NATIONAL TRANSPORTATION SAFETY BOARD
Public Meeting of November 19, 2019
(Information subject to editing)

Aircraft Accident Report: Left Engine Failure and Subsequent Depressurization
Southwest Airlines Flight 1380, Boeing 737-7H4, N772SW
Philadelphia, Pennsylvania
April 17, 2018
NTSB/AAR-19/03

This is a synopsis from the NTSB's report and does not include the Board's rationale for the conclusions, probable cause, and safety recommendations. NTSB staff is currently making final revisions to the report from which the attached conclusions and safety recommendations have been extracted. The final report and pertinent safety recommendation letters will be distributed to recommendation recipients as soon as possible. The attached information is subject to further review and editing to reflect changes adopted during the Board meeting.

Executive Summary

On April 17, 2018, about 1103 eastern daylight time, Southwest Airlines (SWA) flight 1380, a Boeing 737-7H4, N772SW, experienced a left engine failure while climbing through flight level 320 en route to the flight's assigned cruise altitude. The flight had departed from LaGuardia Airport, Queens, New York, about 30 minutes earlier. As a result of the engine failure, the flight crew conducted an emergency descent and diverted to Philadelphia International Airport (PHL), Philadelphia, Pennsylvania. Portions of the left engine inlet and fan cowl separated from the airplane, and fragments from the inlet and fan cowl struck the left wing, the left-side fuselage, and the left horizontal stabilizer. One fan cowl fragment impacted the left-side fuselage near a cabin window, and the window departed the airplane, which resulted in a rapid depressurization. The airplane landed safely at PHL about 17 minutes after the engine failure occurred. Of the 144 passengers and 5 crewmembers aboard the airplane, 1 passenger received fatal injuries, and 8 passengers received minor injuries. The airplane was substantially damaged. The regularly scheduled domestic passenger flight was operating under the provisions of Title 14 *Code of Federal Regulations* (*CFR*) Part 121 with a destination of Dallas Love Field, Dallas, Texas.

The airplane was equipped with two CFM International CFM56-7B24 turbofan engines. The CFM56-7B engine has 24 fan blades installed in the fan disk. The left engine failure occurred when one of the fan blades fractured at its root (referred to as a fan-blade-out [FBO] event). The fan blade fractured due to a low-cycle fatigue crack that initiated in the dovetail (part of the blade root), which remained within a slot of the fan disk.

The separated fan blade impacted the engine fan case and fractured into multiple fragments. Some of the fan blade fragments traveled forward of the engine and into the inlet.[1] In addition, the fan blade's impact with the fan case caused the fan case to deform locally over a short period of

[1] The inlet is part of the nacelle, which is the airplane structure that houses the engine.

time. This deformation traveled both around and forward/aft of the fan case. After reaching the airplane structure (the inlet attach ring, which was secured to the engine fan case A1 flange), the deformation generated large loads that resulted in local damage to the inlet. The forward-traveling fan blade fragments and the deformation compromised the structural integrity of the inlet, causing portions of the inlet to depart the airplane.

The impact of the separated fan blade with the fan case also imparted significant loads into the fan cowl (also part of the nacelle) through the radial restraint fitting, which was located at the bottom of the inboard fan cowl.[2] These loads caused cracks to form in the fan cowl skin and frames near the radial restraint fitting. This damage then propagated forward and aft, severing the three latch assemblies that joined the inboard and outboard halves of the fan cowl, which caused large portions of both fan cowl halves to separate and depart the airplane. One fan cowl part that was recovered after the accident was the inboard fan cowl aft latch keeper. The left side of the fuselage near the location of the missing cabin window (row 14) had impact damage and witness marks that were consistent with the size and shape of the inboard fan cowl aft latch keeper and surrounding structure.

During the accident sequence, the fan blade fragments traveling forward of the fan case had a trajectory angle that was greater than that observed during the CFM56-7B engine FBO containment certification tests. Also, the inlet damage caused by the forward-traveling fan blade fragments was greater than that observed during the engine FBO containment certification tests and accounted for in Boeing's 737-700 certification analyses (which used the state-of-the-art analytical modeling tools that were available at the time). In addition, FBO-generated loads were transmitted to the fan cowl through the radial restraint fitting, which was not accounted for in the fan cowl's design, and the stresses in the fan cowl were greater than those calculated in the certification analyses. Since the time that the CFM56-7B engine and the Boeing 737-700 airplane were certificated (in December 1996 and December 1997, respectively), new technologies and analytical methods have been developed that will better predict the interaction of the engine and airframe during an FBO event and the response of the inlet, fan cowl, and associated airplane structures.

Metallurgical examinations of the fractured fan blade found that the crack had likely initiated before the fan blade set's last overhaul in October 2012. At that time, the overhaul process included a fluorescent penetrant inspection (FPI) to detect cracks; however, the crack was not detected for unknown reasons. After an August 2016 FBO event involving another SWA 737-700 airplane equipped with CFM56-7B engines, which landed safely at Pensacola International Airport, Pensacola, Florida, CFM developed an eddy current inspection (ECI) procedure to be performed at overhaul (in addition to the FPI that was already required). An ECI has a higher sensitivity than an FPI and can detect cracks at or near the surface (unlike an FPI, which can only detect surface cracks).

[2] The 737-700 is one of four Boeing 737 next-generation (NG) airplane models. (The NG-series of Boeing 737 airplanes also includes the 737-600, -800, and -900.) Boeing 737NG-series airplanes have an asymmetric fan cowl and a flat-bottom nacelle to accommodate the requirements of the CFM56-7B engine. The radial restraint fitting on the fan cowl engages with a radial restraint bracket on the engine fan case to help the fan cowl maintain its shape.

The crack on the fan blade involved in the PHL accident was also not detected during the on-wing fan blade visual inspections (subsequent to the overhaul) that were conducted as part of fan blade relubrications, which CFM recommended to maintain the fan blade loads within the predicted range and prevent wear on the fan disk and the fan blade dovetail coating. After the August 2016 FBO event, CFM developed an on-wing ultrasonic inspection technique that could be performed at the time of fan blade relubrication. ECIs at the time of overhaul or ultrasonic inspections at the time of fan blade relubrication identified 15 blade cracks on separate engines (as of August 2019).

The NTSB identified the following safety issues as a result of this accident investigation:

- **Need to ensure the structural integrity of the fan cowl on Boeing 737 next-generation (NG)-series airplanes after an FBO event involving CFM56-7B engines.** The separated fan blade impacted the fan case at the six o'clock position (at the bottom of the engine). During the CFM56-7B engine FBO containment certification tests, the CFM-selected fan blade release position was at twelve o'clock. Boeing's postaccident analyses found that the fan cowl structure is more sensitive and more susceptible to failure when a separated fan blade impacts the fan case near the six o'clock position because of the proximity of this fan blade impact location to the radial restraint fitting (at the bottom of the inboard fan cowl). It is important that the interaction of the fan case, radial restraint fitting, and fan cowl during an FBO event be well understood to preclude a failure of the fan cowl structure on Boeing 737NG-series airplanes.

- **Need to determine whether other airframe/engine combinations have any critical fan blade impact locations and how an impact at those locations could affect nacelle components.** This investigation revealed the concept of a critical location for an FBO impact and its effect on the structural integrity of the nacelle and its components. Other engine/airframe combinations may also be sensitive to the location of an FBO impact and have unintended load paths and/or loads that are greater than those accounted for in structural analyses. No Federal Aviation Administration (FAA) regulation under 14 *CFR* Part 25, Airworthiness Standards: Transport Category Airplanes, currently requires manufacturers, as part of the design of the nacelle, to account for critical FBO impact locations in all engine operating conditions. The corresponding European Aviation Safety Agency regulations also do not include this requirement.

- **Need to emphasize the importance of having flight attendants secured in a jumpseat during emergency landings.** Although the flight attendants were aware of the imminent landing, none was in her assigned jumpseat in preparation for the landing. Instead, all three flight attendants were seated on the cabin floor, which was contrary to the procedures in the SWA flight attendant manual that required flight attendants to occupy their assigned jumpseats during a planned emergency landing. One of the flight attendants who was stationed in the forward cabin reported that she did not have time to return to her jumpseat; the other flight attendant assigned to the forward cabin sat on the floor in the aft galley. Thus, the forward dual-position flight attendant jumpseat was unoccupied during the landing. The flight attendant assigned to the aft cabin also sat on the floor in the aft galley because her jumpseat was occupied by a passenger from row 14 (who had relocated to the aft cabin so that the injured passenger could receive medical care) and an SWA company employee. If an emergency evacuation was needed, the flight attendants' ability to rapidly evacuate the airplane could have been hindered because they were not in a position to open their assigned exits.

- **Need to mitigate hazards to passengers affected by an in-flight loss of seating capacity.** The accident flight was full, with no open cabin seats remaining, and the flight attendants needed to reseat two passengers from row 14. Both passengers went to the aft galley; one passenger sat on the flight attendant aft jumpseat, and the other sat on the cabin floor. The SWA flight attendant manual provided information in several sections about reseating passengers, but none of the situations were similar to that aboard the accident flight, and the manual did not discuss any actions to take if no seats were available for a passenger who needed to be reseated. The NTSB's review of FAA regulations and advisory circulars and its *Flight Standards Information Management System* did not identify any specific guidance addressing options for reseating passengers when no additional passenger seats are available. Such guidance would help air carriers implement procedures to mitigate hazards to passengers resulting from an in-flight loss of seating capacity.

Findings

1. None of the following were factors in this accident: (1) flight crew qualifications, which were in accordance with US regulations; (2) flight crew medical conditions; (3) the airworthiness of the airplane before the left engine failure occurred; and (4) Southwest Airlines' maintenance of the airplane.

2. The low-cycle fatigue crack in the fan blade dovetail initiated because of higher-than-expected dovetail stresses under normal operating loads, and this crack was most likely not detectable during the fluorescent penetrant inspection at the time of the fan blade set's last overhaul and subsequent visual inspections at the time of fan blade relubrications.

3. The requirement to perform an eddy current inspection at the time of fan blade overhaul and an ultrasonic inspection at the time of blade relubrication should enable cracked fan blades in CFM56-7B engines to be detected and removed from service before the cracks reach a critical size and the blades fracture.

4. The fan blade fragments that traveled forward of the fan case, along with the displacement wave created by the fan blade's impact with the fan case, caused damage that compromised the structural integrity of the inlet and caused portions of the inlet to depart from the airplane.

5. Portions of the fan cowl departed the airplane because (1) the impact of the separated fan blade with the fan case imparted significant loads into the fan cowl through the radial

restraint fitting and (2) the associated stresses in the fan cowl structure exceeded the residual strength of the fan cowl, causing its failure.

6. The impact of the inboard fan cowl aft latch keeper with the fuselage near the cabin window adjacent to seat 14A caused the window to depart the airplane, the rapid depressurization of the cabin, and the passenger fatality.

7. This accident demonstrated the susceptibility of the fan cowl installed on Boeing 737 next-generation-series airplanes to a fan-blade-out impact location near the radial restraint fitting and the effects of such an impact on the structural integrity of the fan cowl.

8. Given the results of CFM's engine fan-blade-out (FBO) containment certification tests and Boeing's subsequent structural analyses of the effects of an FBO event on the airframe, the post-FBO events that occurred during this accident could not have been predicted.

9. The structural analysis modeling tools that currently exist to analyze a fan-blade-out (FBO) event and predict the subsequent engine and airframe damage will allow airplane manufacturers to better understand the interaction of the engine and airframe during an FBO event and the response of the inlet, fan cowl, and associated structures in the airplane's normal operating envelope.

10. Performing required checklists according to standard operating procedures is a critical part of safe flight operations. However, given the emergency situation aboard this flight, the flight crew's performance of most, but not all, of the items on the Engine Fire or Engine Severe Damage or Separation non-normal checklist and the nonperformance of the three other relevant non-normal checklists allowed the crew to appropriately balance the procedural requirement of executing checklists with the high workload associated with maintaining airplane control and accomplishing a safe and timely descent and landing.

11. The flight crew's decision to land at Philadelphia International Airport was appropriate given the airplane's location at the time of the emergency, the circumstances of the emergency, and the airport's multiple runways and aircraft rescue and firefighting capabilities.

12. Although not a factor in the outcome of this accident, the flight attendants should have been properly restrained in their assigned jumpseats in case an emergency evacuation after landing was necessary.

13. Federal Aviation Administration guidance addressing options for reseating passengers if an in-flight loss of seating capacity were to occur would help air carriers implement procedures to address this situation.

Probable Cause

The National Transportation Safety Board (NTSB) determines that the probable cause of this accident was a low-cycle fatigue crack in the dovetail of fan blade No. 13, which resulted in the fan blade separating in flight and impacting the engine fan case at a location that was critical to the structural integrity and performance of the fan cowl structure. This impact led to the in-flight separation of fan cowl components, including the inboard fan cowl aft latch keeper, which struck the fuselage near a cabin window and caused the window to depart from the airplane, the cabin to rapidly depressurize, and the passenger fatality.

Recommendations

To the Federal Aviation Administration

1. Require Boeing to determine the critical fan blade impact location(s) on the CFM56-7B engine fan case and redesign the fan cowl structure on all Boeing 737 next-generation-series airplanes to ensure the structural integrity of the fan cowl after a fan-blade-out event.

2. Once the actions requested in Safety Recommendation [1] are completed, require Boeing to install the redesigned fan cowl structure on new-production 737 next-generation-series airplanes.

3. Once the actions requested in Safety Recommendation [1] are completed, require operators of Boeing 737 next-generation-series airplanes to retrofit their airplanes with the redesigned fan cowl structure.

4. Expand the Title 14 *Code of Federal Regulations* Part 25 and 33 certification requirements to mandate that airplane and engine manufacturers work collaboratively to (1) analyze all critical fan blade impact locations for all engine operating conditions, the resulting fan blade fragmentation, and the effects of the fan-blade-out-generated loads on the nacelle structure and (2) develop a method to ensure that the analysis findings are fully accounted for in the design of the nacelle structure and its components.

5. Develop and issue guidance on ways that air carriers can mitigate hazards to passengers affected by an in-flight loss of seating capacity.

To Southwest Airlines

6. Include the lessons learned from the accident involving Southwest Airlines flight 1380 in initial and recurrent flight attendant training, emphasizing the importance of being secured in a jumpseat during emergency landings.

To the European Aviation Safety Agency

7. Expand your certification requirements for transport-category airplanes and aircraft engines to mandate that airplane and engine manufacturers work collaboratively to (1) analyze all critical fan blade impact locations for all engine operating conditions, the resulting fan blade fragmentation, and the effects of the fan-blade-out generated loads on the nacelle structure and (2) develop a method to ensure that the analysis findings are fully accounted for in the design of the nacelle structure and its components.