LIGHTINING 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;
&
John Gokcen,
Senior Structures Engineering Instructor

While Boeing Airplanes Incorporate Extensive Lightning-Strike Protection, Strikes Can Cause Costly Delays And Service Interruptions.

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.

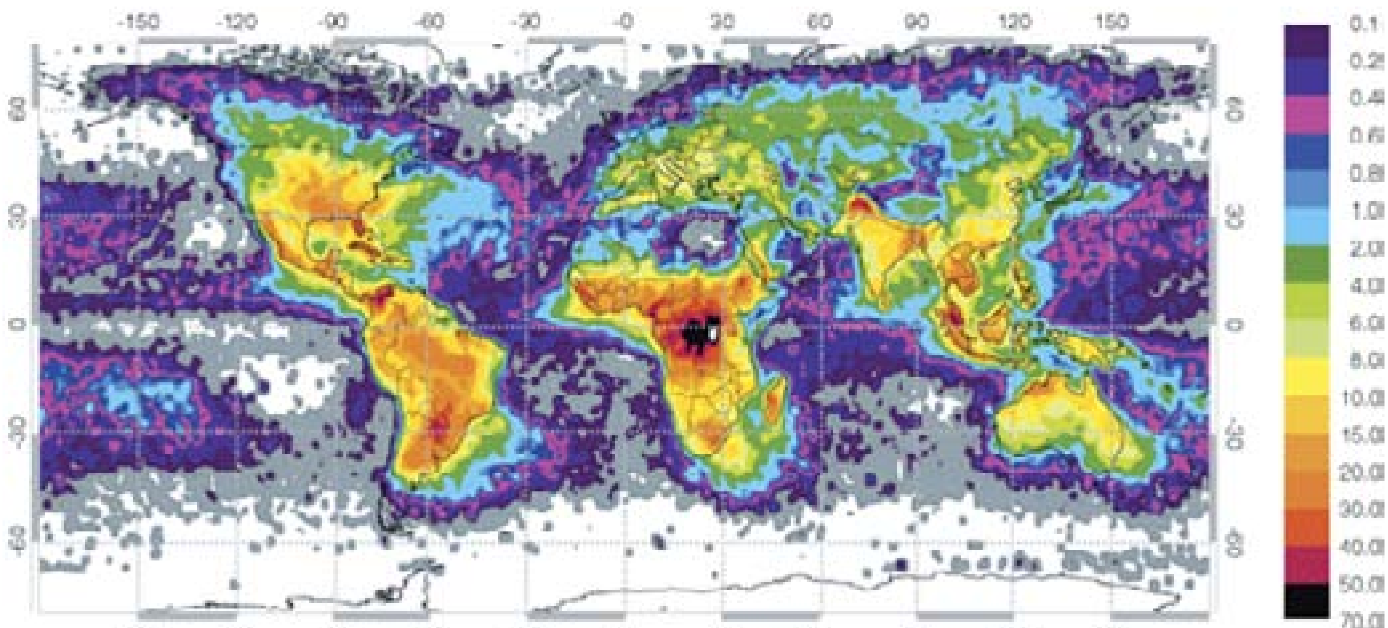
Lightning activity can vary greatly by geographic location. For example, in the United States, parts of Florida average 100 thunderstorm days per year, while most of the West Coast averages only 10 thunderstorm days per year. In the rest of the world, lightning tends to occur most near the equator because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

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.

Lightning Observations for April 1995 through February 2003

Flash Density (flashes/kilometers2/year)

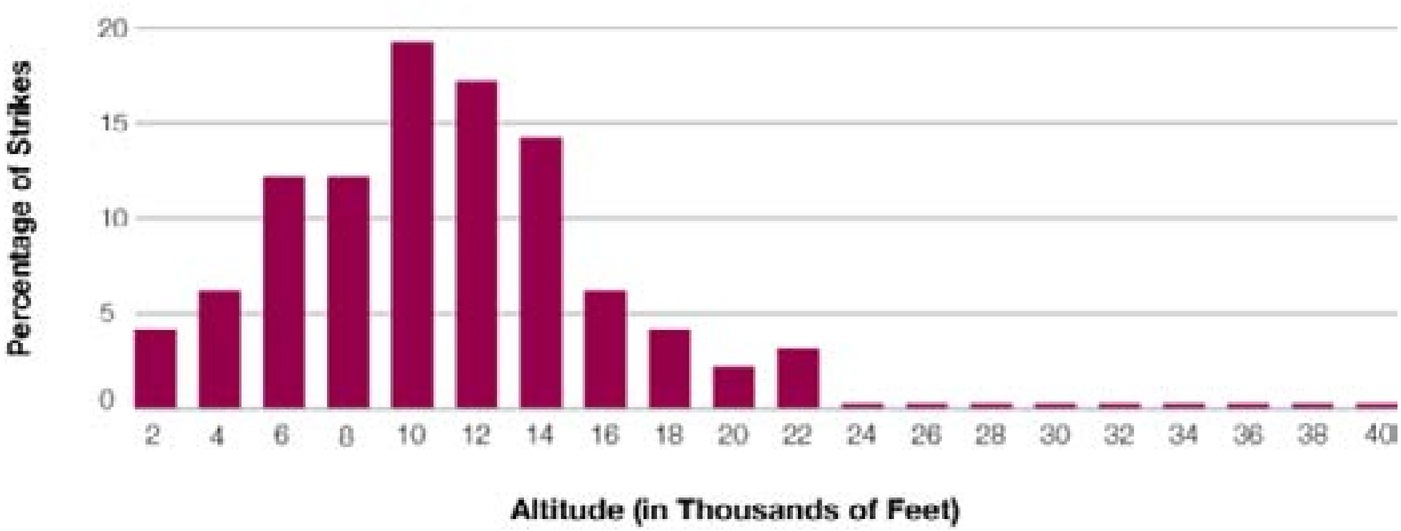


More jet airplane lightning strikes occur while in clouds, during the climb and descent phases of flight, than any other flight phase (see fig. 2). The reason is that lightning activity is more prevalent between 5,000 to 15,000 feet (1,524 to 4,572 meters) altitude (see fig. 3). Airplanes that fly short 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.

Most airplane lightning strikes occur when an airplane is flying in clouds. *Sixty-two strikes did not report orientation of clouds during strike event.

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.

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 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.

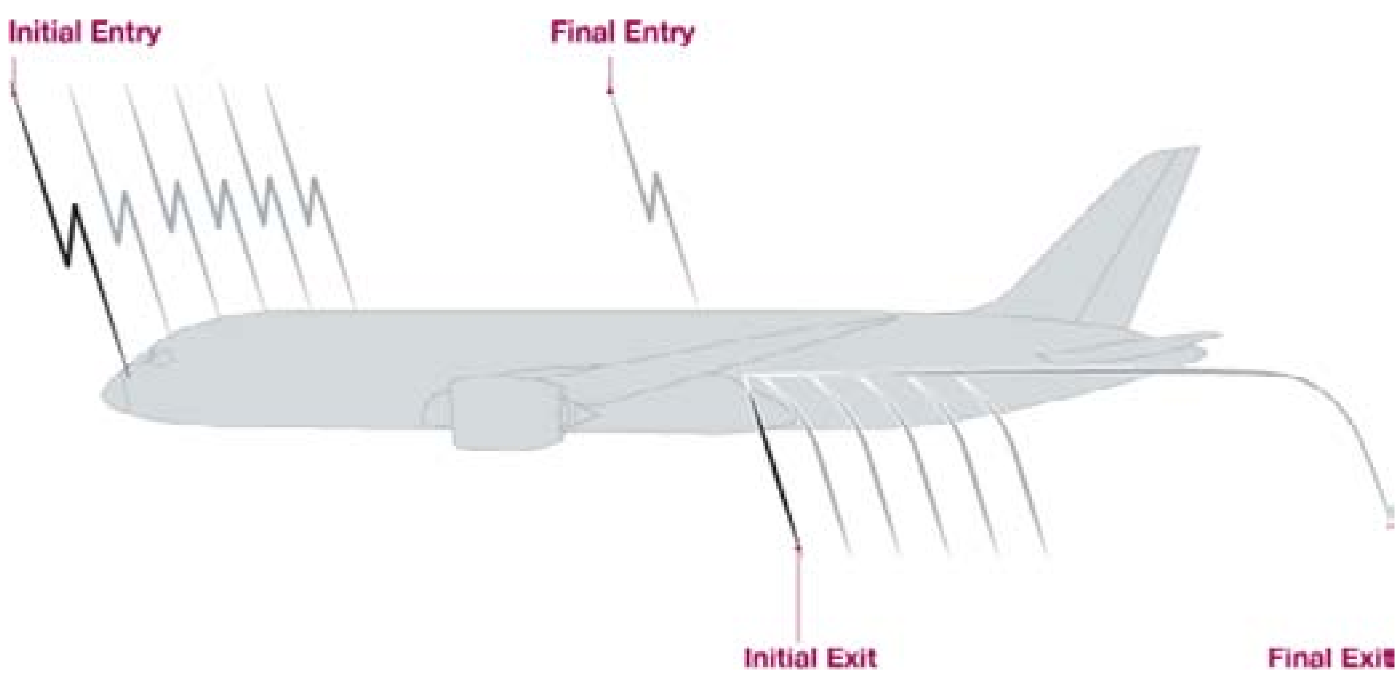
Although 70 percent of lightning-strike events occur during precipitation, lightning can affect airplanes up to five miles away from the electrical center of the cloud. Approximately 42 percent of the lightning strikes reported by airline pilots were experienced with no thunderstorms reported in the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

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.

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.



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 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 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.

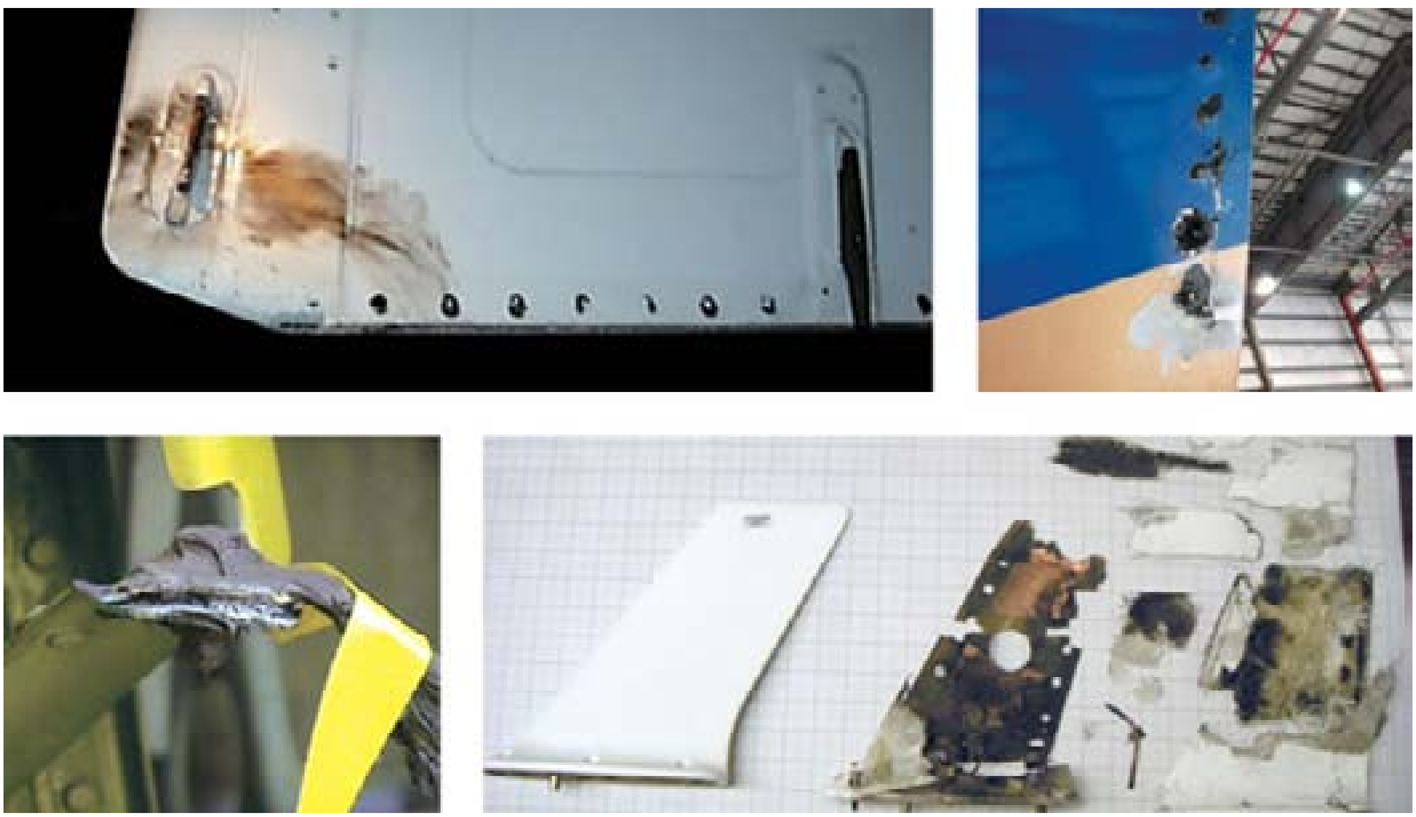
IDENTIFYING LIGHTNING-STRIKE DAMAGE ON A COMMERCIAL AIRPLANE

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

Figure 5: Lightning protection and strike damage

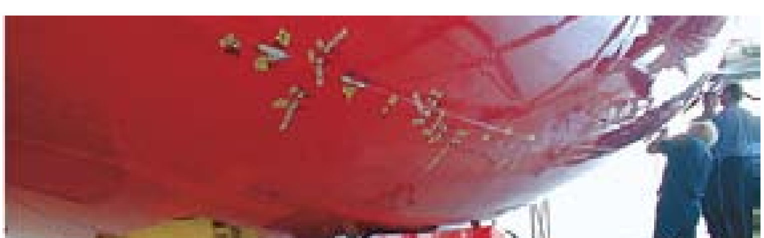
Clockwise from upper left: Lightning damage to a horizontal stabilizer, rudder, antenna, and bond jumper.



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).

Figure 6: Damage caused by lightning moving along an airplane

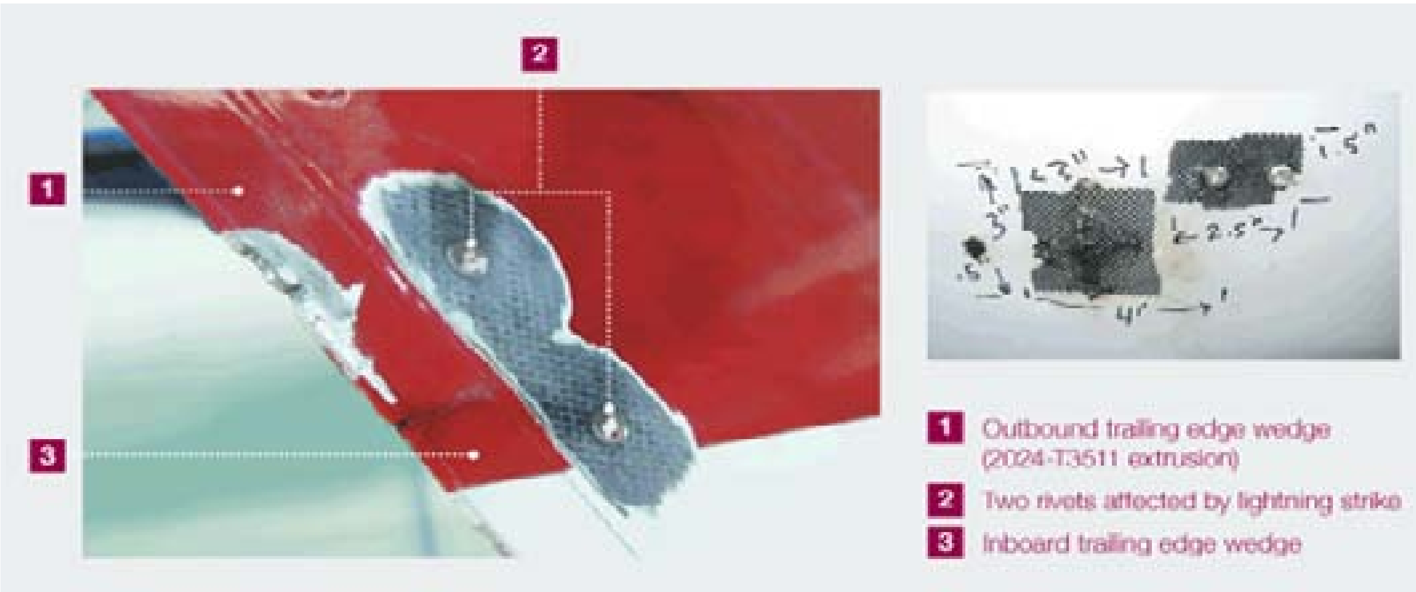
When a lightning strike moves along an airplane, it can cause "swept stroke" damage.



Lightning 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).

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.



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.
- 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).

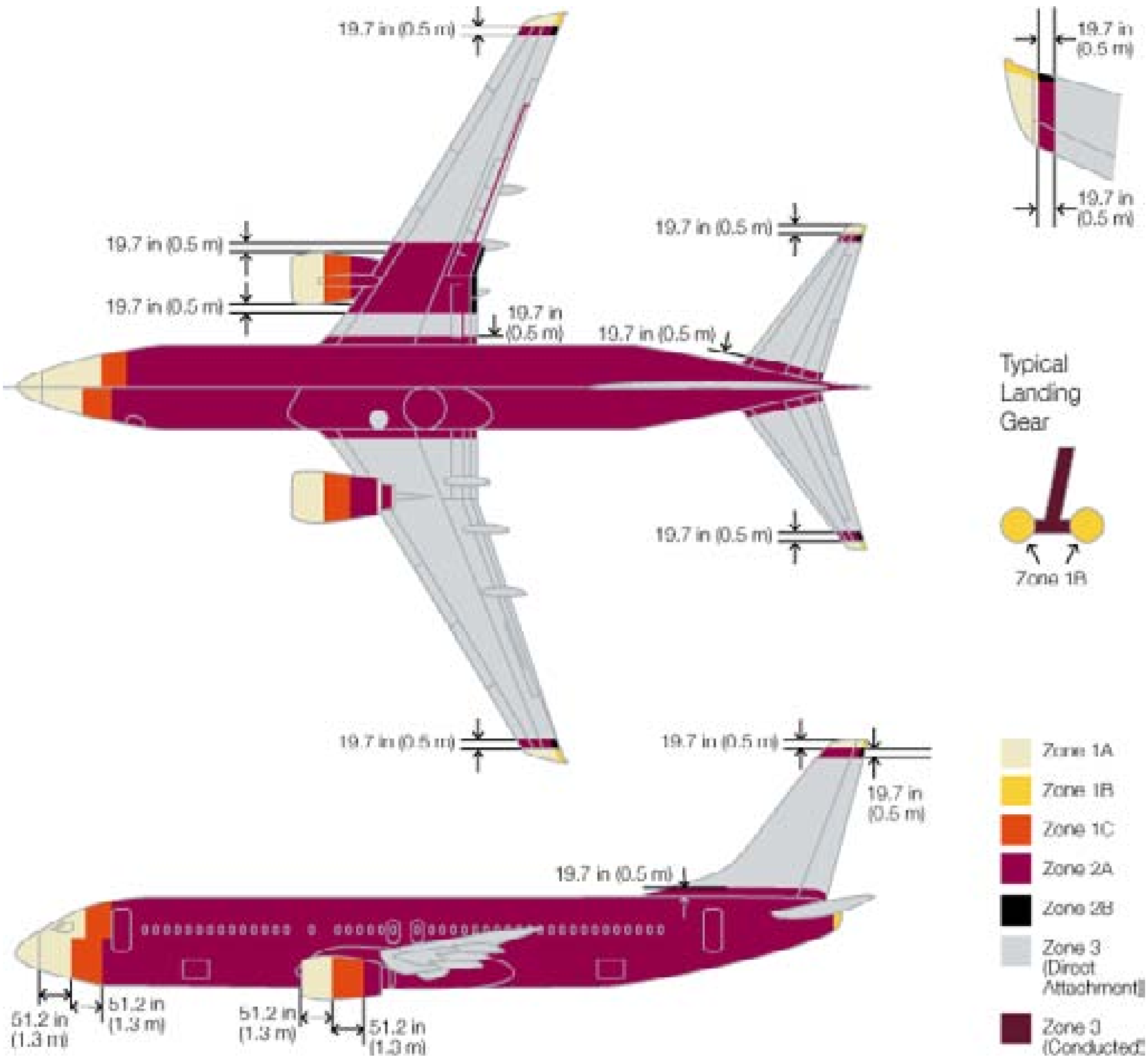
Figure 8: Lightning zone definitions

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.

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.



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:
  - o 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.
  - o Examine the metallic and nonmetallic structure for damage.
  - o For composite structure, delamination can be detected by instrumental non-destructive inspection methods or by a tap test.
  - o 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 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:
  - o Broken light assemblies.
  - o Broken or cracked lenses.
  - o 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.

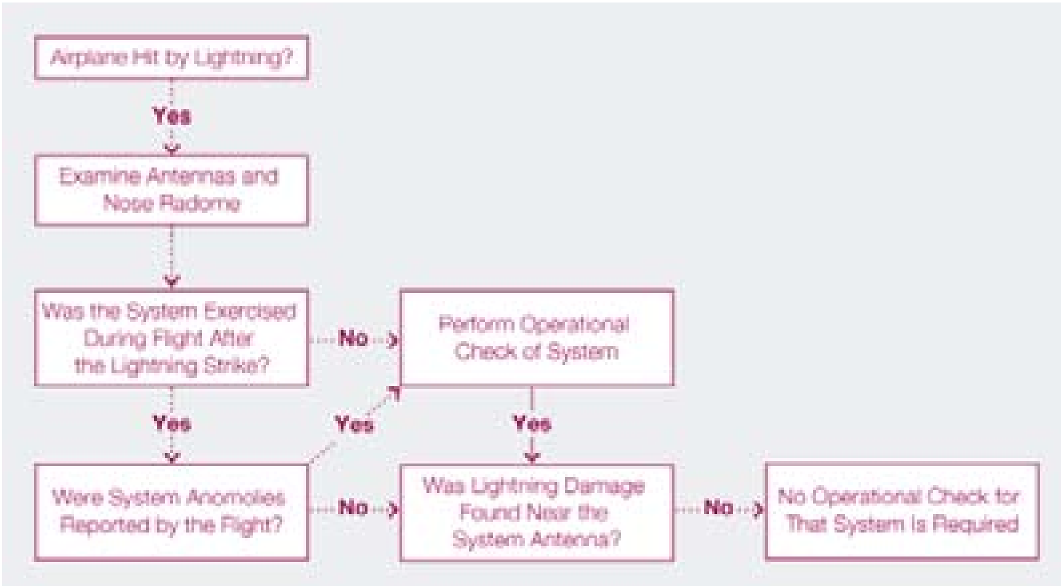
For example, if all the navigation and communications systems are operated by the flight crew in flight after the lightning strike and no anomalies are found, checks to the operated systems would not normally be required.

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).

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.



LIGHTNING-STRIKE STRUCTURAL REPAIRS

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

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.

Credits: Captain Abid Mustafa : Flight Safety Officer
Captain Abid Mustafa : Editor
Asst. Manager IT : IT Support
Boeing Aeromagzine : Content Support