

27 April 2018
66-ZB-H200-ASI-19034

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Washington DC 20594-003
[REDACTED]

Subject: Boeing Submission for FedEx MD-10-10F N370FE Left Main Landing Gear
Collapse at Fort Lauderdale, Florida - 28 October 2016

Reference: NTSB Tech Review Meeting, 30 March 2018

Dear Dr. Bower,

As requested during the reference technical review, please find attached the Boeing submission on the subject accident. Per your request we are sending this electronic version to your attention for distribution within the NTSB.

We would like to thank the NTSB for giving us the opportunity to make this submission. If you have any questions, please don't hesitate to contact us.

Best regards,

[REDACTED]
Robert J. McIntosh
Director, Product Safety

Enclosure: Boeing Submission to the NTSB for the subject accident





Submission to the
National Transportation Safety Board
for the

**FedEx MD-10-10F N370FE
Left Main Landing Gear Collapse at
Fort Lauderdale, FL
28 October 2016**

**The Boeing Company
27 April 2018**



INTRODUCTION

On October 28, 2016, at about 1751 eastern daylight time (EDT), FedEx flight 910, a McDonnell Douglas MD-10-10F, registration N370FE, experienced a left main landing gear collapse and subsequent fire in the left wing after landing on runway 10L at Fort Lauderdale–Hollywood International Airport (KFLL), Fort Lauderdale, Florida. The two flight crew members evacuated the airplane after the airplane came to rest on the side of runway 10L and were not injured. The airplane was substantially damaged. At the time of the accident, the cargo flight was operating under 14 Code of Federal Regulation Part 121 and originated from Memphis International Airport, Memphis, Tennessee.

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.
- The airplane landed with a normal touchdown and initial roll out.
- Approximately 12 seconds after touchdown, and 1.5 seconds after brake application, the airplane began to roll left as the left main landing gear failed.
- The left main landing gear cylinder fractured around its entire circumference passing midway through the air fill valve bore.
- A fatigue crack initiated at a corrosion pit in the air fill valve bore and led to the fracture failure.
- No evidence of cadmium plating was detected in the air fill valve bore. Boeing Alert Service Bulletin DC1032A259 requires cadmium plating of the air fill valve bore to provide corrosion protection.
- The left wing fire was predominately fed by jet fuel leakage from a breached left engine fuel pipe and damage to the left wing’s lower skin.
- With the exception of the collapse of the left MLG, the airplane’s systems and structures performed as expected during the conditions encountered during the accident sequence.



BOEING ASSISTANCE WITH THIS INVESTIGATION

The National Transportation Safety Board (NTSB) is conducting the investigation into this FedEx MD-10-10F accident. Assisting the NTSB in their investigation are the Federal Aviation Administration (FAA), FedEx, the Airline Pilots Association (ALPA), Boeing, and other designated parties.

As the manufacturer of the MD-10-10F 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, airline maintenance records, materials laboratory data, and a finite element model (FEM) supported fatigue analysis.



THE WEATHER

At 1753, about 2 minutes after the accident, the METAR (official report of weather conditions at the airport) reported wind from 050 degrees at 15 gusting to 24 knots, 10 miles visibility, few clouds at 2600 feet agl (above ground level), broken ceiling at 5000 feet agl, overcast clouds at 25,000 feet agl, temperature 26°C, dewpoint 21°C, altimeter setting 29.98 inches of mercury. A peak wind speed had been recorded at 1732 of 060 degrees at 26 knots. About an hour prior to the accident, at 1653, the METAR reported wind from 050 degrees at 15 gusting to 25 knots, 10 miles visibility, few clouds at 2400 feet agl, scattered clouds at 3300 feet agl, broken ceiling at 4100 feet agl, overcast clouds at 25,000 feet agl, temperature 26°C, dewpoint 20°C, altimeter setting 29.99 inches of mercury.¹ Weather was not considered a factor in this accident.

FLIGHT DATA RECORDER INFORMATION

The flight data recorder information indicates the approach and touchdown were typical for the wind conditions present at the time of the event. The 1.25G touchdown was not identified as a hard landing and the initial rollout was nominal. The following is a timeline of the rollout sequence of events:

Time	Event
17:50:31.00	Spikes in vertical and longitudinal accelerations indicating the approximate time of the initial touchdown. [Approximate Touchdown]
17:50:41.25	Increase in brake pedal position angle and decrease in longitudinal acceleration indicate braking. [Brakes Applied]
17:50:43.00	Left roll angle increases indicating that the gear has collapsed. [Gear can no longer support the aircraft (start of roll)]
17:50:44.00	Roll angle stabilizing at about -12 degrees (left wing down) and large vertical acceleration spike indicate that the left wing and/or engine have contacted the ground. [Left wing/engine hits the ground (roll stabilizes concurrent with spike in vertical acceleration)]

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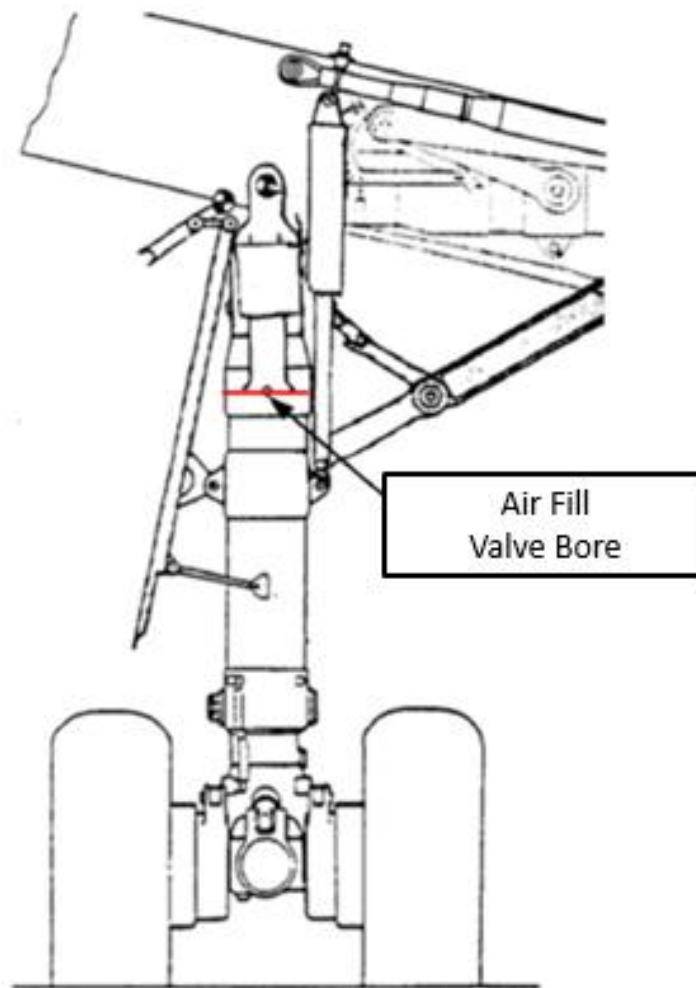
¹ NTSB Operational Factors / Human Performance Group Chairman's Factual Report, dated 28 August 2017, page 9

² NTSB Flight Data Recorder Specialist's Factual Report, dated 10 August 2017, page 4

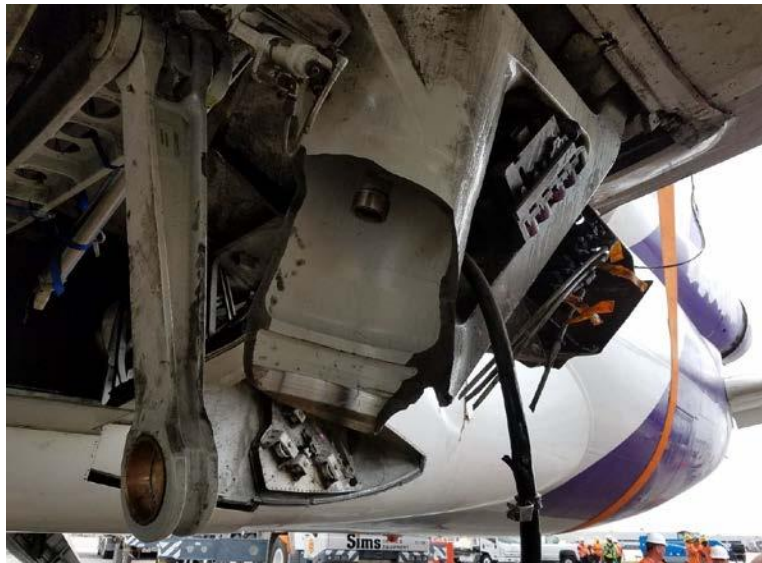
AIRPLANE STRUCTURES AND SYSTEMS

Left Main Landing Gear Failure

On-site post-accident inspection found the left main landing gear cylinder had fractured around its entire circumference and the fracture was noted to pass midway through the air fill valve bore's boss. The upper portion of the cylinder remained attached to the airplane at the forward and aft trunnion lugs. The lower portion of the cylinder, and the landing gear's piston, remained attached to the airplane by the side braces. Three pieces of the left main landing gear's outer cylinder were found on the runway. Two of these pieces were from the air fill valve bore's boss.



**Left Main Landing Gear Looking Forward
Red Line Indicates Fracture Location**



**Upper Portion of Left Main Landing Gear Cylinder Attached to the Airplane
(looking aft and inboard)**



Aft Side of Lower Section of Left Main Landing Gear Cylinder and Air Fill Valve Bore



Fracture Surface on the Lower Section of the Left Main Landing Gear Cylinder



Air Fill Valve Bore Boss Pieces Recovered From Runway

The recovered pieces of the left main landing gear cylinder were examined in the laboratory. Almost all of the fracture surfaces exhibited a dull luster with a rough surface, with radial lines and chevron marks. These features were consistent with overstress fracture in low ductility (hardened) metal alloys. These features were consistent with the fracture originating at the air fill valve bore on the landing gear. At the bore location was a flat, thumbnail-shaped crack. This feature was consistent with a pre-existing crack prior to complete fracture of the landing gear.³ All of the overstress features were consistent with having emanated from the thumbnail crack near the bore.⁴

The radius of the curved portion of the landing gear bore at the location of the thumbnail crack initiation site was measured between 0.105 and 0.154 inches, with an average of 0.128 inches.⁵ The thumbnail crack was examined using a scanning electron microscope. Fatigue striations were present in the initial portion of the crack.⁶ The most prominent observation of the initiation site was a feature consistent with a corrosion pit. The corrosion pit measured 0.004 inches wide with a depth of 0.002 inches.⁷

The bore was inspected to determine if there were any electrodeposits or remnants of other metallic coatings in the area. No indications of cadmium or cadmium compounds were found in the bore using EDS. Likewise, inspection of the fracture surface and bore using backscattered electron imaging found no evidence of any particles consistent with previous nickel, chromium, or cadmium plating.⁸ A 100X bright field micrograph of a cross-section of

³ NTSB Materials Laboratory's Factual Report, dated 14 April 2017, page 2

⁴ NTSB Materials Laboratory's Factual Report, dated 14 April 2017, page 3

⁵ NTSB Materials Laboratory's Factual Report, dated 14 April 2017, page 2

⁶ NTSB Materials Laboratory's Factual Report, dated 14 April 2017, page 3

⁷ NTSB Materials Laboratory's Factual Report, dated 14 April 2017, page 4

⁸ NTSB Materials Laboratory's Factual Report, dated 14 April 2017, page 4

a thread root in the bore was performed. The threads exhibited no indication of a metallic coating.⁹

A Finite Element Model (FEM) supported fatigue (crack initiation) analysis of the incident main landing gear cylinder was performed. It was determined that the main landing gear cylinder has two critical areas in the air fill valve bore that experience high stress levels during landing. These areas are at the 3:00 o'clock and 9:00 o'clock positions of the air fill valve bore and each area is approximately 0.12 square-inch in size. The FEM was developed to represent the pit found on the main landing gear cylinder from the accident airplane, including the pit's location on an oversized .090 inch radius at the junction of the air fill valve bore to the inner diameter of the main landing gear cylinder, in a critical area on the 3:00 o'clock – 9:00 o'clock plane. The fatigue analysis results shows that under these conditions crack initiation is likely to occur.

The area where the air fill valve bore is located on the interior of the MD-10-10F main landing gear's shock strut cylinder, manufactured from 300M steel, is considered by Boeing to be a low corrosion prone location, because this area of the shock strut is constantly pressurized with dry nitrogen and also occasionally wetted with shock strut oil. In addition, the threaded section of the air fill valve bore is not considered a corrosion prone environment, as the servicing valve is threaded into this area of the air fill valve bore and torqued to approximately 125 inch/pounds.

Brush cadmium plating is an industry practice often used for corrosion protection of 300M steel landing gear components during their manufacture, overhaul, and repair. Service experience has shown that when properly applied, cadmium plating effectively protects 300M landing gear components from corrosion between landing gear overhauls.

When used for corrosion protection, cadmium is sacrificed to protect the base metal. Therefore, in environments prone to corrosion, cadmium is lost to corrosion over time and may eventually not be present on the base metal. When that occurs on a part manufactured from 300M steel, base metal corrosion will be observed as red rust. The amount of time required for the cadmium to corrode is directly related to the corrosiveness of the environment to which the cadmium is exposed. Red rust in the air fill valve bore was not noted in the laboratory analysis and very little red rust was found in photographic evidence from the laboratory.



Picture of Two Pieces with Air Fill Valve Bore Taken In Laboratory

⁹ NTSB Materials Laboratory's Factual Report, dated 14 April 2017, page 5



The sealed dry nitrogen and strut oil environment of the air fill valve bore provides a benign environment. When brush cadmium is properly applied to a MD-10-10 main landing gear cylinder's air fill valve bore per Boeing's published procedures, cadmium loss to corrosion will be minimal and sufficient cadmium plating will be present to protect the bore from corrosion between overhauls.

In February of 2017, one landing gear overhaul provider requested Boeing review a proposed alternate air fill valve bore cadmium plating procedure for inclusion in the MD-10-10F main landing gear overhaul manual. The proposed procedure would cadmium plate the air fill valve bore while other areas of the cylinder are immersion cadmium plated in a tank. The intent of the request was to reduce the number of work steps required to plate all of the areas on the cylinder that require cadmium plating. Boeing has requested information regarding the proposed alternate procedure from the overhaul provider. If in the future Boeing can approve the proposed procedure, it will be added to the main landing gear overhaul manual as an alternate procedure for cadmium plating of the air fill valve bore. As the existing brush cadmium plating procedure provides acceptable results when properly performed, it will remain in the overhaul manual as an approved procedure for cadmium plating of the air fill valve bore. With two procedures in the overhaul manual, overhaul facilities will have the opportunity to select the procedure that works best for their operations.

Left Wing Fire

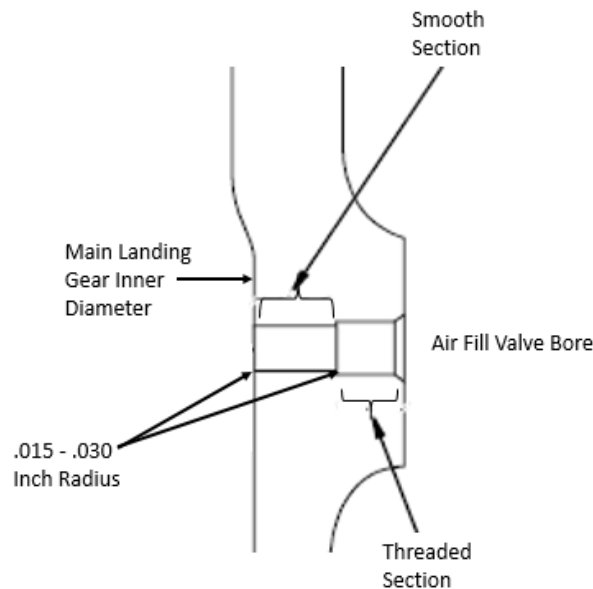
Substantial fire damage was noted on the left wing, including damage associated with an explosion that caused an approximately 25.5 foot by 9 foot section of the top wing skin to separate from the airplane. The left engine and pylon assembly were found oriented with the inlet upward and trailing end of the pylon near the ground. The aft pylon attach bracket had broken and the two pylon attach points at the forward wing spar were intact¹⁰, which allowed the engine to pivot. One result of the engine pivoting about the forward attach points was the breaching of a pylon fuel tube, which is downstream of the fuel shutoff valve that was activated by the flight crew, via the left engine fire handle in the cockpit, after the airplane came to rest. The left outboard flap hinge had separated from the wing, allowing a section of the wing's lower skin, forward of the left outboard aileron, to contact the ground. This resulted in the wing fuel tank being breached. The left wing fire was predominantly fed by jet fuel leakage from damage to the lower left wing and the breached left engine pylon fuel pipe.

MAINTENANCE RECORDS

The left main landing gear's last overhaul was completed on 28 February 2008 and the gear was installed on the event airplane on 31 March 2008. During the overhaul, compliance with Boeing Alert Service Bulletin DC1032A259 was recorded. This service bulletin was issued after a previous NTSB investigation was performed involving a fracture of a similar main landing gear cylinder. This fracture originated at a small fatigue crack inside the air fill valve bore. The NTSB probable cause stated that the left main landing gear fractured from fatigue cracking in the air fill valve bore due to the presence of stray nickel electroplating in the air fill valve bore. Inadequate maintenance procedures had allowed nickel electroplating in the air fill valve bore during overhaul that contributed to the fatigue crack initiation. Boeing issued Alert Service Bulletin DC1032A259 on October 30, 2007. The bulletin instructed the operator to perform repetitive inspections of the main landing gear cylinder air fill valve bore for stray nickel or chromium electroplating deposits, corrosion, or cracks. If any of these conditions

¹⁰ NTSB Investigator's Factual Report of Investigation for Aircraft Systems and Powerplants, dated 18 September 2017, page 16

were found, the service bulletin provided instructions for repair or replacement of the main landing gear shock strut cylinder assembly.¹¹ Terminating action for the repetitive inspections was the repair of the air fill valve bore per the service bulletin's instructions. These instructions include making two 0.015-0.030 Inch radii. One radius is at the junction of the air fill valve bore's smooth section to the inner diameter of the main landing gear cylinder. The second radius is at the junction of the air fill valve bore's smooth section to the air fill valve bore's threaded section. The service bulletin's instructions also include brush cadmium plating the air fill valve bore's smooth section, threaded section, and the two radii. Cadmium plating is intended to protect the base metal from corrosion.



Maintenance records show Boeing Alert Service Bulletin DC1032A259 was complied with during the left main landing gear's last overhaul, which was completed in February of 2008. A review of the work cards completed during the overhaul found a work step statement to "maintain radius of bore at I/D wall and thread junction 0.015-0.030".¹² After rework, the radius at the junction of the air fill valve bore's smooth section to the air fill valve bore's threaded section was recorded on the work card as 0.030 inch and the radius at the junction of the air fill valve bore's smooth section to the inner diameter of the main landing gear cylinder was recorded as 0.090 inch. This recorded radius at the junction of the air fill valve bore's smooth section to the inner diameter of the main landing gear cylinder is beyond the 0.030 inch value required by Boeing Alert Service Bulletin DC1032A259. No additional records were found that addressed the exception.¹³ Additionally, it was noted a work card step to "brush cad plate the valve bore holes"¹⁴ was stamped, indicating the work card step was completed.

¹¹ NTSB Materials Laboratory's Factual Report, dated 14 April 2017, page 5

¹² NTSB Maintenance Factual – Federal Express Group Chairman's, dated 8 June 2017, Appendix 4, OP # 2095 NORM

¹³ NTSB Maintenance Factual – Federal Express Group Chairman's, dated 8 June 2017, page 16

¹⁴ NTSB Maintenance Factual – Federal Express Group Chairman's, dated 8 June 2017, Appendix 4, OP # 4402 NORM



KNOWLEDGE GAINED DURING THE INVESTIGATION (Findings)

The following knowledge gained is pertinent to drawing conclusions:

- The weather conditions were not a factor in this accident.
- The touchdown was not indicative of a hard landing
- During the landing roll out, the left main landing gear failed due to a crack in the landing gear's cylinder that existed prior to the accident.
- Laboratory analysis and a FEM supported fatigue analysis indicate that the pre-existing crack initiated at a corrosion pit in a critical stress area of the cylinder.
- Cadmium plating specified by Boeing Alert Service Bulletin DC1032A259, intended to protect the air fill valve bore's base metal from corrosion, was not found in the area of the pit during post-accident laboratory evaluation.
- Significant red rust, which is an indicator of previously applied cadmium plating in a corrosion prone environment, was not noted in the in the air fill valve bore by laboratory analysis or photographic evidence.
- The radius where the corrosion pit occurred was beyond the limits specified by Boeing Alert Service Bulletin DC1032A259.
- The left wing fire was predominantly fed by jet fuel leakage from a breached left engine pylon fuel pipe and damage to the left wing's lower skin.
- With the exception of the collapse of the left MLG, the airplane's systems and structures performed as expected during the conditions encountered during the accident sequence.

CONCLUSIONS

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

This accident resulted from the failure of the left main landing gear due to a crack that had initiated at a corrosion pit in a radius between the inner diameter and the air fill valve bore of the landing gear's outer cylinder. The corrosion pit occurred because cadmium plating was not applied to the radius during the landing gear's last overhaul, as specified by a Boeing alert service bulletin.