When Lightning Strikes

Aircraft designs incorporate systems to protect against direct and indirect damage.

BY CLARENCE E. RASH

Understanding the mechanisms and consequences of lightning strikes on aircraft has been a decades-long learning experience.

When the first known lightning-caused airplane accident occurred in 1929, scientists and aeronautical engineers initially insisted that lightning played no part in the crash — and that there was "no proved instance of an airplane ever having been struck by lightning."[1] Over time, the experts of the 1920s were proved incorrect — aircraft lightning strikes occur frequently, although they rarely are associated with accidents.

Lightning is a discharge of electricity that occurs in the atmosphere and can be thought of as a high-current — about 20,000 amperes — electric spark associated with thunderstorms.

Lightning is produced when supercooled liquid and ice particles above the freezing level collide and build up large and separate regions of positive and negative electric charges in the clouds. After these charges become large enough, a giant "spark," or discharge, occurs between them, lasting less than a tenth of a second. The spark — lightning — can occur between clouds, between sections of a single cloud, between the cloud and air, or between the cloud and the ground — or some object on the ground.

The most common type of lightning discharge is cloud-to-ground, or "negative" lightning, which accounts for 90 percent of all lightning strikes. The discharge usually begins when a significant difference develops between the negative charge in the cloud and the positive charge on the ground — or in another cloud. At this point, the negative charge begins moving toward the ground, forming an invisible conductive path, known as a leader stroke. This leader stroke descends through the air in discrete zigzag steps, or jumps, each approximately 150 ft (46 m) long. Concurrently, a positively charged streamer is sent out from the positively charged ground or other cloud. When the leader and the streamer meet, an electrical discharge — lightning — takes place along the streamer, up and into the cloud. It is this return stroke that is the most luminous part of the lightning discharge, usually the only part of the lightning process that is actually seen.

Another type of lightning — known as "positive lightning" because there is a net transfer of positive charge from the cloud to the ground — originates in the upper parts of a thunderstorm, where a high positive charge resides. This type of lightning develops almost the same way as negative lightning, except that the descending stepped leader carries a positive charge and the subsequent ground streamer has a negative charge. Positive lightning accounts for less than 5 percent of all lightning but is much more powerful, lasts longer and can discharge at greater distances than the more common negative lighting.

Global Pattern

Lightning is a global phenomenon. Flashes have been seen in volcanic eruptions, intense forest fires, heavy snowstorms and large hurricanes; however, it is most often associated with thunderstorms.[2]

While global in occurrence, lightning is not uniformly distributed geographically. About 70 percent of all lightning flashes occur between 30 degrees N and 30 degrees S latitudes — not surprisingly, in the tropics, where most thunderstorms occur. In addition, lightning over land, or over water that is close to land, is 10 times more frequent than lightning over oceans.[3]

Every 1,000 Flight Hours

Until the past decade, when information-gathering became more effective, detailed data on lightning strikes to aircraft were difficult to obtain.[4]

However, when the extraordinary frequency of lightning is considered in concert with the frequency of flight — estimated at 77 million aircraft movements worldwide in 2008[5] — it can be no surprise that aircraft lightning strikes occur relatively often. The French Office National d'Etudes et Recherches Aérospatiales (the national aerospace research center) estimates that an aircraft is struck by lightning on average every 1,000 flight hours — for commercial airlines, the equivalent of one strike per aircraft per year (Table 1, p. 21).

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While more study is needed, current evidence points to altitude as a factor in lightning strikes. Current data show there are more lightning strikes at intermediate altitudes (8,000–14,000 ft) than at cruise altitudes.[6] Other leading factors in the probability of a lightning strike include being inside a cloud (90 percent) and/or the presence of rain (more than 70 percent).

An aircraft lightning strike is often attributed to "being in the wrong place at the wrong time" — in other words, getting in the way of a lightning discharge. But estimates are that such a scenario accounts for only 10 percent of aircraft lightning strikes. Actually, almost 90 percent of aircraft lightning strikes are self-triggered, as when an aircraft flies through a heavily charged area of clouds — a fact not known until the 1980s.[7]

Fortunately, although aircraft lightning strikes are not uncommon, accidents in which lightning has been identified as a primary or contributing cause are.

Searches of accident databases and historical records maintained by various aviation agencies, historical societies and lightning safety organizations produce a diverse listing and history of incidents and accidents that have been attributed to lightning strikes.

Based on these searches, the first aviation accident attributed directly to a lightning strike occurred Sept. 3, 1915, when a German Zeppelin LZ40 (L10) was destroyed by a lightning strike while venting hydrogen gas off Neuwerk Island, Germany.[8] From 1915 through the early 1920s, a number of airship accidents were attributed to lightning strikes.

The Sept. 3, 1929, crash of a Transcontinental Air Transport Ford Tri-Motor named the "City of San Francisco" usually is cited as the first heavier-than-air aircraft destroyed by a lightning strike. All eight occupants died when the airplane struck the ground near Mt. Taylor, New Mexico, U.S., on the Albuquerque-to-Los Angeles leg of a cross-country journey divided into airplane and train segments.[9]

Over the next few decades, only a dozen or so additional accidents were attributed to lightning strikes; in many of those cases, however, lightning was not firmly established as the cause.

The earliest lightning-related accident for which a detailed description is available involved a U.S. Air Force Curtiss C-46D transport plane en route from Dallas to Jackson, Mississippi, U.S., on June 14, 1945. While at 3,000 ft, one wing was struck by lightning. Unable to maintain altitude, the aircraft crashed into a wooded area.[10]

Nearly two decades later, in what often is cited as the first positive lightning strike-induced accident involving a commercial aircraft, a Pan American World Airways Boeing 707-121 crashed on Dec. 8, 1963, while in a holding pattern awaiting clearance to land in Philadelphia after a flight from Baltimore. Accident investigators determined that the lightning strike had ignited fuel vapors. As a consequence of the ensuing investigation by the U.S. Federal Aviation Agency — a precursor of the Federal Aviation Administration (FAA) — devices known as lightning discharge wicks were ordered to be installed on all commercial jet airliners.

The U.S. National Transportation Safety Board (NTSB) Accident/Incident Database from Jan. 1, 1962–April 30, 2010, included 58 events in which lightning — but not necessarily a lightning strike — was cited as a major or contributing causal factor. All of the reports involved commercial or private aircraft, with the exception of one accident involving a balloon.[11]

In those 58 reports, the role of lightning is categorized as follows:

- Forty-one events involved actual lightning strikes to an aircraft during flight.
- Two events involved an aircraft while on the ground. One airplane was struck by lightning, and the other was involved in a taxiway accident attributed to a communication breakdown after ground personnel removed their headsets because of lightning in the area.
- Five events involved nearby lightning strikes that impaired either the pilot's vision or ability to control the aircraft.
- Three events involved lightning-related ground equipment failures that led to accidents during landing. Two of these involved the loss of runway lights, and one involved the loss of air traffic control capability.
- Seven accident/incident reports cited lightning as a weather factor contributing to an accident but did not describe its actual influence.

The 58 incidents and accidents resulted in 202 fatalities and 46 injuries, most of which were associated with two accidents:

- The Aug. 2, 1985, crash of a Delta Air Lines Lockheed L-1011-385 in Dallas/Fort Worth, which killed 135 and injured 30 passengers and crew. Lighting was cited as a contributing factor.[12]
- The July 23, 1973, crash of an Ozark Airlines Fairchild FH227B in St. Louis, which killed 38 and injured six passengers and crew. A lightning strike on final approach was cited as a probable cause.[13]

Also among the 202 fatalities was an aircraft marshaller who was wearing a headset connected to a McDonnell Douglas DC-9-31 when it was struck by lightning on Oct. 7, 1989, while being pushed back from a gate in preparation for takeoff from Orlando International Airport.[14]

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Lightning Effects

Both the occupants of an aircraft and the aircraft itself are subject to the powerful effects of a lightning strike. The inherent structural design of an aircraft provides the occupants almost complete protection despite the massive amount of current involved. This protection is based on the principle known as the Faraday

Lightning … By the Numbers

1,800	Number of thunderstorms in progress worldwide at any given moment
40–100	Average number of lightning flashes each second worldwide
20,000	Number of amperes (amps) of current in a typical lightning discharge
60 ft (18 m)	The distance lightning energy can spread from the strike point
1:750,000	Odds of being struck by lightning in a given year
1:6,250	Odds of being struck by lightning in a lifetime (80 years)
1:28,500	Odds of being killed by lightning
24,000	Average number of deaths per year due to lightning worldwide
240,000	Average number of injuries per year due to lightning worldwide
58	Average number of deaths per year due to lightning in the United States
500	Average number of injuries per year due to lightning in the United States
90	Percentage of lightning-strike victims who survive

Sources: U.S. National Weather Service "Medical Aspects of Lightning," National Oceanic and Atmospheric Administration. <www.lightningsafety.noaa.gov/medical.htm>.

National Lightning Safety Institute. "Fast Facts About Lightning." <www.lightningsafety.com>.

Table 1

cage, first devised by the physicist Michael Faraday in 1836.

A Faraday cage is a hollow enclosure made of conducting material, such as the hull of an aircraft. In the presence of a strong electric field, any electric charge will be forced to redistribute itself on the outside enclosure, but the space inside the cage remains uncharged. Thus, the metal hull of the aircraft acts as a Faraday cage, protecting the occupants from lightning.

Some aircraft are made of advanced composite materials, which — by themselves — are significantly less conductive than metal. To overcome this resulting safety problem, a layer of conductive fibers or screens is imbedded between layers of the composite material to conduct the lightning current.

Regardless of hull material, the direct effects of lightning on the exterior can also include:[15]

- Burning or melting at lightning strike points;
- Increase in temperature;
- Residual magnetism;
- Acoustic shock effects;
- Arcing at hinges, joints and bonding points; and,
- Ignition of fuel vapors.

Accident data indicate that most of these effects are not serious. However, an estimated one-third to one-half of aircraft lightning strikes result in at least some minor damage.[16] Lightning generally enters an aircraft at one location, usually an extremity, and leaves at another. Burn marks are found at the entry and exit point(s) of the strike, although exit points are not present if the energy was dissipated via wicks or rods — static dischargers whose primary purpose is to bleed off into the surrounding air the static charge buildup that occurs during normal flight.

Because many aircraft fly a distance equivalent to several times their own lengths during a lightning discharge, the location of the entry point can change as the discharge attaches to additional points aft of the initial entry point. The location of the exit points may also change. Therefore, for any one strike, there may be several entry or exit points.

Occasionally, in more severe strikes, electrical equipment or avionics may be affected or damaged. This potential problem is addressed in modern aircraft design by redundancy. The functions of most critical systems are duplicated, so a lightning strike is unlikely to compromise safety of flight. In most strike events, pilots report nothing more than a temporary flickering of lights or short-lived interference with instruments.

The exception is the incidence of positive lightning. Positive lightning strikes — because of their greater power — are considerably more dangerous than negative lightning strikes. Few aircraft are designed to withstand such strikes without significant damage.[17]

Protection Methods

Careful flight planning and the use of weather radar help limit an aircraft's exposure to lightning. It is a good safety practice to avoid by at least 20 nm (37 km) any thunderstorm activity that provides a strong radar echo.

Aviation regulatory agencies worldwide have established certification standards that call for an aircraft to be able to withstand a lightning strike and continue flying to land safely at a suitable airport. In addition, modern aircraft designers employ a number of effective lightning protection systems that address possible direct and indirect damage from lightning strikes. These systems are intended to provide preferred paths for the electric current associated with a lightning discharge to enter and exit the aircraft without causing damage to the aircraft or injury to its occupants.[18] These systems can be divided into three general categories of protection: airframe and structure protection; fuel system protection; and electrical and electronic systems (avionics) protection.

The primary goal of airframe and structure protection is to minimize and control lightning entry and exit points. The first step is to identify locations (or zones) of greatest vulnerability to lightning strikes. For most aircraft, these zones, in decreasing vulnerability, are the radome and wing tips, the bottom of the fuselage and the area under the wings.

The second step is to ensure that acceptable discharge pathways are available at these potential entry points and that these pathways adjoin preferred exit points on the aircraft. To a great extent, this is achieved via the electrically conductive hull of the aircraft. In the outer hull design, it is important that conductive bonding strips electrically bridge any gaps between sections, thereby reducing potential arcing.

Preferred exit points at the tips of the wings, stabilizers and fins should be equipped with static dischargers — wicks or rods. These static dischargers are not lighting arrestors, however, and they do not reduce the probability of an aircraft being struck by lightning. Nevertheless, if lightning does strike, chances are that the electricity will go through the discharger rather than through the aircraft.

Fuel System

The primary goal of fuel system protection is to prevent the ignition of fuel vapors.[19] Fuel tanks and associated systems must be free of potential ignition sources, such as electrical arcs and sparks. All the structural joints, hinges and fasteners must be designed to prevent sparks as current from the lightning discharge flows from one section to another. The aircraft skin near the fuel tanks also must be robust enough to prevent burn-through by a lightning strike.

A second aspect of fuel system protection involves the fuel itself. Advances in fuel development have resulted in fuels that produce less explosive vapors. Fuel additives that reduce vapor formation also are available.

Avionics

Today's aircraft are equipped with miles of wiring and an abundance of computers and electronic systems, so most lighting protection methods are designed to protect the current-sensitive avionics systems. Flight-critical and essential equipment must be able to function in the aftermath of both the direct and indirect effects of lightning strikes.

As current from a lightning strike travels along the exterior of an aircraft, it can induce transients — temporary current oscillations — into adjacent wires and electronic equipment. Shielding, grounding and surge suppression are the most common techniques used to avoid this problem.[20] Shielded cables are wires enclosed by a common conductive layer (the shield) that acts as a Faraday cage. Shielded cables in aircraft may have two shields — an outer shield for lightning protection and an inner shield that eliminates unwanted electromagnetic interference (EMI).

Surge suppression is used to limit rapid increases in voltage that are significantly above the normal level for an electronic circuit or system. Rapidly increasing voltages can result in electrical arcing that melts one or more components, effectively destroying the circuit. Surge protection works by diverting the increased power to a grounding line.

Every circuit and piece of equipment that is essential to safe flight must be protected against lightning in accordance with regulations established by civil aviation authorities.

Studies have shown that aircraft incorporating lightning and EMI protection have had a significantly lower percentage of electrical failures and interference caused by lightning strikes.[21]

If a lightning strike occurs, a post-lightning inspection of the aircraft is critical. The most important step is to thoroughly inspect the aircraft for burn spots and pitted areas that potentially identify entry and exit points. Evidence of arcing should be investigated, especially near hinges and bonding strips. A thorough check of all critical and essential avionics should be performed. Additional procedures, as listed in the aircraft's maintenance manual, should be followed.

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