIVE ACTIONS

As previously mentioned, eight of the 32 L3 gearshafts produced from the same production batch, batch DM042218, as the failed SWA L3 gearshaft were put into service. Of those eight, two are no longer in service, and the remaining six have been positively identified as installed in an AGB on an in-service engine. CFMI has a list of the six remaining in-service L3 gearshafts by SN and operator and in the case of the positively identified installation, the AGB in which it is installed, the engine in which the AGB is installed, and the airplane in which the engine is installed. The proposed corrective action is to remove and replace all six remaining in-service L3 gearshafts (and this includes one that is currently out-of-service for a total of seven L3 gearshafts) from the same production batch as the failed SWA L3 gearshaft at the next AGB overhaul in accordance with SB CFM56-7B 72-1032-R00; this task should be completed without impact to revenue service but no later than 12 months from the issuance date. CFMI, as a preventative action, released the SB on March 12, 2018.

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, in light of this event, the process is being reviewed for improvements in process documentation.

9.0 FLIGHT RECORDING DEVICE INTERROGATION

The flight data recorder (FDR) was downloaded and various plots were created. The electronic engine control (EEC) was downloaded and fault data was collected. A sequence of events timeline was created based on data from the FDR and EEC and is provided in Table 1. It should be noted that the parameters are sampled at different rates based on the need for the fidelity of that data and are recorded at different times. For example, on the FDR, fan and low rotor speed (N1), engine fail warning, high rotor speed (N2), exhaust gas temperature (EGT), fuel flow (FF), airplane pressure altitude, airplane airspeed, and thrust lever angle (TLA) are sampled every 1 second; engine oil pressure is recorded every 4 seconds, and engine oil temperature every 8 seconds. Also, each second is partitioned into multiple fractions of a second so that even if two parameters are recorded in that same whole second, the order that the parameters were recorded may be chronologically different. Due to variations in sample rates and recording times, it

10 The SWA event part and one previously scrapped part with no scrap ticket available to determine the reason for disposal.
was not possible to align all the parameters perfectly on a common time, instead the information is provided in chronological order and represents the best estimate of the occurrence.

9.1 Flight Data Recorder (FDR) Data

The raw flight data recorder data was downloaded by SWA and transmitted to the NTSB for conversion to tabular data. This tabular data was provided to the party members for review and analysis. The time of the engine failure was determined by reduction in N2 speed consistent with the AGB failure; therefore, the event time was 12 hours (h), 19 minutes (min), 40 seconds (sec) Greenwich Mean Time (GMT) or 8h19min40sec eastern daylight time - local. For discussion purposes, the event time was rounded up to the next whole minute for the INCIDENT and SUMMARY sections. The engine failure occurred 1h2min56sec after takeoff.

9.2 Electronic Engine Control (EEC) Examination

The EEC is a dual channel (Channel A and Channel B) digital controller containing two special purpose computers with associated circuitry. Each computer with its associated circuitry and designed airplane and engine input and output interfaces is referred to as a channel and each channel is electrically isolated, fully redundant, and operates independently of one another. The channel that controls the valves, actuators, relays, etc. in the aircraft and engine is referred to as the Active Channel and the other channel is referred to as the Standby Channel; at no time do both channels control the engine at the same time. However, to enhance reliability, inputs into one channel are available to the other and vice-versa; thus, both Channels are fully functioning at the same time if one of the channels fails. The EEC performs self-diagnostic testing and selects the “healthy” Channel based on fault history. If both channels are equally healthy, then the channels alternate between Active and Standby. The EEC records the last 10 faults for each of the following: “No Dispatch Faults”, “Alternate Mode Faults”, “Short Time Dispatch Faults”, “Long Time Dispatch Faults”, and “Economic Dispatch Faults”. The EEC is manufactured by BAE Systems for CFMI.

EEC, PN 2044M25P19, SN FFFH0368, was shipped to the BAE Systems facility in Fort Wayne, Indiana for FAULT download from the non-volatile memory (NVM). According to the downloaded data, the Active Channel for the event flight was Channel A and a total of 13 faults were recorded. All the faults were recorded during an 18 second period between 12h19min42sec and 12h20min00sec GMT; between 8h19min42sec and 8h20min00sec local time. The first faults consisted of thrust level angle (TLA) position, POE signal, and N2 signal out of range and EEC 115V disconnect relay and were all recorded on Channel A (EEC 115V disconnect relay fault was also recorded on Channel B); POE refers for engine oil pressure. Six seconds later at 8h19min48sec local time, variable stator vane (VSV) position, variable bleed valve (VBV) position, transient bleed valve (TBV) position, N2 signal out of range faults were all recorded on Channel A (N2 signal out of range was also recorded on Channel B).

11 For June 3, 2017, Washington DC time was GMT-4 hours.
**TABLE 1: INCIDENT TIMELINE**

<table>
<thead>
<tr>
<th>ESTIMATED ELAPSED TIME (HOUR:MINUTES:SECONDS)</th>
<th>EVENT DESCRIPTION</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>T = -01:02:56</td>
<td>TAKEOFF</td>
<td>Weight on Wheels (WOW) goes from GROUND to AIR Mode</td>
</tr>
</tbody>
</table>
| T = -00:00:11 | Cruise  
Airspeed 232 Knots  
Pressure Altitude 40997 Feet | N2 speed 90%  
FF 2032 pph  
EGT 607°C  
N1 speed 85%  
Oil temperature 100°C  
Thrust lever angle (TLA) 61° |
| T = -00:00:08 | Cruise  
Airspeed 231 Knots  
Pressure Altitude 40998 Feet | N2 speed 90%  
FF 2016 pph  
EGT 606°C  
N1 speed 85%  
Oil pressure 37 psi  
TLA 61° |
| T = -00:00:04 | Cruise  
Airspeed 232 Knots  
Pressure Altitude 41005 Feet | N2 speed 90%  
FF 2016 pph  
EGT 605°C  
N1 speed 82%  
Oil Pressure 37 psi  
Thrust lever angle (TLA) 61° |
| T = -00:00:03 | Cruise  
Airspeed 232 Knots  
Pressure Altitude 41004 Feet | N2 speed 90%  
FF 2016 pph  
EGT 605°C  
N1 speed 85%  
Oil temperature 100°C  
TLA 61° |
| T = 00:00:00 | Cruise  
Airspeed 231 Knots  
Pressure Altitude 40980 Feet | N2 speed drops to 49%  
FF drops to 1984 pph  
EGT drops to 594°C  
N1 speed drops to 82%  
Oil pressure drops to 30 psi  
TLA remains the same at 61°  
Airspeed 231 knots  
Pressure Altitude 40980 feet |
| T = +00:00:01 | TLA Starts to Increase | N2 speed drops to 25%  
FF drops to 688 pph  
EGT drops to 585°C  
N1 speed drops to 63%  
Oil pressure & temperature not recorded during this time stamp  
TLA increases to 64°  
TLA (ENG1) remains at 61° |

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12 Review of the FDR 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. There are no vibration sensors for the AGB specifically; the engine is equipped with a No. 1 bearing sensor and fan frame compressor case vertical sensor.

13 The engine N2 speed (engine core speed/HP rotor system speed) is measured indirectly by a sensor that measures the handcranking gearshaft (L4 gearshaft) rotational speed. With the failure of the L3 gearshaft, continuity between the AGB and the HP rotor system was lost; the AGB was no longer driven by the engine HP rotor system so the recorded N2 speed values represent L4 gearshaft speed not engine core speed.
<table>
<thead>
<tr>
<th>ESTIMATED ELAPSED TIME (HOUR:MINUTES:SECONDS)</th>
<th>EVENT DESCRIPTION</th>
<th>COMMENTS</th>
</tr>
</thead>
</table>
| T = +00:00:02                                | Engine 2 Fail Warning Annunciated | N2 speed drops to 6%  
FF drops to 192 pph  
EGT drops to 591°C  
N1 speed drops to 53%  
Oil pressure & temperature not recorded during this time stamp  
TLA increases to 65°  
TLA (ENG1) increases at 64°  
EEC Fault: POE out of range  
EEC Fault: N2 Signal out of range  
EEC Fault: TLA position out of range |
| T = +00:00:04                                | Fuel Flow drops to 0 pph  
Oil Pressure drops to 0 psi | N2 speed drops to 4%  
EGT drops to 579°C  
N1 speed drops to 40%  
TLA and TLA (ENG1) increase to 66° |
| T = +00:00:05                                | TLA Reaches Maximum Value and Stabilizes at 66° | N2 speed drops to 3%  
EGT rises slightly to 591°C  
N1 speed drops to 36%  
Oil temperature drops to 99°  
TLA (ENG1) at 66° |
| T = +00:00:06                                | Additional EEC Faults Recorded | EEC Fault: VSV position  
EEC Fault: VBV position  
EEC Fault: TBV position  
EEC Fault: N2 out of range |
| T = +00:00:27                                | HP Rotor Stops  
N2 drops to 0% | EGT drops to 463°C  
N1 speed drops to 25%  
TLA and TLA (ENG1) remain at their highest value of 66° & 67° |
| T = +00:01:14                                | Engine Windmilling  
N1 stabilizes at around 21-20% | EGT drops to 368°C  
TLA and TLA (ENG1) remain at 66° & 67° |
| T = +00:01:49                                | Descent Started | Pressure altitude 40987 feet and continues to decrease till 24000 feet |
| T = +00:03:30                                | TLA Starts to Reduce | EGT drops to 266°C  
TLA drops slightly below 66°  
TLA (ENG1) remains at 67° |
| T = +00:02:58                                | TLA Stabilized at Lowest Value of 36° and remains until after landing | EGT drops to 264°C  
TLA (ENG1) remains at 67° |
| T = +00:03:12                                | Cockpit Crew Shuts Down Engine 2  
ENG 2 Start Lever goes from RUN to CUTOFF | EGT drops to 251°C  
TLA and TLA (ENG1) remain at 36° & 67°  
Airspeed 221 knots  
Pressure altitude 39297 feet |
### TABLE 1: INCIDENT TIMELINE

**NOTE** - Data references are for the No. 2 engine unless otherwise stated

<table>
<thead>
<tr>
<th>ESTIMATED ELAPSED TIME (HOUR:MINUTES:SECONDS)</th>
<th>EVENT DESCRIPTION</th>
<th>COMMENTS</th>
</tr>
</thead>
</table>
| **T = +00:18:03**                           | ENG 2 Restart Attempt - Attempt 1 Initiated | N2 speed rises to 23%\(^{14}\)  
EGT drops to 16°C  
N1 speed remains at 21%  
TLA remains at 36°  
TLA (ENG1) increases to 70°  
ENG 2 start lever still in CUTOFF  
FF still at 0 PPH  
Airspeed 287 knots  
Pressure altitude 24000 feet |
| **T = +00:18:08**                           | Oil Pressure Starts to Rise\(^{15}\) | N2 speed rises to 52%  
EGT remains at 16°C  
N1 speed remains at 21%  
Oil pressure rises from 0 to 18 psi  
TLA and TLA (ENG1) remain at 36° & 70°  
ENG 2 start lever still in CUTOFF  
Airspeed 287 knots  
Pressure altitude 24000 feet |
| **T = +00:18:13**                           | HP Rotor reaches Max Speed for Restart Attempt 1 | N2 speed rises to 56%  
EGT drops to 15°C  
N1 speed remains at 21%  
TLA and TLA (ENG1) remain at 36° & 70°  
ENG 2 start lever still in CUTOFF  
Airspeed 287 knots  
Pressure altitude 23999 feet |
| **T = +00:18:14**                           | Restart Attempt 1 Aborted | N2 speed drops to 49% and continues to decrease  
EGT remains at 15°C  
N1 speed remains at 21%  
TLA and TLA (ENG1) remain at 36° & 70°  
ENG 2 start lever still in CUTOFF  
FF still at 0 PPH  
Airspeed 287 knots  
Pressure altitude 24000 feet |
| **T = +00:18:19**                           | ENG 2 Cutoff goes from CUTOFF to RUN | N2 speed drops to 8%  
TLA and TLA (ENG1) remain at 36° & 70°  
Airspeed 286 knots  
Pressure altitude 23999 feet |
| **T = +00:18:20**                           | Oil Pressure drops to 0 psi | N2 speed drops to 2%  
ENG 2 start lever still in RUN  
TLA and TLA (ENG1) remain at 36° & 70°  
Airspeed 286 knots  
Pressure altitude 23998 feet |

\(^{14}\) As mentioned in footnote 13, the failure of the L3 gearshaft produced a lack of continuity between the AGB and HP rotor system; any rise in N2 speed due to a restart attempt represents the L4 gearshaft speed not engine core speed.

\(^{15}\) With continuity within the AGB between the drive starter gearshaft (L5 gearshaft) and the lubrication unit gearshaft (L11 gearshaft), any changes in L5 gearshaft speed, such as a restart attempt or aborted restart, will result in the lubrication unit to increase or decrease oil pressure according.
### TABLE 1: INCIDENT TIMELINE

**NOTE** - Data references are for the No. 2 engine unless otherwise stated

<table>
<thead>
<tr>
<th>ESTIMATED ELAPSED TIME (HOUR:MINUTES:SECONDS)</th>
<th>EVENT DESCRIPTION</th>
<th>COMMENTS</th>
</tr>
</thead>
</table>
| T = +00:18:21 | HP Rotor Stops  
N2 drops to 0% | N1 speed still stable at the low 20%  
ENG 2 start lever still in RUN  
TLA and TLA (ENG1) remain at 36° & 70°  
Airspeed 285 knots  
Pressure altitude 23998 feet |
| T = +00:18:53 | ENG 2 Start Lever goes from RUN to CUTOFF | N2 speed still at to 0%  
N1 speed still stable at the low 20%  
TLA and TLA (ENG1) remain at 36° & 70°  
Airspeed 284 knots  
Pressure altitude 24001 feet |
| T = +19:00 | ENG 2 Restart Attempt - Attempt 2 Initiated | N2 speed rises to 13%  
ENG 2 start lever still in CUTOFF  
FF still at 0 PPH  
TLA and TLA (ENG1) remain at 36° & 70°  
Airspeed 284 knots  
Pressure altitude 24003 feet |
| T = +00:19:03 | HP Rotor Reaches Max Speed for Restart Attempt 2  
ENG 2 Start Lever goes from CUTOFF to RUN | N2 speed rises to 57%  
FF still at 0 PPH  
Oil pressure rises to 18 psi  
TLA and TLA (ENG1) remain at 36° & 70°  
Airspeed 283 knots  
Pressure altitude 24004 feet |
| T = +00:19:04 | Fuel Flow Starts to Rise  
HP Rotor Speed Drops | FF rises to 96 PPH  
N2 speed decreased 45%  
No EGT change still stable at 14°C Oil pressure not recorded during this time stamp  
TLA and TLA (ENG1) remain at 36° & 70°  
Airspeed 284 knots  
Pressure altitude 24000 feet |
| T = +00:19:05 | Fuel Flow Continues to Rise  
HP Rotor Speed Continues to Drop | FF rises to 192 PPH  
N2 speed continues to decrease 32%  
EGT stable at 14°C Oil pressure not recorded during this time stamp  
TLA and TLA (ENG1) remain at 36° & 70°  
Airspeed 284 knots  
Pressure altitude 24001 feet |
| T = +00:19:06 | Fuel Flow Reaches Max for Restart Attempt 2  
HP Rotor Speed Continues to Drop | N2 speed continues to decrease 22%  
FF rises to 816 PPH  
EGT still at 14°C Oil pressure not recorded during this time stamp  
TLA and TLA (ENG1) remain at 36° & 70°  
Airspeed 284 knots  
Pressure altitude 23999 feet |
### Table 1: Incident Timeline

<table>
<thead>
<tr>
<th>Estimated Elapsed Time (Hour:Minutes:Seconds)</th>
<th>Event Description</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>T = +00:19:07</td>
<td>Restart Attempt 2 Aborted</td>
<td>N2 speed continues to decrease 13%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FF drops to 624 PPH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EGT increase to 27°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oil pressure drops to 0 psi</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ENG 2 start lever still in RUN</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TLA and TLA (ENG1) remain at 36° &amp; 70°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Airspeed 283 knots</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pressure altitude 24000 feet</td>
</tr>
<tr>
<td>T = +00:19:12</td>
<td>HP Rotor Stops N2 drops to 0%</td>
<td>N1 speed still stable at the low 20%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FF drops to 304 PPH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ENG 2 start lever still in RUN</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TLA and TLA (ENG1) remain at 36° &amp; 70°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Airspeed 283 knots</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pressure altitude 23998 feet</td>
</tr>
<tr>
<td>T = +00:19:15</td>
<td>Fuel Flow drops to 0 pph</td>
<td>N1 speed still stable at the low 20%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ENG 2 start lever still in RUN</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TLA and TLA (ENG1) remain at 36° &amp; 70°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Airspeed 283 knots</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pressure altitude 23998 feet</td>
</tr>
<tr>
<td>T = +00:19:50</td>
<td>ENG 2 Start Lever goes from RUN to CUTOFF</td>
<td>N1 speed still stable at the low 20%</td>
</tr>
<tr>
<td>T = +00:52:57</td>
<td>LANDING – SINGLE ENGINE</td>
<td>Weight on Wheels (WOW) goes from AIR to GROUND Mode</td>
</tr>
</tbody>
</table>

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Jean-Pierre Scarfo  
Aerospace Engineer  
Powerplant Lead