NATIONAL TRANSPORTATION SAFETY BOARD
Public Meeting of January 30, 2018
(Information subject to editing)

Uncontained Engine Failure and Subsequent Fire, American Airlines Flight 383
Boeing 767-*323*, N345AN Chicago, Illinois
October 28, 2016
NTSB/AAR-18/01

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 October 28, 2016, about 1432 central daylight time, American Airlines flight 383, a Boeing 767-323, N345AN, had started its takeoff ground roll at Chicago O'Hare International Airport, Chicago, Illinois, when an uncontained engine failure in the right engine and subsequent fire occurred. The flight crew aborted the takeoff and stopped the airplane on the runway, and the flight attendants initiated an emergency evacuation. Of the 2 flight crewmembers, 7 flight attendants, and 161 passengers on board, 1 passenger received a serious injury and 1 flight attendant and 19 passengers received minor injuries during the evacuation. The airplane was substantially damaged from the fire. The airplane was operating under the provisions of 14 *Code of Federal Regulations* Part 121. Visual meteorological conditions prevailed at the time of the accident.

The uncontained engine failure resulted from a high-pressure turbine (HPT) stage 2 disk rupture. The HPT stage 2 disk initially separated into two fragments. One fragment penetrated through the inboard section of the right wing, severed the main engine fuel feed line, breached the fuel tank, traveled up and over the fuselage, and landed about 2,935 ft away. The other fragment exited outboard of the right engine, impacting the runway and fracturing into three pieces.

Examination of the fracture surfaces in the forward bore region of the HPT stage 2 disk revealed the presence of dark gray subsurface material discontinuities with multiple cracks initiating along the edges of the discontinuities. The multiple cracks exhibited characteristics that were consistent with low-cycle fatigue. (In airplane engines, low-cycle fatigue cracks grow in single distinct increments during each flight.) Examination of the material also revealed a discrete region underneath the largest discontinuity that appeared white compared with the surrounding material. Interspersed within this region were stringers (microscopic-sized oxide particles) referred to collectively as a "discrete dirty white spot." The National Transportation Safety Board's

(NTSB) investigation found that the discrete dirty white spot was most likely not detectable during production inspections and subsequent in-service inspections using the procedures in place.

The NTSB's investigation also found that the evacuation of the airplane occurred initially with one engine still operating. In accordance with company procedures and training, the flight crew performed memory items on the engine fire checklist, one of which instructed the crew to shut down the engine on the affected side (in this case, the right side). The captain did not perform the remaining steps of the engine fire checklist (which applied only to airplanes that were in flight) and instead called for the evacuation checklist. The left engine was shut down as part of that checklist. However, the flight attendants had already initiated the evacuation, in accordance with their authority to do so in a life-threatening situation, due to the severity of the fire on the right side of the airplane.

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

- **Lack of recent guidance comparing production inspection processes for nickel alloy engine components.** The HPT stage 2 disk was made of a nickel-based alloy. Ultrasonic inspections are typically performed during the manufacture of nickel alloy engine components to detect internal defects (such as cracks and voids) in the material. However, the discrete dirty white spot, which is consistent with the description of a "stealth" anomaly in a 2008 Federal Aviation Administration (FAA) report on turbine rotor material design, was most likely not detectable by the ultrasonic inspection methods used during production of the HPT stage 2 disk. A 2005 FAA report that presented the results of industry's research about nickel billet inspections found that enhanced ultrasonic inspection techniques, such as multizone and phased array inspections, could better detect internal defects than conventional ultrasonic inspection techniques. The report also stated that multizone inspection techniques were being used for titanium engine parts but that conventional ultrasonic inspection techniques were still being used for nickel engine parts during manufacturing. Additional FAA and industry efforts are needed to evaluate the appropriateness of current and enhanced inspection technologies for nickel engine parts. Updated FAA guidance describing the results of such evaluations would benefit those involved with the inspection process for nickel alloy rotating engine components.

- **Need for improved in-service inspection techniques for critical rotating parts of all engines.** In January 2011, American Airlines performed maintenance – an eddy current inspection (ECI) and a fluorescent penetrant inspection (FPI) – of the forward bore region of the HPT stage 2 disk with no anomalies found. (American Airlines did not have another opportunity to inspect the disk before the accident because no engine maintenance between January 2011 and the time of the accident involved disassembling the HPT stage 2 disk.) These inspection techniques were not capable of detecting the cracks that emanated from the discrete dirty white spot (a subsurface anomaly) because they could only detect cracks and other anomalies at the surface (FPI) and near the surface (ECI) of a material.

  Although ultrasonic inspections might be limited in their capability to detect anomalies during the production stage, such a subsurface inspection technique would be appropriate for in-service maintenance because of the propensity for cracks to propagate over time. If a subsurface ultrasonic inspection had been required at the time of the disk's last inspection, the cracks that developed from the discrete dirty white spot would most likely have been detectable because of the size of the cracks at that time and the sensitivity of ultrasonic inspection techniques.

In September 2017, the FAA issued a notice of proposed rulemaking to mandate the ultrasonic inspection of HPT stage 1 and 2 disks of General Electric CF6-80-series turbofan engines (the model engine on the accident airplane). The proposed airworthiness directive would be an appropriate step for ensuring the continued airworthiness of airplanes with those engines, but the FAA has not addressed ultrasonic inspections on other engine models during in-service maintenance to ensure their continued airworthiness.

- **Lack of recent guidance about design precautions to minimize hazards resulting from uncontained engine failures.** In March 1997, the FAA issued Advisory Circular (AC) 20-128A, "Design Considerations for Minimizing Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor Failure." The AC provided rotor burst and blade release fragment trajectory data so that airframe manufacturers could integrate appropriate design precautions to minimize hazards to an airplane and its occupants. The AC also contained specific information about accepted design precautions to reduce the overall risk of an uncontrolled fire for airplanes with fuel tanks located in impact areas. Since the time that the AC was issued, numerous uncontained disk rupture events have occurred, and lessons learned from these events could be incorporated into more robust guidance, including updated trajectory analyses, for airframe manufacturers to use when considering design mitigations for minimizing hazards resulting from uncontained engine failures. Also, even though the flight 383 accident airplane had design mitigations for reducing the overall risk of an uncontrolled fire that were consistent with the AC's guidance, the uncontained engine failure resulted in a subsequent fire.

- **Need for separate engine fire checklist procedures for ground operations and in-flight operations.** American Airlines' engine fire checklist for the Boeing 767 (which was based on Boeing's engine fire checklist procedure) delayed the flight crew from initiating the evacuation checklist, shutting down the left engine, and commanding an evacuation. The engine fire checklist did not differentiate between an engine fire in flight and an engine fire while the airplane was on the ground and did not include a step, for an engine fire on the ground, to shut down the unaffected engine or perform the evacuation checklist sooner. Also, the engine fire checklist included a 30-second wait time between discharging the first fire extinguishing bottle and determining if the second bottle would also need to be discharged. Engine fire checklists that are specific to ground operations generally instruct flight crews to discharge both fire extinguisher bottles about the same time, which could be critical for containing a fire and/or commanding an evacuation.

- **Need for improved flight attendant training regarding assessing exits for evacuations and using interphone systems during emergencies.** As the evacuation was unfolding, three flight attendants stationed on the right side of the airplane blocked their assigned exits because they recognized that the engine fire would present a danger. A flight attendant stationed on the left side of the airplane blocked her assigned exit until the left engine was shut down. However, another flight attendant stationed on the left side of the airplane assessed the conditions outside the airplane yet opened the left overwing exit while the engine was still operating. The one serious injury that resulted during the evacuation occurred after a passenger evacuated using the left overwing exit. Once on the ground, the passenger stood up to get away from the airplane but was knocked down by the jet blast coming from the left engine.

American Airlines 767-300-series airplanes are equipped with one of two interphone system models, which operate differently. After the accident airplane came to a stop, one flight attendant tried to use the interphone to alert the flight crew that the left engine was still operating but was unsuccessful because she operated the interphone incorrectly. Also, another flight attendant tried to use the interphone to make an announcement to the passengers but could not recall how to use the interphone. The NTSB could not determine, based on the available evidence, if the flight attendants' difficulty operating the interphone was directly related to training deficiencies or the stress associated with the situation. However, the interphone system model installed on the accident airplane was not installed on American Airlines' 767 simulators used for flight attendant training. Further, although company flight attendants were trained on interphone systems during initial training, airplane differences training, and recurrent training, the subject was presented during recurrent training without providing flight attendants with hands-on experience using an interphone during an emergency.

- **Need for research on the effects of evacuating with carry-on baggage.** Video taken during the evacuation and postaccident interviews with flight attendants indicated that some passengers evacuated from all three usable exits with carry-on baggage despite instructions to leave the bags. Although the NTSB has not identified any accident evacuations in which delays related to carry-on baggage caused injuries, passengers evacuating airplanes with carry-on baggage has been a recurring safety concern. The NTSB is not aware of any study that measured the potential delays associated with passengers retrieving and carrying baggage during an emergency evacuation. The results of such a study could help determine appropriate countermeasures to mitigate any potential safety risks.

- **Need for improved communication between flight and cabin crews during emergency situations, including evacuations.** The flight crew did not communicate with the flight attendants to relay its intent not to immediately evacuate. The flight attendants had both the evacuation signaling system and the interphone system available to them to alert the flight crew that an evacuation was underway, but none of the flight attendants activated the signaling system, and only two of the seven flight attendants attempted (unsuccessfully) to communicate with the flight crew using the interphone system. Even with an unfolding emergency, there should have been better communication between the flight and cabin crews.

  The NTSB has a long history of investigating accidents (including three other accident investigations within the last 2 years) in which communication between flight and cabin crews during an evacuation was inadequate and issuing related safety recommendations in response. However, the FAA has not yet acted on a 2009 safety recommendation to revise related guidance (issued in 1988) to reflect the most recent industry knowledge on the subject based on research and lessons learned from relevant accidents and incidents. In addition, the FAA has not yet established a multidisciplinary working group, in response to a 2016 recommendation, to develop best practices to resolve recurring evacuation-related issues. It is time for the FAA to emphasize the importance of ensuring that flight and cabin crew communications can facilitate safe and effective decision-making and action during emergency situations.

Findings

1. The flight crew was properly certificated and qualified in accordance with federal regulations and company requirements. A review of the flight crew's work and sleep schedules and recent activities showed no evidence of factors that could have adversely affected the performance of either crewmember on the day of the accident.

2. The airplane was properly certificated, equipped, and maintained in accordance with federal regulations. No evidence indicated any structural, engine, or system failures before the uncontained engine failure occurred.

3. The right engine experienced an uncontained high-pressure turbine (HPT) stage 2 disk rupture during the takeoff roll. The HPT stage 2 disk initially separated into two fragments. One fragment penetrated through the inboard section of the right wing, severed the main engine fuel feed line, breached the fuel tank, traveled up and over the fuselage, and landed about 3,000 ft away. The other fragment exited outboard of the right engine, impacting the runway and fracturing into three pieces.

4. The high-pressure turbine stage 2 disk failed because of multiple low-cycle fatigue cracks that initiated from an internal material anomaly, known as a discrete dirty white spot, which formed during the processing of the material from which the disk was manufactured.

5. The discrete dirty white spot was most likely not detectable by the inspection methods used during production of the high-pressure turbine stage 2 disk.

6. Additional Federal Aviation Administration and industry efforts are needed to determine if enhanced ultrasonic inspection methods are a best practice for inspecting nickel parts during manufacturing.

7. The fatigue cracks that initiated from the discrete dirty white spot were not detectable at the time of the high-pressure turbine stage 2 disk's last inspection using the surface-based inspection techniques mandated by the applicable airworthiness directive.

8. If a subsurface inspection technique, such as an ultrasonic inspection, had been required at the time of the high-pressure turbine stage 2 disk's last inspection, the cracks that developed from the discrete dirty white spot should have been detectable because of the size of the cracks at that time and the sensitivity of ultrasonic inspection techniques.

9. Future aircraft certification efforts would benefit from guidance on uncontained engine failure debris models and resulting design mitigations that is based on lessons learned from recent in-service events.

10. The captain made a timely decision to reject the takeoff and performed the maneuver in accordance with company training and procedures.

11. The captain's decision to perform the engine fire checklist was appropriate given his training, the information provided by air traffic control, and the fire warnings in the cockpit.

12. Engine fire checklists that specifically address ground operations would allow a flight crew to secure an engine and command an evacuation, if required, in a timelier manner than engine fire checklists that do not differentiate between ground and in-flight operations.

13. The flight attendants made a good decision to begin the evacuation given the fire on the right side of the airplane and the smoke in the cabin, but the left overwing exit should have been blocked while the left engine was still operating because of the increased risk of injury to passengers who evacuated from that exit.

14. If the flight crew or the flight attendants had communicated after the airplane came to a stop, the flight crew could have become aware of the severity of the fire on the right side of the airplane and the need to expeditiously shut down the engines.

15. American Airlines did not adequately train flight attendants qualified on the Boeing 767 to effectively use the different interphone system models installed on the airplane during an emergency.

16. The Federal Aviation Administration's inadequate actions to improve guidance and training on communication and coordination between flight and cabin crews during emergency situations, including evacuations, could lead to negative consequences for the traveling public if this safety issue continues to be unresolved.

17. The flight crewmembers and flight attendants did not coordinate in an optimal manner once the passengers were evacuated.

18. Evidence of passengers retrieving carry-on baggage during this and other recent emergency evacuations demonstrates that previous Federal Aviation Administration actions to mitigate this potential safety hazard have not been effective.

PROBABLE CAUSE

The NTSB determines that the probable cause of this accident was the failure of the HPT stage 2 disk, which severed the main engine fuel feed line and breached the right main wing fuel tank, releasing fuel that resulted in a fire on the right side of the airplane during the takeoff roll. The HPT stage 2 disk failed because of low-cycle fatigue cracks that initiated from an internal subsurface manufacturing anomaly that was most likely not detectable during production inspections and subsequent in-service inspections using the procedures in place. Contributing to the serious passenger injury was (1) the delay in shutting down the left engine and (2) a flight attendant's deviation from company procedures, which resulted in passengers evacuating from the left overwing exit while the left engine was still operating. Contributing to the delay in shutting down the left engine was (1) the lack of a separate checklist procedure for Boeing 767 airplanes that specifically addressed engine fires on the ground and (2) the lack of communication between the flight and cabin crews after the airplane came to a stop.

RECOMMENDATIONS

New Recommendations

As a result of this investigation, the National Transportation Safety Board makes the following new safety recommendations:

To the Federal Aviation Administration:

1. Establish and lead an industry group that evaluates current and enhanced inspection technologies regarding their appropriateness and effectiveness for applications using nickel alloys, and use the results of this evaluation to issue guidance pertaining to the inspection process for nickel alloy rotating engine components.
2. Require subsurface in-service inspection techniques, such as ultrasonic inspections, for critical high-energy, life-limited rotating parts for all engines.
3. Revise Advisory Circular (AC) 20-128A, "Design Considerations for Minimizing Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor Failure," based on an analysis of uncontained engine failure data since the time that the AC was issued, to minimize hazards to an airplane and its occupants if an uncontained engine failure were to occur. The revised AC should include modifications to the accepted design precautions for fuel tanks given the fires that have occurred after uncontained engine failures.
4. When approving the operating procedures of a 14 *Code of Federal Regulations* Part 121 air carrier, require operators to develop and/or revise emergency checklist procedures for an engine fire on the ground to expeditiously address the fire hazard without unnecessarily delaying an evacuation.
5. Develop and issue guidance to all air carriers that conduct passenger-carrying operations under 14 *Code of Federal Regulations* Part 121 regarding (1) discussing this accident during recurrent flight attendant training to emphasize the importance of effectively assessing door and overwing exits during an unusual or emergency situation

and (2) providing techniques for identifying conditions that would preclude opening exits, including an operating engine.

6. Review the training programs of all 14 *Code of Federal Regulations* Part 121 operators and make changes as necessary to ensure that the programs provide flight attendants and flight crews with training aids and hands-on emergency scenarios that account for the different interphone systems that air carriers operate.

7. Conduct research to (1) measure and evaluate the effects of carry-on baggage on passenger deplaning times and safety during an emergency evacuation and (2) identify effective countermeasures to reduce any determined risks, and implement the countermeasures.

To Boeing:

8. Work with operators as required to develop and/or revise emergency checklist procedures for an engine fire on the ground to expeditiously address the fire hazard without unnecessarily delaying an evacuation.

To American Airlines:

9. For all airplanes that you operate, review existing engine fire checklists and make changes as necessary to ensure that the procedures would expeditiously address engine fires occurring on the ground without unnecessarily delaying an evacuation.

Previously Issued Recommendations Reiterated in This Report

The National Transportation Safety Board reiterates the following recommendations to the Federal Aviation Administration:

> Revise Advisory Circular 120-48, "Communication and Coordination Between Flight Crewmembers and Flight Attendants," to update guidance and training provided to flight and cabin crews regarding communications during emergency and unusual situations to reflect current industry knowledge based on research and lessons learned from relevant accidents and incidents over the last 20 years. (A-09-27)

> Develop best practices related to evacuation communication, coordination, and decision-making during emergencies through the establishment of an industry working group and then issue guidance for 14 *Code of Federal Regulations* Part 121 air carriers to use to improve flight and cabin crew performance during evacuations. (A-16-26)

Previously Issued Recommendation Classified in This Report

Safety Recommendation A-16-26 is reclassified "Open—Unacceptable Response" in section 2.3.2.2 of this report.