BOEING

QTR_04
12

A QUARTERLY PUBLICATION
BROUGHT TO YOU BY
THE BOEING EDGE

Making the World's Best-Selling Airplane Even Better

**Understanding the New Widespread Fatigue Damage Rule**

Next-Generation 737 Fuel Performance Improvement

Lightning Strikes: Protection, Inspection, and Repair

# AERO

Cover photo: *737-800 Strakelet Build-up*

# AERO

## Contents



# AERO

**Publisher**
Shannon Myers

**Editorial director**
Jill Langer

**Editor-in-chief**
Jim Lombardo

**Design**
Methodologie

**Writer**
Jeff Fraga

**Distribution manager**
Nanci Moultrie

**Cover photography**
Jeff Corwin

**Printer**
ColorGraphics

**Web site design**
Methodologie



***AERO* Online**
www.boeing.com/boeingedge/aeromagazine

**The Boeing Edge**
www.boeing.com/boeingedge

BOEING EDGE

*AERO* magazine is published quarterly by Boeing Commercial Airplanes and is distributed at no cost to operators of Boeing commercial airplanes. *AERO* provides operators with supplemental technical information to promote continuous safety and efficiency in their daily fleet operations.

The Boeing Edge supports operators during the life of each Boeing commercial airplane. Support includes stationing Field Service representatives in more than 60 countries, furnishing spare parts and engineering support, training flight crews and maintenance personnel, and providing operations and maintenance publications.

Boeing continually communicates with operators through such vehicles as technical meetings, service letters, and service bulletins. This assists operators in addressing regulatory requirements and Air Transport Association specifications.





Print copies of *AERO* are not available by subscription, but the publication may be viewed on the Web at www.boeing.com/boeingedge/aeromagazine.

Please send address changes to csms.catalog@boeing.com. Please send all other communications to *AERO* Magazine, Boeing Commercial Airplanes, P.O. Box 3707, MC 21-72, Seattle, Washington, 98124-2207, USA.
E-mail: WebMaster.BCA@boeing.com

*AERO* is printed on Forest Stewardship Council™ Certified paper.

MIX
Paper from responsible sources
FSC® C102835

# Making the World's Best-Selling Airplane Even Better

At Boeing, we're committed to continuous innovation. That means persistently looking for ways to improve the airplanes that make up your fleet. Our Next-Generation 737 Performance Improvement Package (PIP) is an excellent example of this commitment. The PIP combines aerodynamic and engine performance improvements to reduce fuel burn by up to 2 percent. It follows the 777 PIP, which was offered in 2009 for 777-200, 777-200ER, and 777-300 airplanes.

Elements of the Next-Generation 737 PIP — provided at no charge to customers — have been gradually introduced on airplanes in production during the past 18 months. The final component of the package, a redesigned environmental control system exhaust vent, is scheduled for mid-2013.

You can read more about the Next-Generation 737 PIP beginning on page 13 of this issue of *AERO*.

Since its introduction in 2011, the Next-Generation 737 PIP has proved its value in hundreds of commercial flights on nearly 500 Next-Generation 737s. "The Performance Improvement Package has contributed to a remarkable fuel mileage improvement compared to the non-PIP airplanes," said Takeshi Katsurada, vice president of flight operations engineering for Japan Airlines. "We can validate its improvement through each delivery flight performance monitoring and also daily flight operations monitoring to the extent of more than 2 percent fuel mileage improvement."

We realize that fuel savings of up to even 2 percent can have a big impact on airlines' bottom line. We're committed to their success. That's why we're always looking for ways to make Boeing airplanes even better.

**BEVERLY WYSE**
Vice President and General Manager
Next-Generation 737 Program
Boeing Commercial Airplanes

Operators will need to comply with the limit of validity specified in the airworthiness limitations as early as July 2013.

# Understanding the New Widespread Fatigue Damage Rule

The development of widespread fatigue damage (WFD) in airplane structure is a concern for older airplanes. The U.S. Federal Aviation Administration (FAA) has published a rule that will limit the commercial usage of older airplanes, requiring service actions to preclude the onset of WFD and retirement.

**By Amos W. Hoggard,** Technical Fellow (Retired), Aging Airplane Safety Rule/Widespread Fatigue Damage Program, and
**Stephen R. Johnson,** Aging Airplane Safety Rule/Widespread Fatigue Damage Program Manager, Chief Structures Engineer

On Jan. 14, 2011, a new FAA rule (14 Code of Federal Regulations [CFR] 26 Subpart C) became effective requiring airplane manufacturers to make available service actions necessary to preclude the onset of WFD and to establish operational limits, known as limits of validity (LOV), of the maintenance program that effectively define an airplane's usable life. It is important that operators become familiar with the rule so they can prepare for changes to airworthiness limitations that will limit how long an airplane may be operated in terms of flight cycles or flight hours.

This article describes Boeing's approach to complying with the new rule and its impact on operators of Boeing airplanes throughout the world. It addresses the imminent future changes to airworthiness limitations, how those changes were developed, and how Boeing will assist operators with rule compliance.

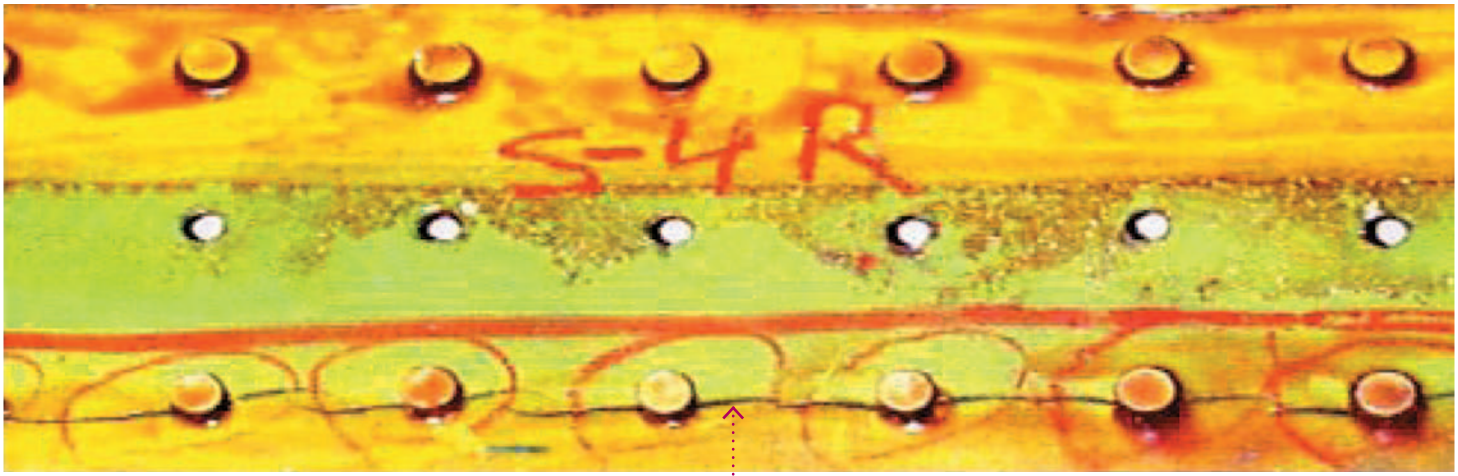
## ABOUT WFD

WFD in an airplane's structure is defined as the simultaneous presence of cracks at multiple locations that are of sufficient size and density that the structure will no longer meet required damage tolerance and will not maintain required residual strength after partial structural failure (see fig. 1). The risk of WFD onset increases as airplanes are operated well past their original design objectives in flight cycles or flight hours.

Because of the increased difficulty of identifying all of the necessary service actions and the inability of non-destructive inspections to reliably detect small cracks associated with the development of a WFD condition, airplane manufacturers, operators, and regulatory authorities have worked together to address WFD in aging airplanes. The result was the creation of the LOV concept that effectively establishes the life limit on an airplane based on when the existing fatigue test evidence is no longer sufficient to reliably predict structural behavior (see "Sources of fatigue test evidence" on page 6).

**Figure 1: Widespread fatigue damage (WFD)**

The cracks on this lap splice are an example of WFD.




Fatigue cracks

## Sources of fatigue test evidence

The establishment of the LOV is based on the fatigue test evidence held by the manufacturer. Sources of this information include:

1. Full-scale fatigue test.
2. Full-scale component tests.
3. Teardown and refurbishment of a high-time airplane.
4. Less than full-scale component tests.
5. Statistical fleet-proven life techniques.
6. Evaluation of in-service problems/test data experienced by this model or other airplanes with similar design concepts.
7. Analysis methods that have been parametrically developed to reflect fatigue test and service experience.

### DEFINING LOV

The LOV represents an operational limit based on fatigue test evidence that supports the maintenance program. The FAA defines the LOV as "the period of time (in flight cycles, flight hours, or both) up to which it has been demonstrated by test evidence, analysis and, if available, service experience and teardown inspections, that widespread fatigue damage will not occur in the airplane structure." It is further defined as the point in the structural life of an airplane at which there is significantly increased risk of uncertainties in structural performance and probable development of WFD.

Once the airworthiness limitations containing the LOV are approved by the FAA, an airplane may not operate beyond the LOV.

### ACTIONS REQUIRED OF AIRPLANE MANUFACTURERS AND OPERATORS

The FAA's WFD rule specifies actions that are required of airplane manufacturers and operators.

Manufacturers must:

- Develop and make available an LOV as an airworthiness limitation according to a model-specific schedule contained in the rule.
- Provide any service bulletins required to preclude the development of WFD up to the LOV and publish those service bulletins in accordance with an FAA-approved binding schedule.

Operators must:

- Incorporate mandatory service actions into their maintenance programs.
- Adopt the LOV values provided by the manufacturer or, should the manufacturer not provide a LOV, adopt the FAA default LOV values by a date specified in the rule.
- Have a plan to stop operation of airplanes under Parts 121 and 129 when the airplanes reach the LOV.

The FAA rule requires the manufacturer and the operator to comply by certain dates depending on the requirement in effect concerning damage tolerance (14 CFR 25.571) when the airplane was originally certified (see fig. 2).

**Figure 2: Boeing compliance schedule**

Boeing will provide amended airworthiness limitations containing limits of validity (LOV) to the FAA for each airplane model by the dates shown on this compliance schedule.

**Group 1 Airplanes** The first group of airplanes affected are those certified prior to 14 CFR 25 Amendment 45.

18 Months | 12 Months

**Jan. 14, 2011**

Rule Effective

**July 14, 2012, LOV and Binding Service Bulletin Schedule**

727, 737-100/-200/-300/-400/-500, 747-100/-200/-300, DC-8, DC-9, MD-80, DC-10

**July 14, 2013**

Operators incorporate airworthiness limitations containing LOV into their maintenance programs.

**Group 2 Airplanes** The second group of airplanes affected are those certified between 14 CFR 25 Amendment 45 and 95.

48 Months | 12 Months

**Jan. 14, 2011**

Rule Effective

**Jan. 14, 2015, LOV and Binding Service Bulletin Schedule**

Next-Generation 737, 747-400/-400 Domestic/-400 Freighter/-400 Boeing Converted Freighter/-400 Large Cargo Freighter, 757, 767, 777-200/-300, MD-10, MD-11, MD-90, 717

**Jan. 14, 2016**

Operators incorporate airworthiness limitations containing LOV into their maintenance programs.

**Group 3 Airplanes** The third group includes all airplanes certified to 14 CFR 25 Amendment 96 or greater.

60 Months | 12 Months

**Jan. 14, 2011**

Rule Effective

**Jan. 14, 2016, LOV and Binding Service Bulletin Schedule**

777-200 Long Range/-300 Extended Range/Freighter, 747-8, 787

**Jan. 14, 2017**

Operators incorporate airworthiness limitations containing LOV into their maintenance programs.

Manufacturer Action

Operator Action

# Identifying WFD-susceptible structure

The FAA with operators and manufacturers documented 16 examples of airplane structure susceptible to multiple-site damage (MSD) and/or multiple-element damage (MED).

- Longitudinal Skin Joints, Frames, and Tear Straps (MSD/MED)
- Circumferential Joints and Stringers (MSD/MED)
- Lap Joints with Milled, Chem-milled, or Bonded Radius (MSD)
- Fuselage Frames (MED)
- Stringer to Frame Attachments (MED)
- Shear Clip End Fasteners on Shear Tied Fuselage Frames (MSD/MED)
- Aft Pressure Dome Outer Ring and Dome Web Splices (MSD/MED)
- Skin Splice at Aft Pressure Bulkhead (MSD) (see fig. 3)
- Abrupt Changes in Web or Skin Thickness — Pressurized or Unpressurized Structure (MSD/MED)
- Window Surround Structure (MSD/MED)
- Over-Wing Fuselage Attachments (MED)
- Latches and Hinges of Non-plug Doors (MSD/MED)
- Skin at Runout of Large Doubler (MSD) — Fuselage, Wing, or Empennage
- Wing or Empennage Chordwise Splices (MSD/MED)
- Rib-to-Skin Attachments (MSD/MED)
- Typical Wing and Empennage Construction (MSD/MED)

*This list is not meant to be inclusive of all structure that might be susceptible on any given airplane model, and it should only be used for general guidance. It should not be used to exclude any particular structure.*

## SERVICE BULLETIN ACTIONS TO PRECLUDE THE ONSET OF WFD UP TO THE LOV

As part of rule compliance, Boeing is required to identify WFD-susceptible areas for both the as-delivered structure and any structure that required modification by an airworthiness directive (AD). Boeing also must predict which of the identified WFD-susceptible areas will develop WFD prior to when the LOV is reached and provide service bulletin actions to prevent that development (see fig. 3). These service actions would be in the form of service bulletins that would require inspection, modification, or both. The FAA will issue an AD to make these service bulletins mandatory.

To assist the industry in defining areas that might be susceptible to WFD, the FAA, with the assistance of operators and airplane manufacturers, identified 16 generic structural areas susceptible to developing WFD (see "Identifying WFD-susceptible structure" on this page). All of these areas are explained in the FAA Advisory Circular 120-104. This list is not meant to be inclusive of all structure that might be susceptible on any given airplane model, and it should only be used for general guidance.

## COST-BENEFIT OF SPECIFIC SERVICE ACTIONS

While the establishment of the LOV will mandate the retirement of very old airplanes, the service bulletin actions to prevent WFD may present even more significant costs to the airline. Service bulletin actions include inspection, modification, or both and must be accomplished prior to utilization thresholds specified in the associated AD.

Similar to the requirements of LOV, operators may not operate airplanes that are past AD thresholds without complying with the AD-mandated inspection and modification requirements. The service bulletin actions for Boeing airplanes were developed with the assistance of the Structures Task Group (STG), which consists of Boeing, operators, and the FAA. The STG was asked to evaluate each proposed service bulletin action and ensure it was of value to the industry.

Using this information, Boeing has committed to make service bulletin actions available to the industry to enable operation up to the LOV (see fig. 4). Specific information about each of these bulletins may be found in the Aging Airplane Program Web site on the MyBoeingFleet.com products page under Structures Task Group.

A similar approach will be used to develop the compliance data for Group 2 and Group 3 airplanes.

## ADDRESSING WFD AS AN OPERATOR

Boeing will provide the FAA with updated airworthiness limitations containing the LOV for each airplane model in accordance with the compliance dates in figure 2. Following approval of the airworthiness limitations by the FAA, Boeing will make them available to operators on MyBoeingFleet.com. Operators will need to acquire the documents (per 14 CFR 91.403) and update their maintenance programs and have those programs approved by their FAA principal maintenance inspector by the dates specified in 14 CFR 121.1115 or 129.115 (see fig. 2).

**Figure 3: Example of structure susceptible to WFD**

This skin splice at an aft pressure bulkhead is one area of airplane structure determined by the FAA to be susceptible to WFD.

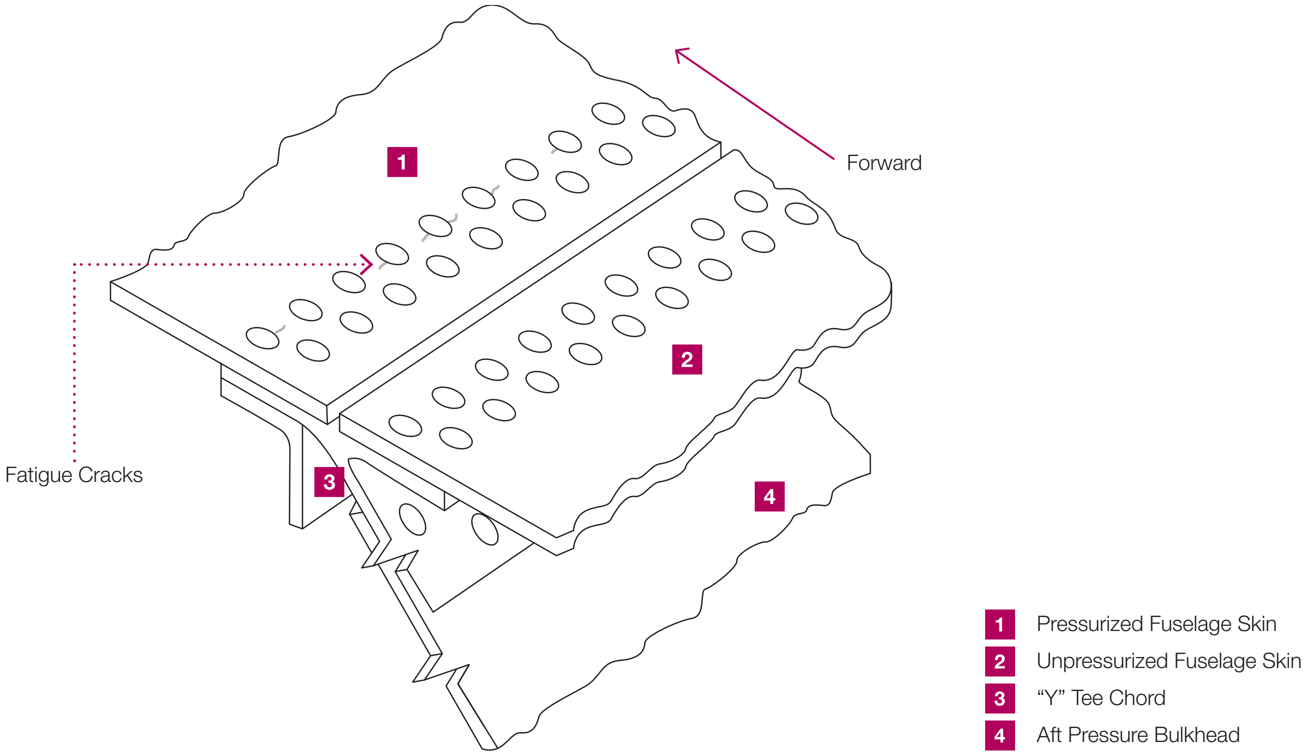



**Figure 4: Group 1 service bulletins required to preclude WFD**

This table details the number of service bulletin actions for Group 1 airplanes (certified prior to 14 CFR 25 Amendment 45) that operators will be required to adopt in order to achieve the LOV.

| Model | Number of Inspection Bulletins | Number of Modification Bulletins | Number of Inspection and Modification Bulletins |
|---|---|---|---|
| 727 | 2 | 0 | 0 |
| 737 | 5 | 3 | 2 |
| 747 | 5 | 3 | 7 |
| DC-8 | 1 | 2 | 0 |
| DC-9 | 2 | 1 | 0 |
| DC-10 | 1 | 0 | 1 |
| MD-80 | 1 | 0 | 0` |

**Figure 5: LOV for Group 1 Boeing airplane models**

| Model | Minor Model | LOV | | Airworthiness Limitation/ Certification Maintenance Requirement (AWL/CMR) Document |
|---|---|---|---|---|
| | | Cycles | Flight Hours | |
| 727 | -100 Line No. 1–47 | 50,000 | 50,000 | D6-8766-AWL |
| 727 | -100/-200 Line No. 48 + | 85,000 | 95,000 | D6-8766-AWL |
| 737 | -100/-200/-200 Cargo Line No. 1–291 | 34,000 | 34,000 | D6-38278-CMR |
| 737 | -200/-200 Cargo/-300/-400/-500 Line No. 292–2565 | 75,000 | 100,000 | D6-38278-CMR |
| 737 | -300/-400/-500 Line No. 2566–3132 | 85,000 | 100,000 | D6-38278-CMR |
| 747 | -100, -200, -300, Special Performance | 35,000 | 135,000 | D6-13747-CMR |
| 747 | Short Range | 35,000 | 135,000 | D6-13747-CMR |
| 747 | -400 (Passenger and Freighter) | 35,000 | 165,000 | D621U400-9 |
| 747 | -400 Domestic | 35,000 | 165,000 | D621U400-9 |
| DC-8 | All | 56,000 | 125,000 | MDC 12K9006 |
| DC-9 | All | 110,000 | 110,000 | MDC 12K9007 |
| MD-80 | All | 110,000 | 150,000 | MDC 12K9008 |
| DC-10 | All | 60,000 | 160,000 | MDC 12K1003 |

**Figure 6: Anticipated LOV for Group 2 and Group 3 Boeing airplane models**

These anticipated values are based on preliminary engineering calculations and are subject to final revision before final submission to the FAA. These LOV values are substantially beyond the original design service objectives embodied in the design of the airplanes. These are anticipated values only and are subject to revision. This information was part of Boeing multi-operator message 10-0783-01B, dated Dec. 19, 2010.

| Model | Minor Model | Anticipated LOV | |
|---|---|---|---|
| | | Cycles | Flight Hours |
| Next-Generation 737 | -600/-700/-700 Cargo/-800/-900/ -900 Extended Range | 100,000 | 125,000 |
| 757 | All | 75,000 | 150,000 |
| 767 | -200/-300 | 75,000 | 150,000 |
| 767 | -300 Freighter/-400 Extended Range | 60,000 | 150,000 |
| 777 | -200/-200 Long Range/-300/ -300 Extended Range | 60,000 | 160,000 |
| 777 | Freighter | 37,500 | 160,000 |
| 747 | 747-8 Intercontinental/747-8 Freighter | 35,000 | 165,000 |
| 787 | All | 66,000 | 200,000 |
| MD-10 | All | 60,000 | 160,000 |
| MD-11 | All | 40,000 | 150,000 |
| MD-90 | All | 110,000 | 150,000 |
| 717 | All | 110,000 | 110,000 |

Boeing strongly recommends that airplanes above their LOV be immediately and permanently removed from service. However, Boeing will continue existing support policies for these airplanes up to the date when operators are required to comply with the operational rule.

For example, Boeing provided the compliance documents to the FAA on July 13, 2012, for the 727, 737-100/-200/-300/-400/-500, 747-100/-200/-300, DC-8, DC-9, DC-10, and MD-80. Subsequently, the FAA approved LOV values for Boeing's Group 1 airplanes (see fig. 5). Updates to the airworthiness limitations are now available on MyBoeingFleet.com. Operators of Group 1 airplane models have until July 14, 2013, to integrate the LOV into their maintenance programs and develop a plan to stop operation of these airplanes when they reach the LOV. Boeing has also developed anticipated LOVs for the Group 2 and Group 3 airplanes (see fig. 6).

In the near future, Boeing will begin publishing the service bulletin actions required to preclude WFD for Group 1 airplanes. These Boeing service bulletins will be identified by a statement in the background section of the bulletin. The FAA will mandate each of these bulletins in due course. If an airplane is above a specific threshold in the bulletin, Boeing recommends performing the service bulletin actions as instructed.

## BOEING SUPPORT OF AIRPLANES BEYOND LOV

Boeing estimates that approximately 25 Group 1 airplanes will exceed their FAA-approved LOV by the initial operational compliance date of July 14, 2013. Because the existence of WFD in the structure cannot be reliably detected by maintenance inspections beyond the LOV, Boeing strongly recommends that airplanes above their LOV be immediately and permanently removed from service. However, Boeing will continue existing support policies for these airplanes up to the date when operators are required to comply with the operational rule.

With the exception of certain military derivatives, including commercially certified airplanes in military service, Boeing will not provide support to airplanes beyond LOV after the date when operational compliance is required. This includes operations within the United States under any operational rules (not limited to Federal Aviation Regulations Parts 121 and 129), as well as airplanes operated outside of FAA jurisdiction. This also includes the 707/720 model, which has an FAA-defined LOV.

This policy will go into effect as of the respective operational rule compliance dates specified in 14 CFR 121.1115 or 129.115.

## RESOURCES FOR OPERATORS

Boeing has several means to keep operators informed of the latest information concerning WFD rule compliance. When significant information becomes available, Boeing will publish a multi-operator message or a service letter. Boeing also has recently introduced an Aging Airplane Program Web site on the MyBoeingFleet.com products page. This Web site is updated on a regular basis and contains links to the current versions of all service letters and multi-operator messages, as well as FAA rules and advisory circulars. It also provides directions for obtaining documents required for operator compliance.

Information concerning upcoming STG meetings and Boeing seminars on topics of general interest is also available on the Web site.

## SUMMARY

Concern about WFD increases as airplanes operate beyond their original design objectives. Manufacturers, operators, and the FAA have worked together to address WFD by defining service bulletin actions necessary to preclude the onset of WFD up to the LOV specified in the airworthiness limitations. Operators will need to comply with the LOV specified in the airworthiness limitations as early as July 2013 and to comply with future ADs.

For more information, please contact agingairplaneprograms@boeing.com.


The Next-Generation 737 PIP lowers operational costs while improving the environmental signature of the airplanes that use it.

# Next-Generation 737 Fuel Performance Improvement

The Next-Generation 737 Performance Improvement Package (PIP) combines aerodynamic and engine performance improvements to reduce fuel burn by up to 2 percent.

**By Dennis Tesch,** 737 Systems Senior Manager, Performance Improvement Package Program Manager

Boeing has developed a number of performance enhancements to the Next-Generation 737 that reduce fuel consumption and emissions. Elements of the PIP have been introduced gradually on the 737 since early 2011. Boeing has delivered more than 490 Next-Generation 737s with a PIP.

This article reviews the elements of the Next-Generation 737 PIP and the aerodynamic and propulsion efficiency improvements that have resulted in reduced fuel burn and emissions. It also discusses the expected benefits to the operator.

## COMPONENTS OF THE NEXT-GENERATION 737 PIP

The Next-Generation 737 PIP comprises both drag reduction and propulsion efficiency components.

Drag reduction components are aerodynamic-shaped anti-collision (AC) lights, refined wing control surfaces, spoiler trailing edge gap reduction, ski-jump wheel-well fairings, and environmental control system (ECS) inlet/exhaust modulation.

Greater propulsion efficiency results from enhancements to the CFM International (CFM) engine and improvements to the exhaust system.

## DRAG REDUCTION IMPROVEMENTS

Aerodynamic AC lights. Replacing the upper and lower red AC light assemblies with a more aerodynamically designed shape reduces airplane drag (see fig. 1). The upper skin was revised, and no electrical interface changes were required to accommodate the new AC lights.

**Figure 1: Aerodynamic-shaped anti-collision (AC) lights**

New AC lights (right) are more aerodynamic than the previous lights (left).

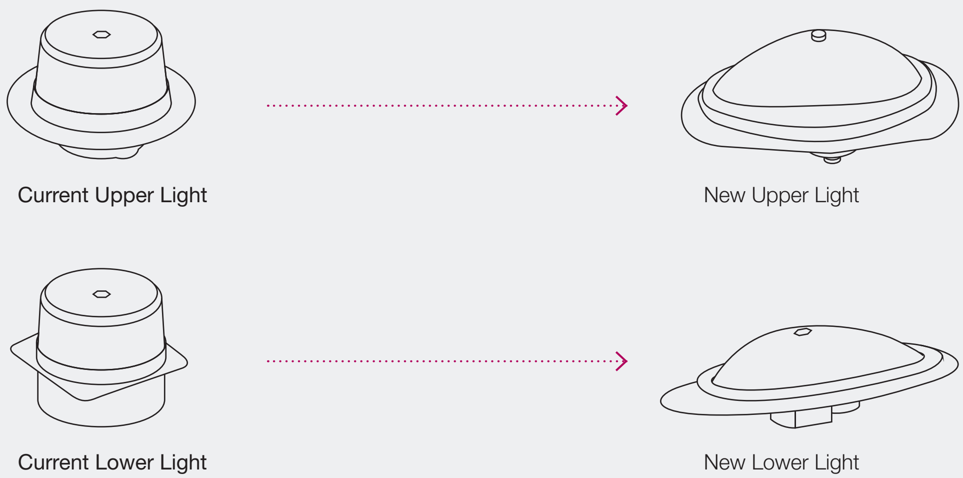
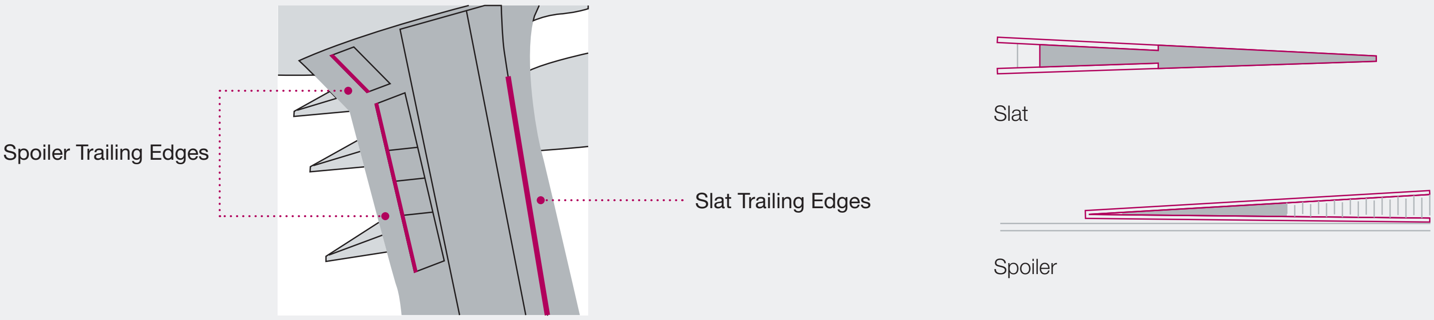



**Figure 2: Streamlined slat and spoiler trailing edges**

Trailing edges on the spoiler (left) and slat (right) are 60 percent thinner to reduce drag.




Refined wing control surfaces. Reducing the thickness of the spoiler trailing edge reduces drag caused by the aft-facing step on the trailing edge of the spoilers. The trailing edge's extruded aluminum filler has been replaced with a machine-tapered filler. A reduction in the slat trailing edge's thickness further reduces drag by reducing the thickness of the trailing edge wedge (see fig. 2).

Spoiler trailing edge gap reduction. This change reduces drag by reducing the gap between spoilers 2, 3, 4, 9, 10, and 11 and their respective flaps (see fig. 3). Analysis and flight tests have shown these new gaps meet stability and control requirements.

Wheel-well fairings. The five aft wheel-well fairing assemblies have been recontoured to smooth the airflow near the main landing gear, reducing airplane drag (see fig. 4).

New ECS exhaust vent. The PIP also reduces drag by modifying the existing ram air inlet systems and adds new modulated ram air exhaust systems associated with the left and right air-conditioning packs (see fig. 5). The previous ram air inlet actuators have been replaced by new "smart actuators" that allow position feedback and communicate with the added ram air exit actuators. The new smart actuator is mounted at a slightly different orientation at the inlet than the current actuator, and the ram air exit has been changed from a plain duct opening to a duct with a series of three exit louvers. The exit louvers are actuated by a combination of shafts and linkages that are driven by the added exit actuators. To accommodate installation, structural changes have been made forward of the wheel wells on both sides of the airplane.

The system — inlet and exit — is tuned to open and close together at a very specific relationship to optimize thrust recovery of the air exiting the exhaust louvers, reducing fuel burn of the airplane.

**Figure 3: Spoiler trailing edge gap reduction**

Adjusting the smaller gaps results in reduced drag.

| Spoiler Panels | Previous Gap | New Gap |
|---|---|---|
| 1, 12 | 0.07 in (0.18 cm) | 0.08 in (0.20 cm) |
| 2, 11 | 0.32 in (0.81 cm) | 0.10 in (0.25 cm) |
| 3, 10 | 0.27 in (0.69 cm) | 0.065 in (0.165 cm) |
| 4, 9 | 0.27 in (0.69 cm) | 0.065 in (0.165 cm) |
| 5, 8 | 0.06 in (0.15 cm) | 0.065 in (0.165 cm) |
| 6, 7 | 0.05 in (0.13 cm) | 0.08 in (0.20 cm) |

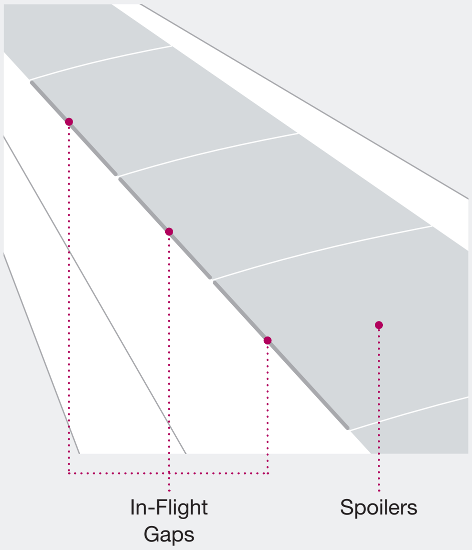



**Figure 4: Ski-jump wheel-well fairings**

The PIP includes five new contoured panels on the aft side of the wheel wells.

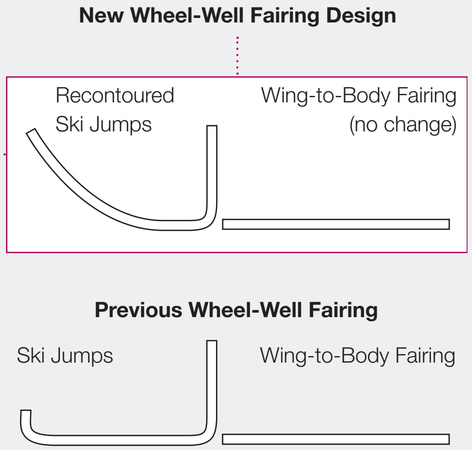
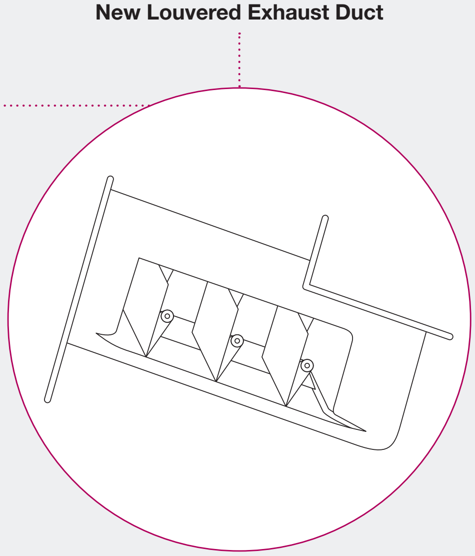
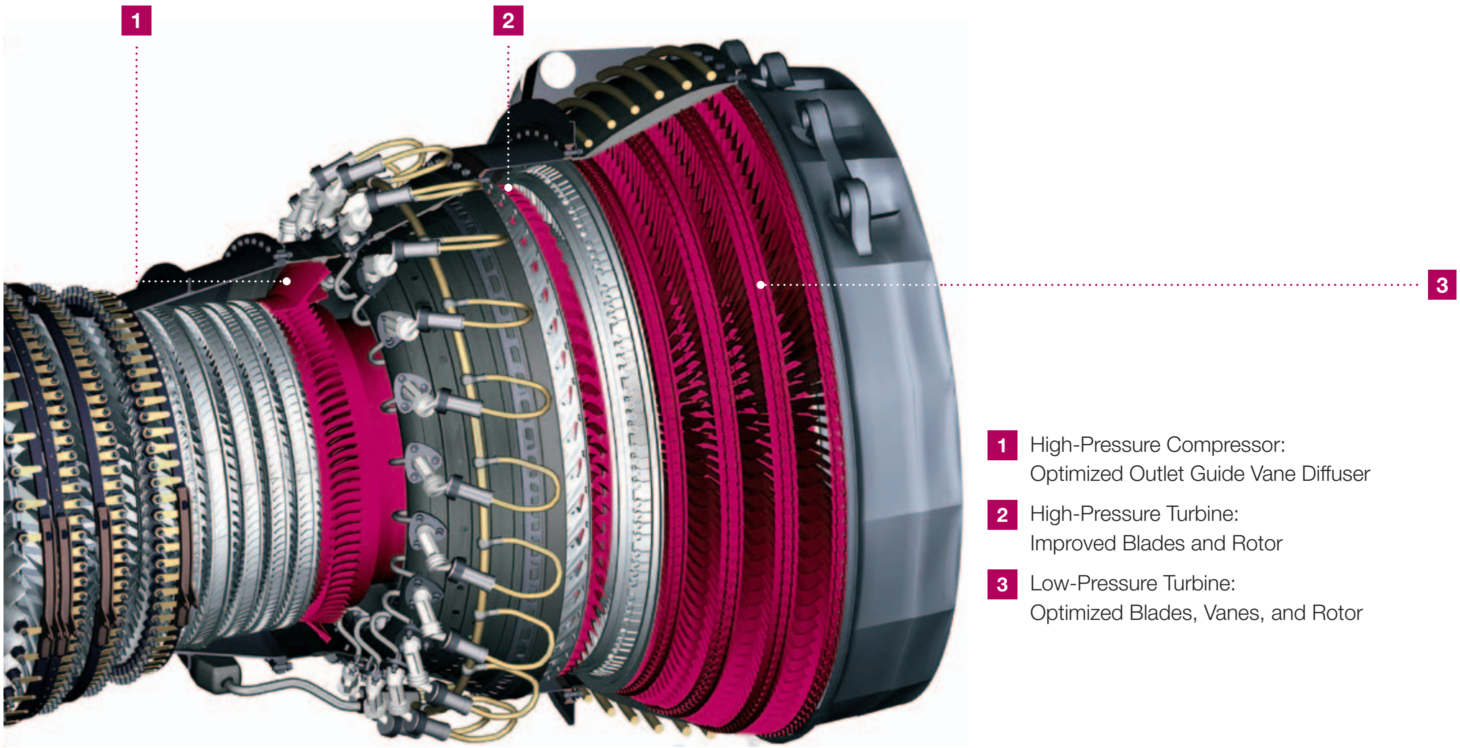



**Figure 5: Newly configured exhaust vents designed to reduce drag**



## Figure 6: CFM engine changes

Changes to the CFM engines improve propulsion and reduce fuel consumption.




**1** High-Pressure Compressor: Optimized Outlet Guide Vane Diffuser

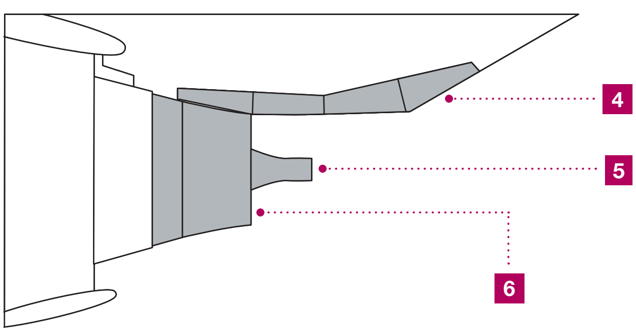
**2** High-Pressure Turbine: Improved Blades and Rotor

**3** Low-Pressure Turbine: Optimized Blades, Vanes, and Rotor

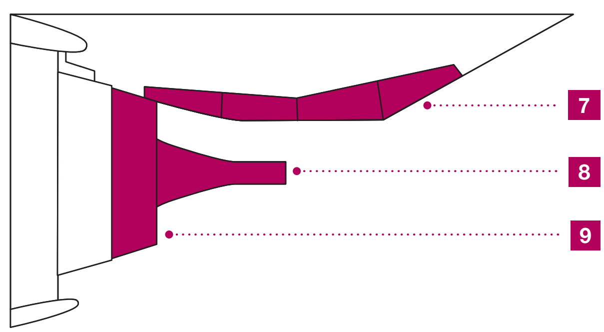
## Figure 7: Engine exhaust system reconfigured to improve performance

The new engine exhaust configuration reduces aft fairing thermal distress.

### Previous Engine Configuration




### New Engine Configuration




**4** Heat Shield

**5** Plug

**6** Long Nozzle

**7** New Heat Shield with Plume Suppressor, Insulation Blankets, Scoops, and Strut Cover Plate

**8** New 2.5-in (6.4-cm) Shorter Plug, Recontoured

**9** New 18-in (46-cm) Shorter Nozzle, Recontoured

# Possible post-delivery modifications

| Improvement | Post-Delivery Modification | Modification Process |
|---|---|---|
| Slats | Yes | Replacement parts fully interchangeable with existing slats. |
| Spoilers | Yes | Replacement parts fully interchangeable with existing spoilers; rigging change required for spoiler trailing edge gap reduction. |
| Wheel-well fairings | Yes | Replacement parts fully interchangeable with noncontoured fairings. |
| Anti-collision lights | Yes | New lower light shares common attach point, fastener pattern, and electrical interface with existing lights and are interchangeable. Upper light is not interchangeable because a crown skin change is needed. |
| ECS exhaust vent | No | No modification available. |
| CFM56-7BE engines | Yes | Interchangeable with previous engines. |
| Engine exhaust system | Yes | Nozzle and plug are interchangeable parts, but only specific combinations are allowed, and both require the new strut heat shield. |

## PROPULSION EFFICIENCY IMPROVEMENTS

The propulsion system improvements include changes to both the engine (see fig. 6) and exhaust system. The engine changes include:

- The diffuser contours of the high-pressure compressor (HPC) outlet guide vane (OGV) are optimized to improve the diffuser-area ratio and reduce pressure losses. The OGV replaces the two-dimensional airfoil with a three-dimensional design.
- A new high-pressure turbine (HPT) incorporates modified blades for aerodynamic improvements that increase efficiency and durability. The HPT rotors have been modified to accept a reduced blade count, from 80 to 76.
- A new low-pressure turbine (LPT) incorporates new optimized blades, vanes, and rotors. The number of blades and vanes has been reduced by approximately 9 percent overall. New disks and retainers match the blade count, and new case and shrouds match the new axial staggering.

The new CFM56-7BE (PIP) engines are interchangeable and intermixable with previous CFM56-7B and CFM56-7B3 Next-Generation 737 GE engines.

Changes to the exhaust system (see fig. 7) include:

- A new primary nozzle is approximately 18 inches (46 centimeters) shorter than the previous engine and has recontoured lines for improved nozzle coefficients and losses. An acoustically treated honeycomb lining incorporated into the primary nozzle's inner wall ensures no increase to community noise occurs as a result of this efficiency improvement.
- A new strut aft fairing heat-shield assembly has been incorporated with heat shield blankets and an inboard plume suppressor. These components will reduce aft fairing thermal distress and are required to accommodate the short nozzle configuration.
- The primary plug has been recontoured for improved plug coefficients and losses. An oil drain pan and tube are installed to reduce oil pooling within the plug.

## BENEFITS TO OPERATORS

For a Next-Generation 737 operation carrying the same payload and flying the same route as a non-PIP airplane, the PIP-equipped version will fly with reduced fuel consumption and carbon dioxide and nitrous oxide emissions.

The engine improvements result in:

- Improved fuel burn.
- Engine maintenance costs reduced up to 4 percent for the highest thrust rating — the higher the thrust rating, the higher the maintenance cost improvement. PIP engines are operationally transparent to the flight crew; there are no changes to normal flight crew procedures or airplane flight manual performance relative to previous engines.

More than a year after the first Next-Generation 737 PIP airplane was delivered, operators have validated the benefits of the package, reporting fuel burn reductions of up to 2 percent. Improving fuel efficiency by this amount can save more than US$120,000 annually in fuel cost per airplane and reduce the carbon footprint.

## SUMMARY

The Next-Generation 737 PIP demonstrates Boeing's commitment to improving existing in-service airplanes. The package lowers operational costs while improving the environmental signature of the airplanes that use it.

While Boeing airplanes incorporate extensive lightning-strike protection, strikes can cause costly delays and service interruptions.

# Lightning Strikes: Protection, Inspection, and Repair

Lightning strikes can affect airline operations and cause costly delays and service interruptions. Strikes to airplanes are relatively common but rarely result in a significant impact to the continued safe operation of the airplane. Lightning protection is used on Boeing airplanes to avoid delays and interruptions as well as reduce the significance of the strike. To increase the effectiveness of repairs to damage caused by lightning, maintenance personnel must be familiar with lightning protection measures, proper inspection, and repair procedures.

**By Greg Sweers,** Ph.D., Associate Technical Fellow, Lightning/High Intensity Radiated Field Protection;
**Bruce Birch,** Lead Engineer, Structures; and
**John Gokcen,** Senior Structures Engineering Instructor

When commercial airplanes are struck by lightning, the result can range from no damage to serious damage that requires extensive repairs that can take the airplane out of service for an extended period of time. Having an understanding of the typical effects of lightning strikes and proper damage inspection procedures can prepare operators to act quickly when a lightning strike is reported to apply the most effective maintenance actions.

This article helps maintenance and flight crews understand lightning-strike phenomena and helps operators understand lightning-strike damage inspection requirements and associated effective repairs that improve lightning-strike maintenance efficiency.

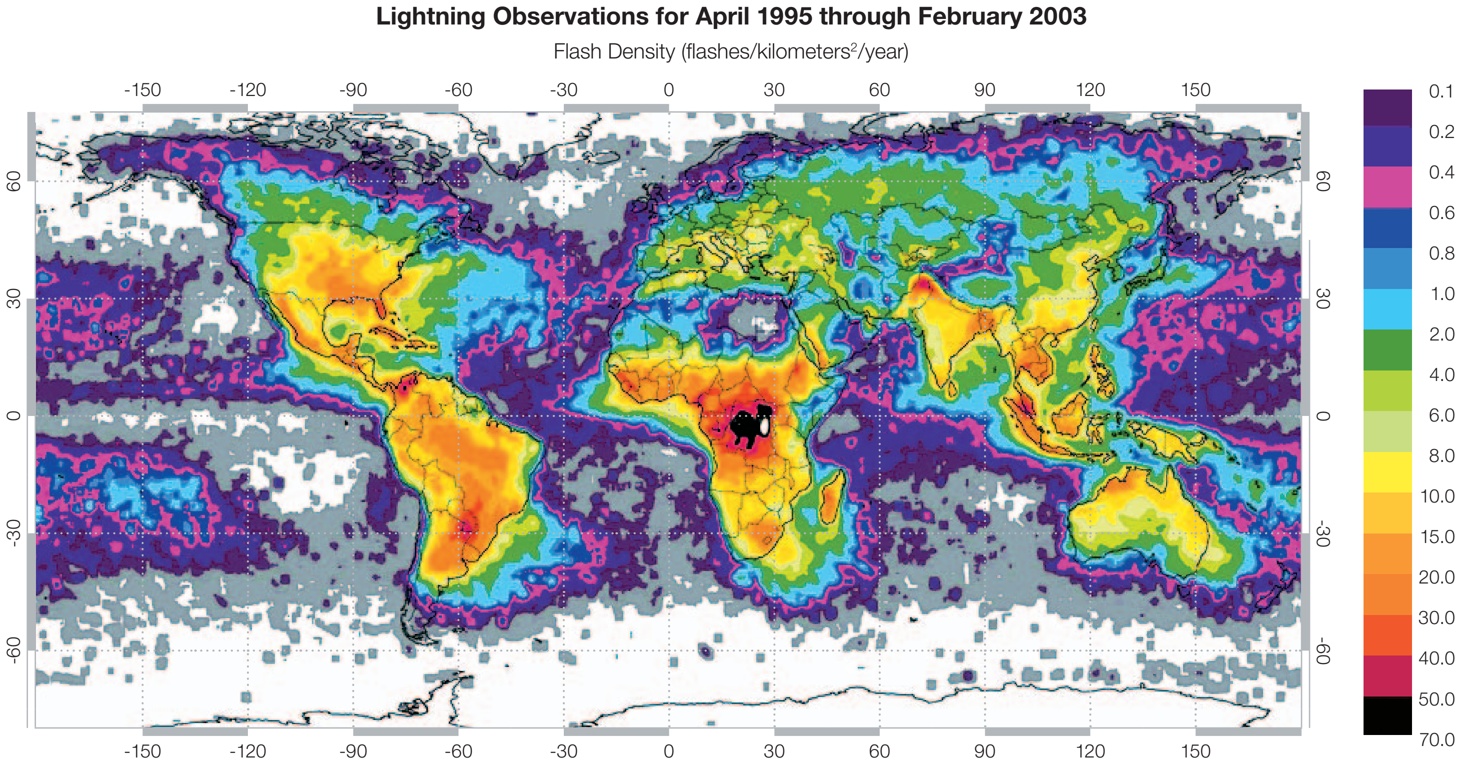
## LIGHTNING OVERVIEW

The frequency of lightning strikes that an airplane experiences is affected by several factors, including the geographic area where the airplane operates and how often the airplane passes through takeoff and landing altitudes, which is where lightning activity is most prevalent.

Lightning activity can vary greatly by geographic location. For example, in the United States, parts of Florida average 100 thunderstorm days per year, while most of the West Coast averages only 10 thunderstorm days per year. In the rest of the world, lightning tends to occur most near the equator because the warmth in this region contributes to convection, creating widespread thunderstorms nearly

**Figure 1: Worldwide lightning activity**

This map shows the global distribution of lightning April 1995–February 2003 from the combined observations of the National Aeronautics and Space Administration (NASA) optical transient detector (April 1995–March 2000) and land information systems (January 1998–February 2003) instruments. *Image courtesy of NASA.*




daily. The world lightning map by NASA shows the geographic distribution of lightning (see fig. 1). Areas of highest activity are shown in orange, red, brown, and black. Areas of low activity are white, gray, purple, and blue. Lightning activity is lowest over the oceans and polar areas. It is highest over warm continental areas. The numbered scale represents lightning flashes per square kilometer per year.

More jet airplane lightning strikes occur while in clouds, during the climb and descent phases of flight, than any other flight phase (see fig. 2). The reason is that lightning activity is more prevalent between 5,000 to 15,000 feet (1,524 to 4,572 meters) altitude (see fig. 3). Airplanes that fly short routes in areas with high incidence of lightning activity are likely to be struck more often than long-haul airplanes operating in more benign lightning environments.

A single bolt of lightning can contain as much as 1 million volts or 30,000 amps. The amount and type of damage an airplane experiences when struck by lightning can vary greatly, depending on factors such as the energy level of the strike, the attachment and exit locations, and the duration of the strike.

Because of these variations among lightning-strike events, it can be expected that the more often an airplane gets hit by severe lightning, the more likely it is that some of those events will result in damage levels that may require repair.

## LIGHTNING INTERACTION WITH AIRPLANES

Lightning initially attaches to an airplane extremity at one spot and exits from another (see fig. 4). Typically, first attachment is to the radome, forward fuselage, nacelle, empennage, or wing tip.

During the initial stages of a lightning strike on an airplane, a glow may be seen on the nose or wing tips caused by ionization of the air surrounding the leading edges or sharp points on the airplane's structure. This ionization is caused by an increase in the electromagnetic field density at those locations.

In the next stage of the strike, a stepped leader may extend off the airplane from an ionized area seeking the large amount of lightning energy in a nearby cloud. Stepped leaders (also referred to as "leaders") refer to the path of ionized air containing a charge emanating from a charged airplane or cloud. With the airplane flying through the charged atmosphere, leaders propagate from the airplane extremities where ionized areas have formed. Once the leader

**Figure 2: Airplane lightning strikes by cloud orientation**

Most airplane lightning strikes occur when an airplane is flying in clouds.

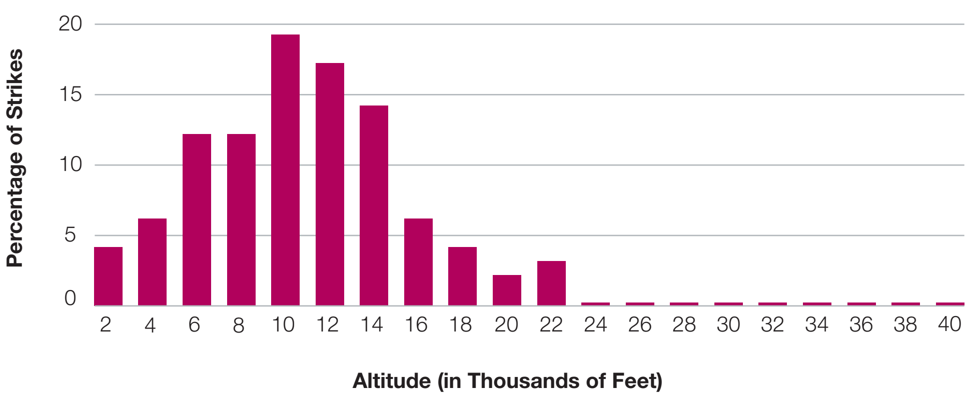
| Cloud Orientation | Percent of Total Reported* |
|---|---|
| Above | <1% |
| Within | 96% |
| Below | 3% |
| Between | <1% |
| Beside | <1% |

**Sixty-two strikes did not report orientation of clouds during strike event.*

*Source: Figure 2 is adapted from* Airlines Lightning Strike Reports Project: Pilot Reports and Lightning Effects *by J. Anderson Plummer, Lightning Technologies Inc., Aug. 2001. Data was gathered from airlines with 881 strikes reported.*

**Figure 3: Distribution of lightning strikes by altitude**

A survey of U.S. commercial jets showed that most lightning strikes occur between altitudes of 5,000 feet (1,524 meters) and 15,000 feet (4,572 meters).




*Source: The data in figures 3 and 4 was adapted from data in* Lightning Protection of Aircraft *by Franklin A. Fisher, J. Anderson Plummer, and Rodney A. Perala, 2nd ed., Lightning Technologies Inc., 2004.*

# Lightning-strike conditions

The highest probability for lightning attachment to an airplane is the outer extremities, such as the wing tip, nose, or rudder. Lightning strikes occur most often during the climb and descent phases of flight at an altitude of 5,000 to 15,000 feet (1,524 to 4,572 meters). The probability of a lightning strike decreases significantly above 20,000 feet (6,096 meters).

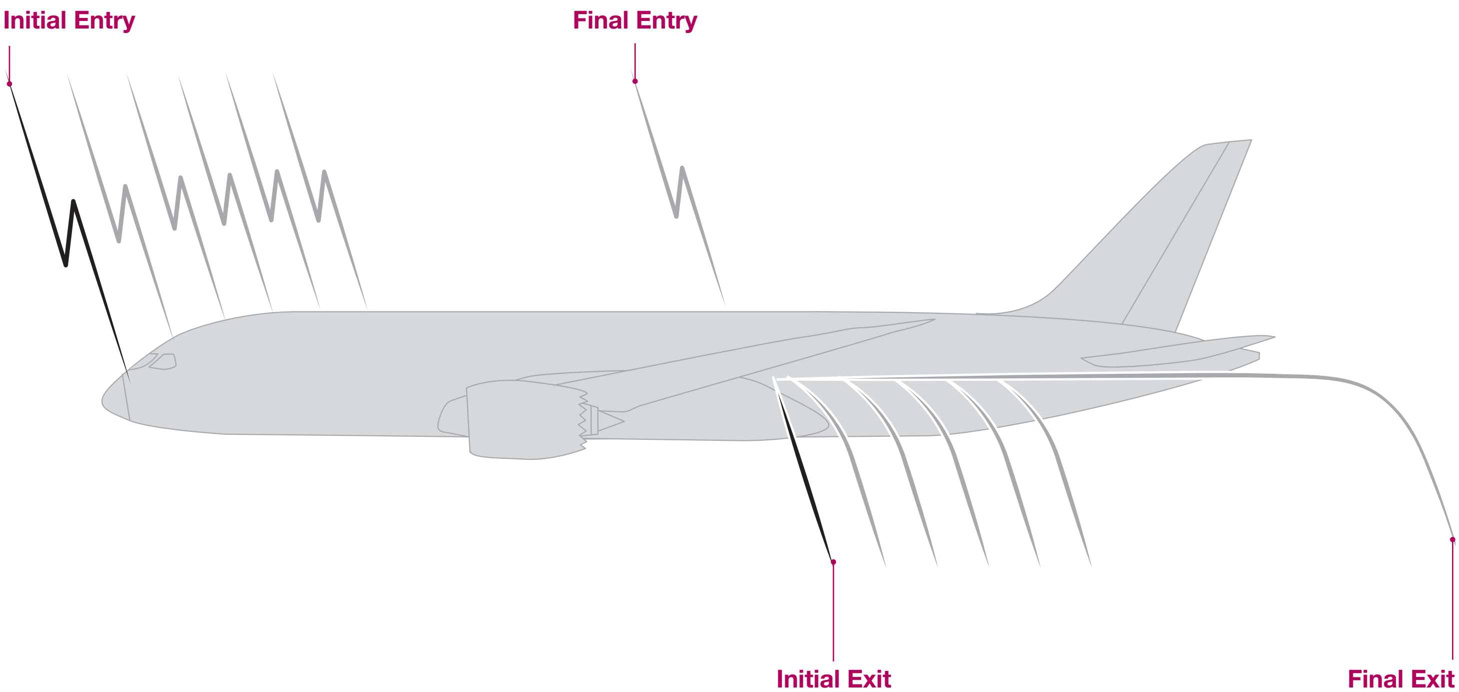
Seventy percent of all lightning strikes occur during the presence of rain. There is a strong relationship between temperatures around 32 degrees F (0 degrees C) and lightning strikes to airplanes. Most lightning strikes to airplanes occur at near freezing temperatures.

Conditions that cause precipitation may also cause electrical storage of energy in clouds. This availability of electrical energy is associated with precipitation and cloud creation. Most lightning strikes affecting airplanes occur during spring and summer.

Although 70 percent of lightning-strike events occur during precipitation, lightning can affect airplanes up to five miles away from the electrical center of the cloud. Approximately 42 percent of the lightning strikes reported by airline pilots were experienced with no thunderstorms reported in the immediate area by the pilots.

**Figure 4: How lightning attaches to an airplane**

Lightning is initiated at the airplane's leading edges, which ionize, creating a strike opportunity. Lightning currents travel along the airplane and exit to the ground, forming a circuit with the airplane between the cloud energy and the ground.




from the airplane meets a leader from the cloud, a strike to the ground can continue and the airplane becomes part of the event. At this point, passengers and crew may see a flash and hear a loud noise when lightning strikes the airplane. Significant events are rare because of the lightning protection engineered into the airplane and its sensitive electronic components.

After attachment, the airplane flies through the lightning event. As the strike pulses, the leader reattaches itself to the fuselage or other structure at other locations while the airplane is in the electric circuit between the cloud regions of opposite polarity. Current travels through the airplane's conductive exterior skin and structure and exits out another extremity, such as the tail, seeking the opposite polarity or ground. Pilots may occasionally report temporary flickering of lights or short-lived interference with instruments.

## TYPICAL EFFECTS OF LIGHTNING STRIKES

Airplane components made of ferromagnetic material may become strongly magnetized when subjected to lightning currents. Large current flowing from the lightning strike in the airplane structure can cause this magnetization.

While the electrical system in an airplane is designed to be resistant to lightning strikes, a strike of unusually high intensity can damage components such as electrically controlled fuel valves, generators, power feeders, and electrical distribution systems.

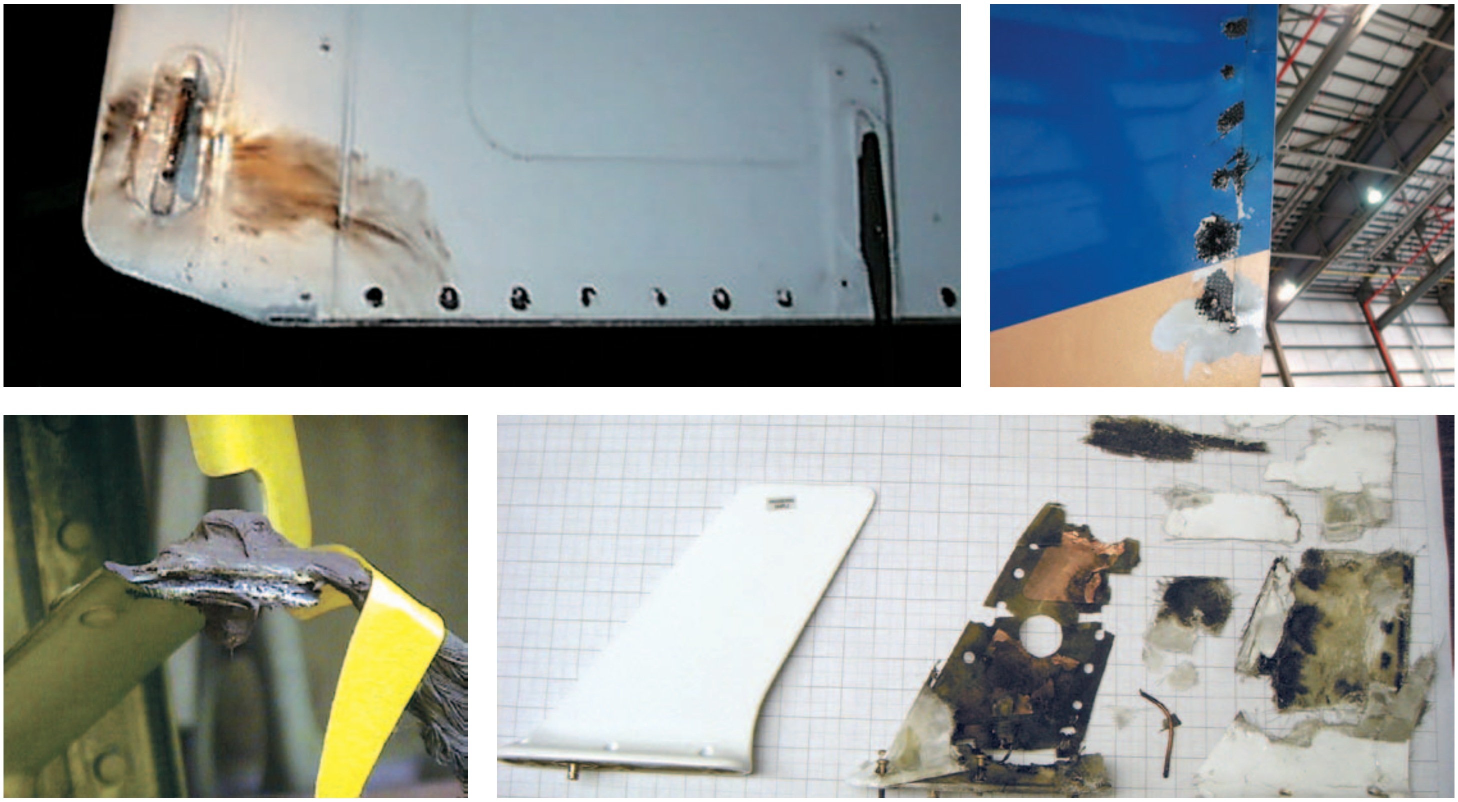
## COMMERCIAL AIRPLANE LIGHTNING PROTECTION

Most of the external parts of legacy airplanes are metal structure with sufficient thickness to be resistant to a lightning strike. This metal assembly is their basic protection. The thickness of the metal surface is sufficient to protect the airplane's internal spaces from a lightning strike. The metal skin also protects against the entrance of electromagnetic energy into the electrical wires of the airplane. While the metal skin does not prevent all electromagnetic energy from entering the electrical wiring, it can keep the energy to a satisfactory level.

By understanding nature and the effects of lightning strikes, Boeing works to design and test its commercial airplanes for lightning-strike protection to ensure protection is provided throughout their

**Figure 5: Lightning protection and strike damage**

Clockwise from upper left: Lightning damage to a horizontal stabilizer, rudder, antenna, and bond jumper.



service lives. Material selection, finish selection, installation, and application of protective features are important methods of lightning-strike damage reduction.

Areas that have the greatest likelihood of a direct lightning attachment incorporate some type of lightning protection. Boeing performs testing that ensures the adequacy of lightning protection. Composite parts that are in lightning-strike prone areas must have appropriate lightning protection.

The large amount of data gathered from airplanes in service constitutes an important source of lightning-strike protection information that Boeing uses to make improvements in lightning-strike damage control that will reduce significant lightning-strike damage if proper maintenance is performed.

Lightning protection on airplanes may include:

- Wire bundle shields.
- Ground straps.
- Composite structure expanded foils, wire mesh, aluminum flame spray coating, embedded metallic wire, metallic picture frames, diverter strips, metallic foil liners, coated glass fabric, and bonded aluminum foil.

## REQUIRED ACTIONS FOLLOWING A LIGHTNING STRIKE TO AN AIRPLANE

Lightning strikes to airplanes may occur without indication to the flight crew. When an airplane is struck by lightning and the strike is evident to the pilot, the pilot must determine whether the flight will continue to its destination or be diverted to an alternate airport for inspection and possible repair.

Technicians may find and identify lightning-strike damage by understanding the mechanisms of lightning and its attachment to airplanes. Technicians must be aware that lightning strikes may not be reported in the flight log because the pilots may not have known that a lightning strike occurred on the airplane. Having a basic understanding of lightning strikes will assist technicians in performing effective maintenance.

## IDENTIFYING LIGHTNING-STRIKE DAMAGE ON A COMMERCIAL AIRPLANE

Lightning strikes to airplanes can affect structure at the entrance and exit points. In metal structures, lightning damage usually shows as pits, burn marks, or small circular holes. These holes can be grouped in one location or divided around a large area. Burned or discolored skin also shows lightning-strike damage.

Direct effects of a lightning strike can be identified by damage to the airplane's structure, such as melt through, resistive heating, pitting to structure, burn indications around fasteners, and even missing structure at the airplane's extremities, such as the vertical stabilizer, wing tips, and horizontal stabilizer edges (see fig. 5). Airplane structure can also be crushed by the shock waves present during the lightning strike. Another indication of

**Figure 6: Damage caused by lightning moving along an airplane**

When a lightning strike moves along an airplane, it can cause “swept stroke” damage.

lightning strike is damage caused to bonding straps. These straps can become crushed during a lightning strike due to the high electromagnetic forces.

Because the airplane flies more than its own length during the time it takes a strike to begin and finish, the entry point will change as the flash reattaches to other spots aft of the initial entry point. Evidence of this is seen in strike inspections where multiple burns are seen along the airplane’s fuselage (see fig. 6).

Lightning can also damage composite airplane structures if protection finish is not applied, properly designed, or adequate. This damage is often in the form of burnt paint, damaged fiber, and composite layer removal (see fig. 7).

## LIGHTNING-STRIKE STRUCTURAL INSPECTION PROCEDURES

If lightning strikes an airplane, a lightning-strike conditional inspection must be performed to locate the lightning-strike entrance and exit points. When looking at the areas of entrance and exit, maintenance personnel should examine the structure carefully to find all of the damage that has occurred.

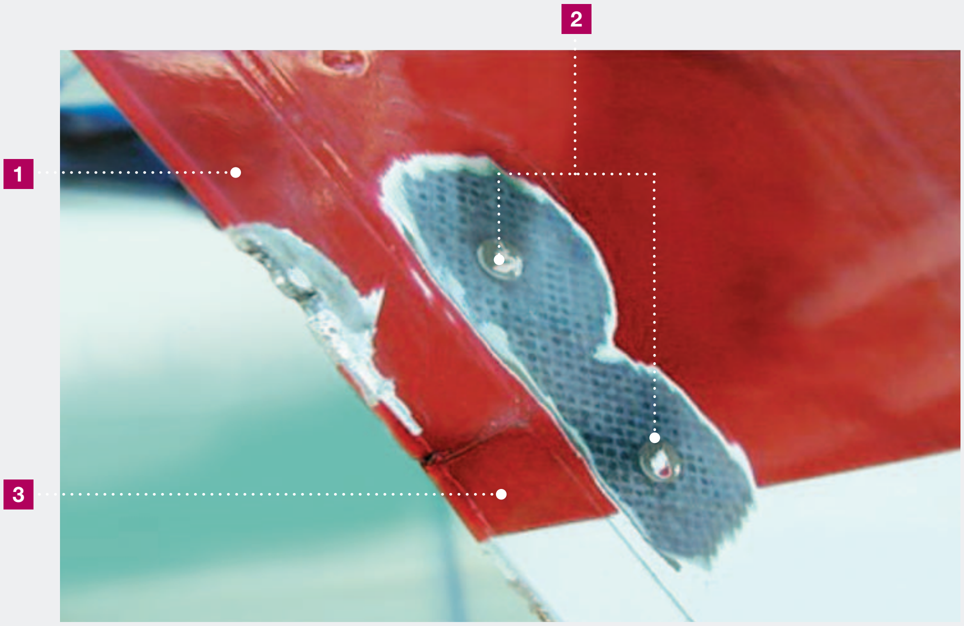
The conditional inspection is necessary to identify any structural damage and system damage prior to return to service. The structure may have burn holes that can lead to pressurization loss or cracks. The critical system components, wire bundles, and bonding straps must be verified as airworthy prior to flight. For these reasons, Boeing recommends that a complete lightning-strike conditional inspection should be performed prior to the next flight to maintain the airplane in an airworthy condition.

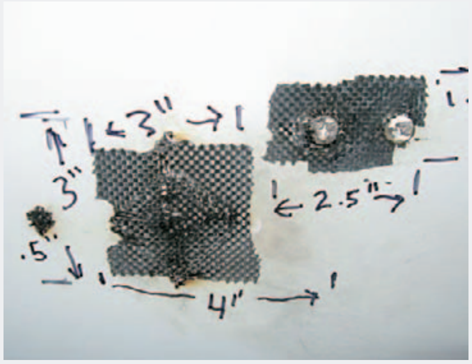
Airplane lightning-strike zones are defined by SAE Aerospace Recommended Practices (ARP) 5414 (see fig. 8). Some zones are more prone to lightning strikes than others (see fig. 9). Lightning-strike entrance and exit points are usually found in Zone 1, but can very rarely occur in Zones 2 and 3. A lightning strike usually attaches to the airplane in Zone 1 and departs from a different Zone 1 area. The external components most likely to be hit are:

- Radome.
- Nacelles.
- Wing tips.
- Horizontal stabilizer tips.

**Figure 7: Lightning damage to a composite airplane**

Composite structures are less conductive than metal, causing higher voltages. This is the type of damage that can occur if a lightning protection finish is not applied or is inadequate.




1 Outbound trailing edge wedge (2024-T3511 extrusion)
2 Two rivets affected by lightning strike
3 Inboard trailing edge wedge

- Elevators.
- Vertical fin tips.
- Ends of the leading edge flaps.
- Trailing edge flap track fairings.
- Landing gear.
- Water waste masts.
- Air data sensors (pitot probes, static ports, angle of attack [AOA] vane, total air temperature probe).

In Zone 2, an initial entry or exit point is a rare event, but in such a case, a lightning channel may be pushed back from an initial entry or exit point. As an example, the radome may be the area of an initial entry point, but the lightning channel may be pushed back along the fuselage aft of the radome by the forward motion of the airplane.

A Zone 3 examination is highly recommended even if no damage is found during the Zone 1 and Zone 2 examinations. In summary, any entrance and exit points must be identified in Zones 1, 2, or 3 so that the immediate areas around them can be thoroughly examined and repaired if necessary.

## LIGHTNING-STRIKE SURFACES EXAMINATION BY ZONE

Boeing provides lightning-strike inspection procedures to ensure external surfaces have not been damaged. Operators should refer to applicable maintenance procedures as the authoritative source for inspection/repair instructions. Typical procedures provided include the following general guidance.

- Perform typical external surface examination for Zone 1 and Zone 2.
- Examine all airplane external surfaces:
  - Examine the external surfaces carefully to find the entrance and exit points of the lightning strike and look in the areas where one surface stops and another surface starts.
  - Examine the metallic and nonmetallic structure for damage.
  - For composite structure, delamination can be detected by instrumental non-destructive inspection methods or by a tap test.
  - For Zone 2, examine the pitot probes, AOA sensors, static ports, and their surrounding areas for damage.

If the entrance and exit points are not found during the examination of Zones 1 and 2, the Zone 3 surface areas should be examined for signs of lightning-strike

**Figure 8: Lightning zone definitions**

Airplane lightning zones as defined by SAE Aerospace Recommended Practices 5414.

| Zone Designation | Description | Definition |
|---|---|---|
| 1A | First return stroke zone | All areas of the airplane surfaces where a first return is likely during lightning channel attachment with a low expectation of flash hang on. |
| 1B | First return stroke zone with a long hang on | All areas of the airplane surfaces where a first return is likely during lightning channel attachment with a low expectation of flash hang on. |
| 1C | Transition zone for first return stroke | All areas of the airplane surfaces where a first return stroke of reduced amplitude is likely during lightning channel attachment with a low expectation of flash hang on. |
| 2A | Swept stroke zone | All areas of the airplane surfaces where a first return of reduced amplitude is likely during lightning channel attachment with a low expectation of flash hang on. |
| 2B | Swept stroke zone with long hang on | All areas of the airplane surfaces into which a lightning channel carry subsequent return stroke is likely to be swept with a high expectation of flash hang on. |
| 3 | Strike locations other than Zone 1 and Zone 2 | Those surfaces not in Zone 1A, 1B, 1C, 2A, or 2B, where any attachment of the lightning channel is unlikely, and those portions of the airplane that lie beneath or between the other zones and/or conduct a substantial amount of electrical current between direct or swept stroke attachment points. |

damage. Inspections of Zone 3 are similar to Zones 1 and 2. Additional inspections for Zone 3 include:

- Examine all of the external lights, looking for:
  - Broken light assemblies.
  - Broken or cracked lenses.
  - Other visible damage.
- Examine the flight control surfaces for signs of lightning-strike damage and perform necessary operational checks.
- Examine landing gear doors.
- Check the standby magnetic compass.
- Check the fuel quantity system for accuracy.
- Examine the static dischargers.

Note: This is an outline of inspection procedures. Maintenance personnel should consult chapter five of the Aircraft Maintenance Manual (AMM) for the airplane model being inspected.

## AIRPLANE INTERNAL COMPONENTS EXAMINATION

If a lightning strike has caused a system malfunction, perform a full examination of the affected system with the use of the applicable AMM section for that system.

Perform a check of the standby compass system only if the flight crew reported a very large compass deviation.

Make sure the fuel quantity system is accurate using the built-in test equipment.

## OPERATION TESTS OF RADIO AND NAVIGATION SYSTEMS

The level of checks after a lightning strike to the airplane is determined by flight crew information and the airplane condition after the incident.

For example, if all the navigation and communications systems are operated by the flight crew in flight after the lightning strike and no anomalies are found, checks to the operated systems would not normally be required.

For systems not operated by the flight crew in flight or systems where anomalies were found, additional operational test procedures, as specified in the respective AMM, may be required. In addition, even if a system were operated in flight after the lightning strike and no anomalies were found, but subsequent inspections showed lightning damage near that system antenna, additional checks of that system may be required.

Logic flow for inspection of internal components in maintenance procedures provided by Boeing follow a similar process (see fig. 10).

## LIGHTNING-STRIKE STRUCTURAL REPAIRS

Detailed information and procedures for common lightning allowable damage limits and applicable rework or repairs can be

**Figure 9: Airplane lightning zones**

Areas of an airplane that are prone to lightning strikes are indicated by zone. Zone 1 indicates an area likely to be affected by the initial attachment of a strike. Zone 2 indicates a swept, or moving, attachment. Zone 3 indicates areas that may experience conducted currents without the actual attachment of a lightning strike.

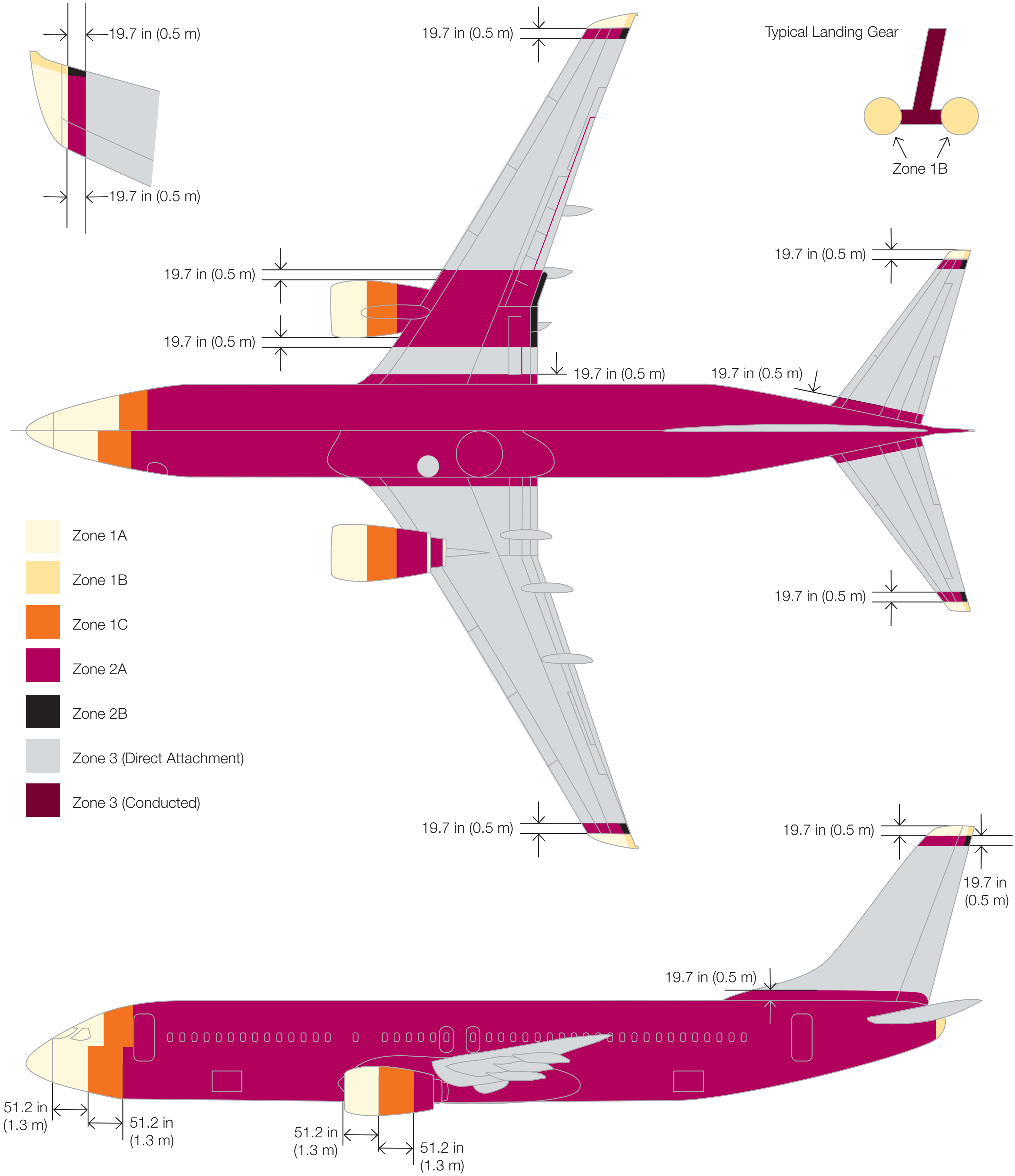
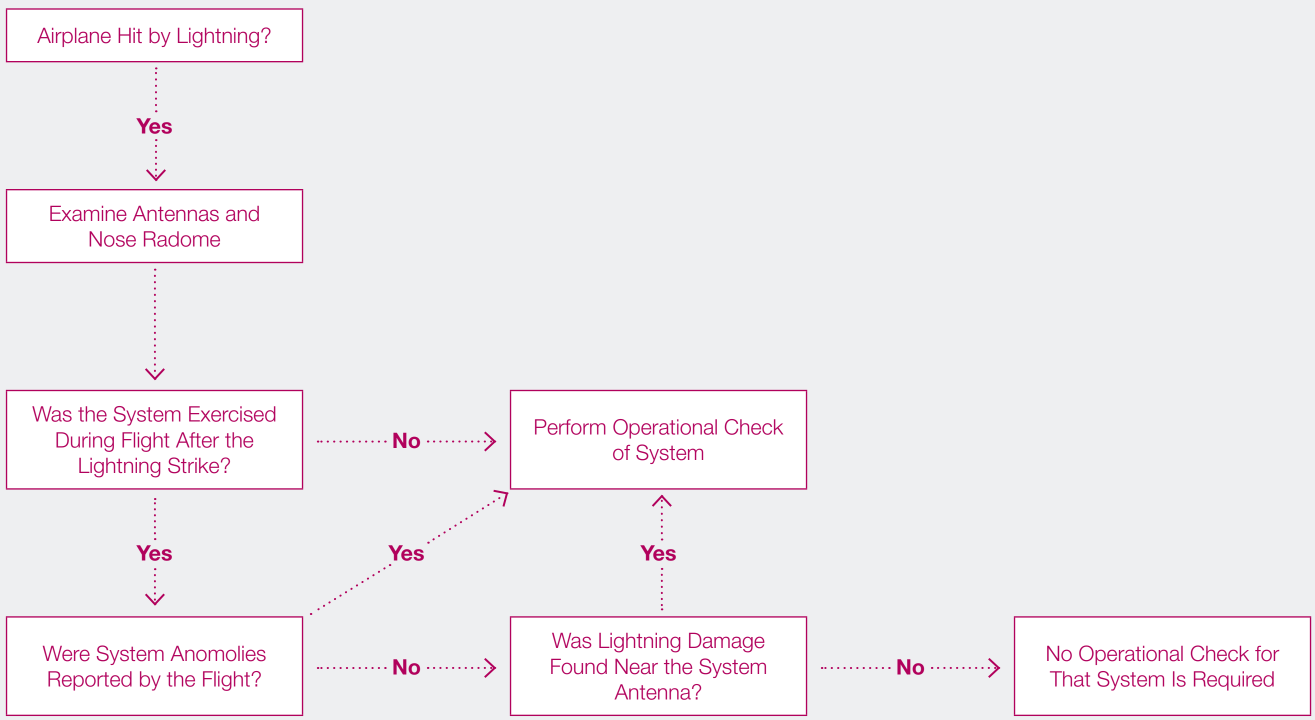


**Figure 10: Conditional inspection flowchart of internal components**

Boeing recommends that a lightning-strike conditional inspection be performed prior to the next flight to maintain the airplane in an airworthy condition.




found in the structural repair manual (SRM) for each airplane model. Maintenance personnel should restore the original structural integrity, ultimate load strength, protective finish, and materials after a lightning strike.

In response to customer requests for training, Boeing has developed an SRM repair course to give maintenance technicians and engineers training in assessing and repairing airplane lightning-strike damage. Topics include the types of damage, lightning-strike protection design principles, damage inspection methods, allowable damage limits, repairs, and restoration of protective methods. Additional training on understanding lightning effects on airplanes and inspection instructions may be requested through the Boeing airlines representative. Upon completion of the course, the student will be able to:

- Identify causes and mechanisms of lightning strikes.
- Identify lightning-strike-prone areas on the airplane.
- Describe lightning-strike-protection design principles.
- Perform appropriate inspections after lightning strikes.
- Identify specific rework procedures for areas that are affected by lightning strikes.
- Understand requirements for restoration of lightning-strike protection and reduction.

For more information on available standard maintenance training, please contact www.myboeingtraining.com.

## SUMMARY

Operators should be aware of the conditions that are conducive to lightning strikes on airplanes and avoid exposing airplanes unnecessarily to lightning-prone environments. While Boeing airplanes incorporate extensive lightning-strike protection, lightning strikes can still affect airline operations and cause costly delays or service interruptions. A clear understanding of proper inspection and repair procedures can increase the effectiveness of maintenance personnel and ensure that all damage caused by lightning is identified and repaired.

BOEING EDGE

www.boeing.com/boeingedge/aeromagazine