Submission to the

National Transportation Safety Board

for the

American Airlines 767-300 N345AN Engine Failure with Fire at Chicago, ILL 28 October 2016

The Boeing Company
28 July 2017

INTRODUCTION

On October 28, 2016, at about 2:32 CDT, American Airlines flight number 383, a Boeing B767-300, N345AN, powered by two General Electric CF6-80C2B6 turbofan engines, experienced a right engine uncontained failure and subsequent fire during the takeoff ground roll on runway 28R at the Chicago O'Hare International Airport (ORD), Chicago, Illinois. The flight crew aborted the takeoff, stopped the aircraft on runway 28R, and an emergency evacuation was conducted. The right engine, the right wing, a portion of the right fuselage and the right hand horizontal stabilizer experienced fire damage. The fire was extinguished by airport rescue and firefighting (ARFF) who arrived after the evacuation was complete. Of the 161 passengers and 9 crew members onboard, one passenger received serious injuries during the evacuation.

Submission Abstract

- The Boeing Company, as the airplane's manufacturer, is an invited party to the investigation and provides technical and operational assistance to the National Transportation Safety Board (NTSB) in their investigation.
- The conclusions presented in this submission are based on factual information received from the NTSB, Boeing expertise, the use of analytical tools, and a methodical investigation process.
- During the takeoff roll, at a ground speed of approximately 128 knots, the right engine experienced an uncontained engine failure in the high pressure turbine common to the stage 2 disk.
- The airplane and all airplane systems were functioning as expected prior to the engine event.
- 1.3 seconds after the engine failure a rejected takeoff (RTO) was initiated by the captain. The airplane systems helped maintain directional control while stopping the airplane.
- The high pressure turbine stage 2 disk ruptured and was found in four major segments/fragments. About 96% of the entire disk was recovered.
- A material manufacturing defect that occurred during the manufacturing process was found in two of the disk segments.
- The material defect led to the failure of the disk.
- One disk fragment penetrated the right wing fuel tank which led to a fuel-fed fire.
- The airplane interior and structural design features protected occupants during the fuel-fed fire and from engine fragments, and allowed for a prompt and complete evacuation.

- The left engine continued to run for approximately 30 seconds while passengers evacuated, temporarily preventing the use of exit 4L during the evacuation and creating a potential hazard for those using exit 2L and 3L.

BOEING ASSISTANCE WITH THIS INVESTIGATION

The National Transportation Safety Board (NTSB) is conducting the investigation into this American Airlines 767-300 accident. Assisting the NTSB in their investigation are the Federal Aviation Administration (FAA), American Airlines, General Electric Aviation (GE), Boeing, and other designated parties.

As the manufacturer of the 767-300 airplane, Boeing's specific role in this investigation has been to provide technical information regarding the airplane design, manufacture and operation to assist the NTSB.

Furthermore, the NTSB requested that all parties submit proposed findings to be drawn from the factual information established during the course of the investigation. Boeing has responded to the NTSB request with this document, which:

- Provides an assessment of the factual information and other pertinent data.
- Identifies knowledge gained from the investigation.
- Identifies conclusions and recommendations supported by the knowledge gained from the investigation.

BOEING ASSESSMENT

The Boeing assessment of the accident is based upon the facts as documented in the NTSB's factual reports. These reports are observations of the airplane and accident site, post-accident examination of airplane systems and components, flight data recorder (FDR) data, the cockpit voice recorder (CVR) transcript, airline maintenance records, materials laboratory data, and crew and passenger interview data.

THE AIRPORT AND WEATHER

The accident occurred at Chicago, O'Hare International Airport (ORD) on runway 28R. At the time of the accident runway 28R was 13,000 feet in length and 150 feet in width. The surface was concrete and in good condition. The flight taxied out to runway 28R for a takeoff from intersection N5. Visual meteorological conditions were present at the time and the reported ambient temperature was about 16°C (61°F).[1] Airport and weather conditions were not considered to be factors in this accident.

THE ACCIDENT AIRCRAFT

The Boeing Company delivered the airplane (registration N345AN, serial number 33084) on April 30, 2003. The airplane had 50,632.3 total hours with 8,120 total cycles at the time of the accident. The airplane was equipped with two General Electric (GE) CF6-80C2B6 engines.

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[1]NTSB Operational Factors/Human Performance Report, Dated March 1 2017, page 5.

FLIGHT AND CABIN CREW

The crew consisted of the Captain (CA), First Officer (FO), and 7 flight attendants (FA). The captain was the pilot flying (PF), the FO was the pilot monitoring (PM).

SEQUENCE OF EVENTS

Below is a chronological overview of the events that occurred based on FDR data, the CVR transcripts and video provided by persons at the airport. The events below are referenced to an estimated elapsed time from when the uncontained failure occurred. All times should be considered approximate.

Estimated Elapsed Time	Event Description
t = 0	Right engine failure occurred during the takeoff roll before the airplane reached rotation speed (FDR)
t = 1.3	The thrust levers are moved to idle. (FDR)
t = 2.0	Fire erupts on the right hand engine (video)
t = 2.3	Rejected Takeoff (RTO) autobrakes activated (FDR)
t = 16.6	Engine Fire R message activated (FDR)
t = 20.6	Captain calls for “checklist” (CVR)
t = 24.6	Right engine fuel control moved to Cutoff (FDR)
t = 26.4	Airplane comes to a full stop (FDR)
t = 36.6	Left over wing doors open (FDR)
t = 54	First person down the slide (video)
t = 54.6	Forward left entry door opened (FDR)
t = 57.4	Captain notices large amount of smoke from fire (CVR)
t = 1:01.7	Captain calls to switch to the evacuation checklist (CVR)
t = 1:04.6	Aft left entry door opened (FDR)
t = 1:25.5	Left engine shut down (FDR)
t = 1:37	Aft left entry door evacuation slide straightens as left engine N2 speed decreases (video)
t = 2:17	Evacuation is complete (video)
t = 2:26	ARFF (aircraft rescue and firefighting) arrives at airplane and applies extinguishing agent to the right engine and wing (video)
t = 9:50	Fire appears to be extinguished. (video)

POWERPLANT

The accident airplane was powered by two GE CF6-80C2B6 turbofan engines. The right engine was serial number (ESN) 690-373. This engine had accumulated 68,785 hours since new (TSN), 10,984 cycles since new (CSN) and had its last engine shop visit in January 2011.

Examination of the right engine revealed that the high pressure turbine (HPT) stage 2 disk, serial number MUNBB592, experienced a rotor bore to rim fracture. Fragments of the ruptured high pressure turbine stage 2 disk as well as blade and vane fragments: 1) penetrated through the high pressure turbine case and right engine nacelle structure, 2) one disk segment impacted and penetrated through the right wing fuel tank creating two distinct holes, 3) small fragments impacted the right side of the fuselage (but did not penetrate), 4) small fragments impacted right and left landing gear doors, 5) two small fragments impacted and penetrated the left engine nacelle with no engine effects observed, and 6) one disk segment along with smaller fragments created multiple impact scars and gouges into runway 28R. The HPT stage 2 disk ruptured and was found separated into four major pieces and about 96% of the entire disk was recovered.[2]

Laboratory Examination and Testing

The event stage 2 disk, SN MUNBB592 was manufactured in 1997. A metallurgical examination by both GE and the NTSB revealed that the second largest disk fragment recovered contained a subsurface production material anomaly located near the bore of the disk from which multiple cracks initiated.[3] The material anomaly is known in the metallurgical community as a “discrete dirty white spot” (DDWS) and occurs during the production of the ingot from which the disk is ultimately made. In the process of fabricating a HPT stage 2 disk, an ingot is created by melting raw materials together using a triple melt process to form a desired chemistry. From the ingot a forging is made by mechanically altering the shape of the ingot. Another mechanical alteration takes place in making the forging into a log shaped billet. It is at the billet stage that the first inspections using an ultrasonic test inspection (UTI) looking for defects like the DDWS takes place. From the billet log, segments are cut and then press forged, heat treated, machined and another UTI is performed. Final machining and inspections occur as the turbine disk takes its final configuration. The DDWS in the event stage 2 disk was subsurface (relatively deep), had a similar density as the disk material and was without voids. This condition made detection by UTI very unlikely. A review of the production records throughout the manufacturing process reveals no identified defects or rejections.

Historical production and testing results on the triple-melt process indicate that DDWS is an inherent infrequent characteristic of the vacuum arc melting process.[4] According to the FAA, the AA 383 event is the first and only Inconel alloy 718 triple-melt related anomaly that has resulted in either a cracked or a fractured part in commercial aviation.[5] Furthermore, since the production of HPT disk SN MUNBB592 in 1997, several process changes (manufacturing and inspection) have been incorporated. Data collected by the FAA and industry show that these changes have resulted in a significantly lower incidence of anomalies.

Maintenance Records

No discrepancies were found during the review of applicable airplane or powerplant Airworthiness Directives and Service Bulletin incorporation.

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[2] NTSB Powerplant Group Chairman’s Factual Report, Dated June 12 2017, page 2

[3] NTSB Powerplant Group Chairman’s Factual Report, Dated June 12 2017, page 2

[4] NTSB Powerplant Group Chairman’s Factual Report, Dated June 12 2017, page 3

[5] NTSB Powerplant Group Chairman’s Factual Report, Dated June 12 2017, page 65

GE Actions

Based on this event, GE issued Service Bulletin 72-1562 for the CF6-80C2 engine model and plans to issue Service Bulletin 72-0869 for the CF6-80A engine model. Both service bulletins call for ultrasonic inspections of the high pressure turbine stage 1 and stage 2 disks. Service Bulletins 72-0869 is anticipated to be released by the end of August 2017.

AIRPLANE SYSTEMS AND STRUCTURES

The airplane and all airplane systems were functioning as expected prior to the engine event. After the engine event, the airplane systems continued to function to maintain directional control while stopping the airplane on the runway.

The fire that occurred after the right engine failure was a result of leaked fuel which ignited in the engine nacelle and leaked onto the ground below the aircraft after the right wing fuel tank was penetrated by the turbine disk segment. The right wing, right horizontal stabilizer and right side aft fuselage were damaged by the fire.

Right wing impact damage due to the uncontained failure was limited to inboard of the right engine.[6] Two through hole penetrations were found; one hole was located forward of the front spar in the fixed-wing leading edge panel and the other was located aft of the wing front spar between wing rib 6 and 7 in the area of the dry bay. The fuel that fed the ground fire came from the right wing tank damage at rib 6 and the dry bay. The fuel feed line for the right engine runs through the dry bay and was also damaged. Based on calculations of fuel lost during the event and fuel pump/fuel line capability, the severed fuel line contributed a relatively small amount of fuel to the event fire.

There was no evidence of engine debris penetrating the pressurized fuselage section.[7] The right side exterior of the fuselage was damaged by the fire but the materials surrounding the passenger cabin provided sufficient protection to allow the occupants to evacuate. The visible damage inside the passenger cabin (other than crazed and melted windows) was limited to charring of a seat cushion at row 34 and charring and melting of the interior sidewall panels at seat rows 30, 32, 34, and 35.[8] The liners of the aft cargo compartment showed no signs of heat damage or soot.[9]

Dry Bay and Fuel System Integrity

At the time of the 767 development program the industry regulation to minimize the hazard following an assumed rotor disk burst event was FAR 25.903(d)(1).

> FAR 25.903(d)(1); For turbine installations- *Design precautions must be taken to minimize the hazards to the airplane in the event of an engine rotor failure or of a fire originating within the engine which burns through the engine case.*

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[6] NTSB Airworthiness Group Chairman's Factual Report, dated 28 April 2017 page 15

[7] NTSB Airworthiness Group Chairman's Factual Report, dated 28 April 2017 page 30

[8] NTSB Airworthiness Group Chairman's Factual Report, dated 28 April 2017 page 47

[9] NTSB Airworthiness Group Chairman's Factual Report, dated 28 April 2017 page 52

Typically the FAA provides guidance on how to comply with a regulation. For this installation, FAA Order 8110.11 was written in 1975 and in effect at the time the 767 was designed and certified.

Order 8110.11; "Design Considerations for Minimizing Damage by Uncontained Aircraft Turbine Engine Rotor Failures,"

c. Fuel tanks should not be located in impact zone areas. If, however, should it become absolutely necessary to locate fuel tanks in these vulnerable areas, then the following observations are pertinent:

(1) Fragment punctures of fuselage fuel tanks are unacceptable if the fuel will spill into the fuselage bays, whereas punctures of the wing fuel tanks may be acceptable if the fuel spills into the airstream away from the aircraft.
(2) The dry bay should be sized based on analysis of possible fragment trajectories through the fuel tank wall and the subsequent fuel leakage from the damaged fuel tank so that fuel will not migrate to an engine, APU or other ignition source during either in flight or ground operation. A minimum drip clearance distance of 10 inches from potential ignition sources of the engine nacelle, for static conditions, is acceptable.

The 767-300 meets the intent of FAR 25.903(d)(1). Boeing considered placing the engine sufficiently far forward of the wing to protect against the danger of fuel dripping onto the engine, but this design was impractical for a variety of factors, including weight & balance, flutter, and additional engine burst exposure to fuselage. Instead, Boeing designed the wing of the 767-300 to include a fuel-free compartment, identified as a "dry bay", that is located directly above the engine in the forward part of the fuel tank. The purpose of the dry bay design is to minimize the possibility of fuel spillage onto the engine hot section or into a fire caused by a turbine rotor failure.

The 767-300 dry bay also satisfies the guidance contained in FAA Order 8110.11. Boeing analyzed the likely fragment trajectories in an uncontained engine failure and designed the dry bay to minimize the risk that fuel would migrate to the engines during in-flight or ground operations. Specifically, the dry bay design results in a minimum 10+ inches of horizontal drip clearance, as discussed in ¶ c.(2), given a rotor burst trajectory into the wet side of the dry bay.

Long after the 767-300 entered service, the FAA issued in 1997 Advisory Circular (AC) 20-128A. This AC described means to comply with FAR 25.903. The dry bay sizing criteria, including a 10-inch minimum drip clearance, were based upon proven design practices in use at that time and balanced the need for fuel capacity in the wing fuel tanks with the regulatory requirement to minimize the hazard from uncontained engine failure. The 767-300 meets the standards set forth in AC 20-128A.

Fuselage and Cabin Interior Integrity

The materials installed in the airplane interior and cargo compartments performed as expected during the event by providing protection to occupants and allowing adequate time for evacuation. Thermal damage to the interior cabin was confined to a seat cushion at row 34 and the insulation and wall panels at right hand window seat locations at rows 30 through 35. The Assistant Deputy Fire Commissioner confirmed upon removal and inspection behind the sidewall panels at seat 28 to 34 that no flames were found inside the airplane or behind the ceiling and sidewall panels when he inspected the airplane.[10] Additionally, there was no evidence of soot or thermal damage on the aft cargo compartment liners.[11] While an area of thermally damaged fuselage skin on the right side of the airplane did exhibit buckling and some cracks, it is Boeing's opinion that the cracks occurred during extinguishing the fire and are not areas of burn through. There was a hole in the fuselage skin between frames at station 1197+22 and 1197+44, between stringers 23R and 24R. The edges of the hole were very thin indicating potential burn through.

SURVIVAL FACTORS

After the airplane came to a stop the flight crew proceeded with the Engine Fire checklist based on information from the tower that they had a fire "off the right wing" and the engine fire warning bell. While the flight crew was executing the Engine Fire checklist, some cabin crew attempted unsuccessfully to contact the flight crew to discuss evacuation. The cabin crew separately decided to open doors and begin evacuation, prompted by both passenger demands and a visible fire on the right side of the airplane. Different doors were opened at different times during the evacuation.

Notable events that occurred after the engine failure and during the evacuation included the following:

- During the aborted takeoff as the airplane was coming to a stop, passengers began moving from the right side of the airplane to the left.[12]
- Despite commands from multiple Flight Attendants (FA's) to remain seated, passengers began rushing to the exits as the airplane came to a stop.[13]
- At least two FA's made some attempt to contact the cockpit but were unable to complete the task.
- The evacuation began while the flight crew performed the Engine Fire checklist. The flight crew was unaware of the evacuation in the cabin at the time they started the Evacuation checklist.
- At least 3 FA's, as allowed per American Airlines procedures, elected to proceed with an evacuation without consent from or notice to the flight crew.
- For approximately 30 seconds, the left engine continued to run while passengers evacuated using the left overwing slide common to doors 2L and 3L. This resulted in passengers passing through the exhaust thrust. During this time slide 4L was blown back and rendered unusable.
- The passenger who sustained a serious injury used the left overwing slide while the left engine was running.
- The evacuation was completed using 1L, 2L, 3L and 4L.

Engine Fire and Evacuation Checklist

The 767 Flight Crew Operations Manual (FCOM) Quick Reference Handbook (QRH) contains checklists for engine fires and evacuation. After the aircraft came to a stop, the flight crew

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[10] NTSB Airworthiness Group Chairman's Factual Report, dated 28 April 2017, page 46

[11] NTSB Airworthiness Group Chairman's Factual Report, dated 28 April 2017, page 52

[12] NTSB Survival Factors Group Chairman's Factual Report, dated 29 June 2017, page 13

[13] NTSB Survival Factors Group Chairman's Factual Report, dated 29 June 2017, page 13

first used the Engine Fire checklist. From the CVR, the fire handle for the right engine was pulled prior to the start of the Engine Fire checklist as a memory item in shutting the engine down. However, the fire handle was not rotated (this releases the extinguishing agent) until approximately 24 seconds after the start of the Engine Fire checklist. After two "whooshing" sounds and the CA comments of "oh look at the smoke – check out the smoke" the CA then called to do the Evacuation checklist"[14]. Approximately 22 seconds after the Evacuation checklist was called for both fuel control switches were set to cutoff.[15]

KNOWLEDGE GAINED DURING THE INVESTIGATION (Findings)

The following knowledge gained is pertinent to drawing conclusions:

- Airport and weather conditions were not a factor in this accident.
- During takeoff the right engine experienced an uncontained engine failure of the high pressure turbine stage 2 disk. A 1/3 segment of the disk penetrated the right wing tank which led to a fire on the right side of the airplane.
- The airplane and all airplane systems were functioning as expected prior to the engine event. After the engine event, the airplane systems continued to function to maintain directional control while stopping the airplane.
- The airplane interior and structural design features prevented fragments of the engine from entering the cabin, protected occupants during the fuel-fed fire, and allowed for a prompt and complete evacuation.
- The cause of the stage 2 disk failure was determined to be a manufacturing defect known as a "discrete dirty white spot" that occurred during the billet manufacturing process.
- Improvements in manufacturing and inspection techniques since the disk was manufactured have significantly lowered the possibility of a similar occurrence.
- The uncontained engine failure was within the airplane design envelope.
- A lack of communication between the cabin crew and the flight crew resulted in the flight crew being unaware of the cabin crew initiated evacuation.
- The left engine continued to run for approximately 30 seconds while passengers evacuated, temporarily preventing the use of exit 4L and creating a potential hazard for those using exit 2L and 3L during the evacuation.

CONCLUSIONS

Boeing believes that the evidence supports the following conclusions for the accident:

> This accident occurred due to an uncontained failure of the right engine high pressure turbine stage 2 disk which penetrated the right wing fuel tank resulting in leaked fuel that ignited and resulted in a ground pool fire under the wing of the airplane. The

[14] NTSB Cockpit Voice Recorder Group Chairman's Factual Report, dated 17 January 2017, page 13

[15] NTSB Cockpit Voice Recorder Group Chairman's Factual Report, dated 17 January 2017, page 14

failure of the high pressure turbine disk was due to cracking caused by a material defect which occurred during the manufacturing process of the disk.

RECOMMENDATIONS

Boeing makes the following recommendations based on the knowledge gained:

- A review of existing flight and cabin crew training that relates to ground fire emergency evacuations, including but not limited to training and communication and crew resource management, should occur at the industry level with participation by airlines, regulators, safety associations and manufacturers. We recommend that an appropriate industry committee, forum, or task force be convened with the representatives from these and any other appropriate, entities.

BOEING ACTIONS

As a result of this investigation, Boeing has:

- Held discussions and reviewed potential flight and cabin crew training enhancements. Furthermore, we are prepared to participate in any industry committee, forum or task force that is convened on this subject matter.
- Reviewed the Quick Reference Handbook Engine Fire and Evacuation checklists for accuracy and completeness. We determined that if performed correctly the checklists are correct and appropriate for each situation they were intended to address.