



AVIATION



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Aviation Investigation Final Report

Location:	London,	Incident Number:	ENG15IA037
Date & Time:	October 10, 2014, 13:00 UTC	Registration:	N26906
Aircraft:	Boeing 787-8	Aircraft Damage:	Minor
Defining Event:	Flight instrument malf/fail	Injuries:	N/A
Flight Conducted Under:	Part 121: Air carrier - Scheduled		

Analysis

Based on crew reports and verified with images from the crew and the EAFR, the flight crew lost the use of three of the five head down displays following a lightning strike. The crew followed published procedures, however the procedures did not contain a checklist related to a partial loss of displays. After the crew elected to follow the "Loss of All Displays Checklist", none of the affected displays recovered to an operational state. The crew did land the aircraft successfully using the remaining displays available to the crew. All of the displays did recover normal operation after accomplishing a power cycle to the displays while the aircraft was on the ground. No procedures existed for a power reset of the displays to occur while in flight, which most likely would have resulted in a restoration of the displays.

Reviewing the design and display certification requirements, the displays passed their respective certification testing required by the FAA. Supplemental testing by the investigation also showed the displays operating satisfactorily at testing levels that were above levels specified in the original certification of the aircraft and system. However, when subjecting the displays to testing that was based on different standardized system level testing (typically associated with military aircraft) that was not required to be conducted for display unit or aircraft certification, the failure could be repeated. This failure was attributed to the display's response to a rapid transient radiated electric field. The electrical field analysis of the aircraft cockpit confirmed that similar electrical transients can be present during certain lightning strikes experienced by an aircraft. Although the displays passed the required certification testing required by the FAA, it was determined that certain environmental conditions exist that could cause adverse conditions of the display operation resulting in a loss of the display.

Probable Cause and Findings

The National Transportation Safety Board determines the probable cause(s) of this incident to be:

A shutdown of the displays due to the inability to operate through a rapid transient radiated electric field brought on by a near field lightning strike. Contributing to the loss of displays for the remainder of the flight was the lack of guidance to the crew to perform a controlled power reset to the display.

Findings

Aircraft	Central display - Failure
Aircraft	Central display - Capability exceeded

Factual Information

History of Flight

Initial climb	Other weather encounter
Initial climb	Flight instrument malf/fail (Defining event)

HISTORY OF FLIGHT

On October 10, 2014 about 1300 UTC, a N26906, Boeing 787-824 operated by United Airlines (UA) as a 14 Code of Federal Regulations, Part 121 international flight from London's Heathrow International Airport (LHR), United Kingdom, to Houston's International Airport (IAH), Houston, Texas, was struck by lightning and three of five primary display units went blank, a status message related to a power distribution channel was displayed, and the captain's forward windshield heat became inoperative. The standby instruments and the heads up displays (HUD) were unaffected by the event. The lightning strike occurred approximately six minutes after take-off during the climb portion of the flight.

There was no checklist for a partial loss of displays and the crew elected to use the checklist for "Loss of All Displays". The procedure did not recover use of any of the three failed displays. The crew accomplished the abnormal checklist for the window heat. The checklist did not restore the function of the window heat. The remaining two displays were reconfigured and the flight crew landed the airplane uneventfully at LHR. There were no injuries to the crew and passengers. After landing, LHR maintenance performed a lightning inspection and found external nonstructural damage in five locations along the nose which was addressed in accordance with structural repair manual (SRM) allowable damage criteria. A power reset to the aircraft per maintenance manual procedures was accomplished, and the displays and other affected systems returned to normal function. After a review by United maintenance personnel, the aircraft was approved for dispatch and continued the flight to IAH with no further faults noted.

INJURIES

No injuries to passengers or crew were reported.

DAMAGE TO AIRPLANE

An on-site examination of the aircraft was performed while on the ground at LHR and the aircraft display systems were restored using aircraft maintenance manual (AMM) procedures. An external inspection of the aircraft by UA maintenance personnel revealed possible lightning strike attachment points on the left hand side of the nose of the aircraft. Damage was noted around the captain's windshield (L1) in the area of the seals of the windscreen. A review of maintenance records revealed that approximately one month prior to the event, window seal damage was noted in the same area of the L1 windows and was previously repaired. An additional set of possible lightning attachment points were documented on the left wing in the area of the left outboard aileron. The damaged areas were inspected by UA maintenance.

The aircraft was approved for dispatch in accordance with structural repair manual (SRM) allowable damage criteria. The flight continued from LHR to IAH without any other incidents.

An additional aircraft examination was conducted in March 2015. The interior of the nose area of the forward equipment bay in the location of the lightning strike points was inspected. The left side cockpit windows were visually inspected for signs of delamination of damage from the cockpit. No notable signs of additional damage were seen in the area of the lightning strike points or on the left side cockpit windows. A display unit and forward instrument panel electrical ground bonding check was performed finding all grounds satisfactory.

Three displays, the left inboard, left outboard and right outboard displays blanked during the event. The aircraft health monitoring system (AHM) noted faults related to the three display units, the left forward window heat system and the secondary power distribution system related to the left forward window heat system. After the flight's return to LHR, United maintenance performed an aircraft inspection and aircraft power reset per aircraft maintenance manual procedures and the displays and window heat system resumed normal functionality.

AIRCRAFT INFORMATION

The event airplane, a Boeing 787-824, serial number 34829, was manufactured and delivered to the operator in October, 2012 and had accumulated 6,582 hours and 996 cycles. The left inboard and outboard displays were delivered new with the aircraft. The right outboard display was installed in the aircraft in December 2012 to replace a unit that was removed due to erroneous display switching without crew input. None of the affected display units had been returned to the display manufacturer since the time of delivery of the aircraft.

METEOROLOGICAL INFORMATION

The crew reported the aircraft was flying through a "moderate non-CB (Cumulonimbus) rain shower" with cloud tops of 10,000 ft. at the time of the lightning strike.

FLIGHT RECORDERS

The aircraft was equipped with an Enhanced Airborne Flight Recorder (EAFR). The data from the EAFR was successfully retrieved and sent to NTSB for analysis.

TEST AND RESEARCH

Aircraft Level Grounding/Bonding Test

In March 2015, a grounding/bonding test was performed on the event aircraft. Bonding checks were performed on the head down displays and the P300 and P400 electrical panels. The bonding measurements were consistent with bonding measurements from an exemplar aircraft. A visual inspection was also conducted and confirmed that the grounding straps between the forward instrument panel and the bulkhead on both the captain's and first officer's side were attached and secured.

Component Level Testing

The left and right inboard and outboard display units (DU), Secondary Power Distribution Unit (SPDU) microprocessor card, Graphics Generator Module (GGM) and Window Heat Protection Unit (WHPU) were removed from the event aircraft for additional testing and inspections. The details of the testing and inspections can be found in the NTSB Systems Group Chairman's Factual Report contained in the public docket for this incident.

Additional fault history data was recovered from the non-volatile memory on the Secondary Power Distribution Unit (SPDU) microprocessor card, Graphics Generator Module (GGM) and the four removed display units (DU). A review of the DU fault history data showed that the display units that blanked all recorded a "LCD Supply Voltage Fault" at the approximate time of the lightning strike as reported by the crew.

The right inboard and outboard units were subjected to the manufacturer's acceptance test procedures (ATP) and return to service (RTS) test procedures. Both units passed both the ATP and RTS test procedures. The left outboard unit was selected to be used for additional testing and the left inboard unit was quarantined as a control unit.

Exemplar Unit Testing

Testing on an exemplar display unit was performed by the component manufacturer. The exemplar unit was equivalent to the event units except for the display software. The software in the exemplar display was modified to add additional internal fault reporting output, but was otherwise equivalent to the event units.

The testing consisted of both radiated field and cable coupling tests, in both grounded and floating conditions (when applicable) for the display. The different test conditions the exemplar display was subjected to and all the test levels exceeded or were outside of 787 display specifications. During the exemplar unit testing, the display did not have any adverse effects or fault messages logged that were directly related to the effects or messages seen during the event.

Near Strike Lightning Testing

Additional testing was identified that addressed radiated electric fields that are coupled directly into the equipment. The purpose of the testing was to evaluate the susceptibility of a 787 DU when exposed to a high intensity electric field radiated inside the cockpit generated by a nearby lightning strike. The testing did not look at magnetic field effects. The testing was based on standardized system level testing as described in MIL-STD-464C and was not required to be conducted for display unit or aircraft certification.

The testing was conducted at the aircraft manufacturer's lightning laboratory. Testing was conducted on both an exemplar DU and the event airplane's left outboard DU. Nine near lightning strikes were performed on the exemplar unit with one strike resulting in a blanking event on the display. A review of the NVM fault data for the display showed a "Grayscale voltage fault" was logged by the unit.

The left outboard unit from the event aircraft was tested. Four near lightning, two in a near vertical (approximately 19° from vertical) orientation and two in a horizontal orientation were performed. Blanking of the display was observed in one of the vertical and both of the horizontal tests. Each test that resulted in blanking resulted in a "LCD Supply Voltage Fault" logged by the display unit.

Flat Plate Testing

Based on the results from the near strike lightning testing, additional testing using a flat plate to create a transient electric field across the display surface was performed at the display manufacturer. The testing that was performed was not required to be conducted for display unit or aircraft certification. The testing was performed on the exemplar display and the left inboard, right onboard and outboard display units. A charge would be applied to the flat plate placed on a Lexan sheet resting on the display unit. Once the appropriate charge level was achieved the plate was rapidly discharged and the display behavior was observed. All four units, experience blanking at different applied voltages and recorded both "Grayscale voltage fault" and "LCD Supply Voltage Fault" during the blanking events.

ADDITIONAL INFORMATION

Electrical Field Analysis

Based on the results from both the near strike lightning testing and the flat plate testing, the Boeing Company conducted an analysis of the electrical fields present in the cockpit during a lightning event.

The analysis used three current waveforms ("A", "D" and "H"), from ARP 5412 revision B, which are the same waveforms used during certification testing and analysis of flight deck equipment.

The analysis confirmed that under some dynamic lightning conditions, the spark gap device installed in the Window Heat Protection Unit will fire. The firing of this spark gap device affected the transient electrical field characteristics. Comparing the display blanking electrical field thresholds seen during the near strike lightning and flat plate testing, the electrical field analysis results showed that, based on the lower blanking thresholds demonstrated during the near strike lightning testing and the flat plate testing, the lightning model results exceeded the lower bound estimate of the display blanking threshold during every case where a "fast" spark gap fired or a waveform "H" was applied. The upper blanking threshold was never exceeded.

Lightning Certification

According to the Boeing Model 787-8 Type Certificate Data Sheet (TCDS), the 787-8 airplane was granted transport category approval on August 26, 2011. The applicable certification basis was the 14 Code of Federal Regulations (CFR) Part 25 Airworthiness Standards, through Amendment 25-119 and amendments 25-120, 25-124, 25-125 and 25-128 with some exceptions and special conditions (SC) as noted in the 787-8 TCDS.

The particular regulation regarding lightning is found in 14 CFR 25.1316 (Amendment 25-80) and states:

"§ 25.1316 System lightning protection.

(a) For functions whose failure would contribute to or cause a condition that would prevent the continued safe flight and landing of the airplane, each electrical and electronic system that performs these functions must be designed and installed to ensure that the operation and operational capabilities of the systems to perform these functions are not adversely affected when the airplane is exposed to lightning.

(b) For functions whose failure would contribute to or cause a condition that would reduce the capability of the airplane or the ability of the flightcrew to cope with adverse operating conditions, each electrical and electronic system that performs these functions must be designed and installed to ensure that these functions can be recovered in a timely manner after the airplane is exposed to lightning.

(c) Compliance with the lightning protection criteria prescribed in paragraphs (a) and (b) of this section must be shown for exposure to a severe lightning environment. The applicant must design for and verify that aircraft electrical/electronic systems are protected against the effects of lightning by:

- (1) Determining the lightning strike zones for the airplane;
- (2) Establishing the external lightning environment for the zones;
- (3) Establishing the internal environment;
- (4) Identifying all the electrical and electronic systems that are subject to the requirements of this section, and their locations on or within the airplane;
- (5) Establishing the susceptibility of the systems to the internal and external lightning environment;
- (6) Designing protection; and
- (7) Verifying that the protection is adequate.

[Doc. No. 25912, 59 FR 22116, Apr. 28, 1994]"

The FAA also provided an Advisory Circular (AC) that outlines a means of compliance, but not the only means, by which a manufacturer can show compliance with the regulations, AC 20-136A "Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning."

The current industry standard for lightning tests do not include test conditions simulating a rapid transient radiated electric field.

Actions Taken Since Event

After the event, the aircraft manufacturer notified the fleet operators of the event and subsequent loss of displays. The manufacturer has implemented a software change to the 787-10 aircraft, which will start with the first production aircraft's entry into service (estimated 2018). The software change will automatically reset a display unit if the unit blanks due to certain internal fault conditions. For current and retrofit 787-8 and 787-9 models, the manufacturer has evaluated an equivalent software change, based on the 787-10, and the expected implementation for the changes is in 2019.

Information

Certificate:	Age:
Airplane Rating(s):	Seat Occupied:
Other Aircraft Rating(s):	Restraint Used:
Instrument Rating(s):	Second Pilot Present:
Instructor Rating(s):	Toxicology Performed:
Medical Certification:	Last FAA Medical Exam:
Occupational Pilot:	Last Flight Review or Equivalent:
Flight Time:	

Aircraft and Owner/Operator Information

Aircraft Make:	Boeing	Registration:	N26906
Model/Series:	787-8 NO SERIES	Aircraft Category:	Airplane
Year of Manufacture:	2012	Amateur Built:	
Airworthiness Certificate:	Transport	Serial Number:	34829
Landing Gear Type:	Retractable - Tricycle	Seats:	
Date/Type of Last Inspection:	October 8, 2014 Continuous airworthiness	Certified Max Gross Wt.:	
Time Since Last Inspection:		Engines:	
Airframe Total Time:	6582 Hrs at time of accident	Engine Manufacturer:	
ELT:	Installed, not activated	Engine Model/Series:	
Registered Owner:	UNITED AIRLINES INC	Rated Power:	
Operator:	UNITED AIRLINES INC	Operating Certificate(s) Held:	Flag carrier (121)

Meteorological Information and Flight Plan

Conditions at Accident Site:	Unknown	Condition of Light:	Day
Observation Facility, Elevation:		Distance from Accident Site:	
Observation Time:		Direction from Accident Site:	
Lowest Cloud Condition:	Few / 3000 ft AGL	Visibility	
Lowest Ceiling:		Visibility (RVR):	
Wind Speed/Gusts:	12 knots /	Turbulence Type Forecast/Actual:	/ None
Wind Direction:	220°	Turbulence Severity Forecast/Actual:	/
Altimeter Setting:		Temperature/Dew Point:	
Precipitation and Obscuration:			
Departure Point:	London (EGLL)	Type of Flight Plan Filed:	IFR
Destination:	HOUSTON, TX (IAH)	Type of Clearance:	IFR
Departure Time:	13:57 Local	Type of Airspace:	

Airport Information

Airport:	Heathrow International Airport EGLL	Runway Surface Type:	
Airport Elevation:	83 ft msl	Runway Surface Condition:	Unknown
Runway Used:		IFR Approach:	Unknown
Runway Length/Width:		VFR Approach/Landing:	Unknown

Wreckage and Impact Information

Crew Injuries:	N/A	Aircraft Damage:	Minor
Passenger Injuries:		Aircraft Fire:	None
Ground Injuries:	N/A	Aircraft Explosion:	None
Total Injuries:	N/A	Latitude, Longitude:	51.4775,-0.461388(est)

Administrative Information

Investigator In Charge (IIC): Bauer, Michael

Additional Participating Persons:

Original Publish Date: April 23, 2018

Last Revision Date:

Investigation Class: [Class](#)

Note: The NTSB did not travel to the scene of this incident.

Investigation Docket: <https://data.nts.gov/Docket?ProjectID=90240>

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The NTSB does not assign fault or blame for an accident or incident; rather, as specified by NTSB regulation, “accident/incident investigations are fact-finding proceedings with no formal issues and no adverse parties ... and are not conducted for the purpose of determining the rights or liabilities of any person” (Title 49 *Code of Federal Regulations* section 831.4). Assignment of fault or legal liability is not relevant to the NTSB’s statutory mission to improve transportation safety by investigating accidents and incidents and issuing safety recommendations. In addition, statutory language prohibits the admission into evidence or use of any part of an NTSB report related to an accident in a civil action for damages resulting from a matter mentioned in the report (Title 49 *United States Code* section 1154(b)). A factual report that may be admissible under 49 *United States Code* section 1154(b) is available [here](#).