WX BRIEF

Lightning rods

What pilots need to know about this common but potentially dangerous part of summer flying.

Photo courtesy DoD

Lightning strikes near Balad Air Base in Iraq as a USAF Lockheed C130 rolls for takeoff. Aircraft often become caught up in the ion channel that routes lightning through the sky, and may be struck repeatedly over the course of their lives.

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You thread your aircraft through the gap in the radar echoes that signify mature and developing convective cells, mesmerized by the intense display of lightning illuminating the cumulonimbi from within. Occasionally, a flickering tongue of light emerges from the top or side of one of these airborne behemoths, like a snake warning you to steer clear of it. As you emerge from the gap and skirt the leading edge of one of these anvil-topped giants, your senses overload as a brilliant flash of light explodes from the windscreen. With spots dancing in your eyes, a ringing in your ears, and the faint acrid smell of burnt wiring, you reset just about every circuit breaker and start checking your aircraft systems for anything that might prevent you from getting down to the closest airport for a damage inspection.

A 2003 study by researchers at the University of Florida revealed that on average a commercial aircraft is likely to be struck by lightning every 3000 flight hours (approximately once per year). While a disturbing statistic, it is not surprising given that, in the US alone, about 40 million lightning strokes hit the ground—and meteorologists estimate that such a number accounts for only about 20% of all lighting strokes. This means another 160 million strokes happen within and between the clouds.

Globally, the quantity of lightning is, naturally, even more impressive. At any given moment there are about 2000 active thunderstorms raging somewhere on the planet, producing about 100 lightning strokes every second. This equates to more than 8 million per day, and around 3 billion every year.

Of course, some regions are more prone to lightning than others. For example, the perennial thunderstorm belt that rings the planet at the tropics is responsible for a significant proportion of those strokes. The storms that pop along the cold fronts associated with the midlatitude cyclones that migrate along the polar jet are another key producer. Monsoonal flow and the storms that develop as air flows up against the planet's mountain ranges account for many of the remaining lightning strikes. In fact, satellite sensors have recorded lightning strikes on every single continent, and over almost every square mile of populated land around the world. Lightning is ubiquitous, and it's bound to affect your flying at some point.

Lightning is nothing more than a discharge of electricity, and serves to maintain the electrical balance of the atmosphere. This is the only factor that defines a thunderstorm. Technically, a cumulus cloud that is producing precipitation but is not producing lightning is not a thunderstorm, no matter how big it may be.

Anatomy of a lightning stroke

Although a lightning stroke can be displayed in infinite ways, they all have the same formative process. This process starts with positive and negative charges building up in different places—either within a cloud, between 2 clouds, or between a cloud and the ground. Don't worry, though—your aircraft is incapable of building a sufficient charge to trigger a lightning stroke.

When the electrical difference between the positive and negative charges becomes great enough, the negatively-charged electrons become attracted to the positively-charged regions and start to flow toward them. The trail blazed by the electrons, commonly from the base of the cloud toward the ground, is known as a stepped leader. It is "stepped" not because it may alter its direction or fork into a series of branches, but rather because the electrons surge about 50 meters at a time, pausing for about 50 microseconds (50 millionths of a second) before surging the next 50 meters. At this rate, it takes only a few seconds for a stepped leader to establish an ion channel that reaches almost all the way to the positively charged area.

On the other end, as the stepped leader approaches, positive ions are drawn toward it. When the 2 channels connect, the circuit is established and the positive charge flows quickly up the ion channel toward the cloud. The speed at which the return stroke moves up the channel is about 1/3 the speed of light, which often makes the motion of longer flashes visible to the eye.

The light in lightning is due to the current heating the air molecules to about 50,000°F (28,000°C), or about 5 times the temperature on the surface of the Sun. That intense heat emits the bright light of the lightning stroke. It also produces the rapid expansion of the air that creates the shock wave we hear as thunder.

The return stroke current usually neutralizes most of the negative charge but not all of it. Within the second, remaining electrons move down the same channel, generating follow-on return strokes. These dart leaders may repeat several times, giving the appearance of a single, flickering lightning stroke. Also, the used ion channel can remain a path of least resistance for a second or two after the return stroke, allowing a 2nd or even 3rd discharge along the same path and making it appear that lightning does strike twice in the same place.

Although the basic principles of lightning are well understood, meteorologists are still trying to figure out the exact mechanism that leads to the separation of charged particles within a thunderstorm. There are 2 leading theories.

The first is that the updrafts and downdrafts within the storm cell either loft positively-charged particles from the ground into the upper reaches of the storm, or draw negatively-charged particles from the cloud tops to their bases, building up a large potential.

The second theory is that individual rain drops, snow flakes, ice pellets and hail develop various charges as they collide, break up and coalesce. Positive ions are transferred from larger droplets or crystals to smaller ones. The heavier precipitation carries a negative charge to the cloud bases, while the lighter precipitation remains in the upper part of the storm.

Because lightning has only been observed in clouds that are precipitating and also extend above the freezing level, the 2nd theory appears to be more influential than the 1st and appears to be more dependent on ice crystal interaction in the upper parts of the storm than on the movement of liquid precipitation.

What makes lightning dangerous?

The scale at which lightning works to balance the atmosphere's electrical field is far greater than anything we can deal with easily. First of all, for a lightning stroke to even happen requires a potential of around 3 billion volts per kilometer. This means that for a cloud base 1 km (3300 ft) from the ground, 3 billion volts of charge difference is necessary for cloud-to-ground lightning discharge to occur. Longer strokes may be 2 or 3 km in length, giving them an electromotive force of 6–9 billion volts.

Lightning strikes the Statue of Liberty in New York Harbor. Charged particles will travel along a path of least resistance, which often means going through objects that rise above the surrounding landscape.

Because the huge potential is discharged almost instantaneously, the current—the flow of that potential, which is measured in amperes (A)—is incredible. A typical lightning stroke discharges at a current of around 20,000–40,000 A. Compare this with most aircraft circuit breakers which trip at 5 A or less, and the 80 milliamperes (80/1000 A) of current that can lead to cardiac arrest, and you can see how dangerous lightning really is. To get an idea of how much energy is being transferred in a single lightning stroke, just multiply the 3 billion volts of a 1-km stroke by the 40,000-A current to get 120 trillion watts (120 terawatts) of power delivered in under a second. Even the largest power plants produce only a few gigawatts of power over the course of an hour.

Thunder in close proximity of a lightning strike will register around 120 dB. This is about as loud as a chainsaw, and on par with a gunshot at the same distance. Eardrums are damaged at about 160 dB, but an impact sound that loud can temporarily disable the auditory nerves that process sound—leading to ringing or a high-pitched whine in the ears for several minutes thereafter. An additional danger is that, during the recovery time from an impact sound such as a close lightning strike, your sense of equilibrium may also be compromised—leading you to think you are banking when your wings are in fact level. If you are impaired, but confident your autopilot is still functional, engaging it may provide critical time for you to recover your senses.

Lightning and aircraft

An aircraft filled with metal parts and charged electrical systems *flying* through an area of high charge separation seems like an invitation to trigger a lightning strike, with the aircraft at the receiving end of things. However, given the huge difference in charge required before a discharge, it is unlikely that an aircraft would be generating a positive or negative charge sufficient to instigate a lightning bolt. Instead, an aircraft simply acts as a path of least resistance as it flies between 2 polarized regions of the clouds. A nearby stepped leader will pass through an aircraft since it will be more conductive than a nearby path through empty air. Unfortunately, that means the aircraft becomes part of the ion channel when the circuit completes and the return stroke fires.

Most lightning strokes are much shorter than 1 km, and therefore have a discharge threshold well below 3 billion volts. However, the current across even a short lightning path can still be in the region of 5000–20,000 A—more than enough to melt wires and damage sensitive electronics.

When lightning does pass through an aircraft, it will generally begin by attaching to an extremity, such as a wing tip, nacelle or antenna. The path will then migrate aft as the aircraft moves forward, attaching to other spots until the charge has been neutralized. Where the lightning strikes the aircraft, the intense heat produced by the current may scorch the skin or even burn a small hole. Lightning channels are at most around 4 inches in diameter, and usually an inch or less. The marks left behind are of similar diameter. Aircraft with conductive skins, such as aluminum, tend to fare better with lightning strikes than those without. Modern aircraft with fiber composite skins generally incorporate a thin layer of conductive material into the skin. Without that layer, lightning can cause substantial damage to fiberglass or carbon fiber skins.

There have been a number of fatal aircraft accidents involving lightning. These include aircraft that broke apart in flight after a lightning strike ignited flammable vapors in the fuel tank. In other cases, lightning has caused complete electrical failures, welded control cables and damaged hydraulics. In still other instances, pilots have crashed after being blinded by lightning strikes while flying at low altitude.

Most of the accidents involving mechanical damage occurred decades ago, and aircraft manufacturers have since put a great deal of effort into ensuring that all critical systems are adequately shielded against lightning damage. Today's aircraft are generally able to handle a lightning strike with minimal impact.

Modern aircraft skins are also stronger and more capable of withstanding burn-through from a lightning strike. They are also designed to channel electrical charges away from critical systems and out toward wingtips where they can be dissipated easily by static discharge wicks. Wiring beneath the skin is better shielded to protect against transient currents entering the wiring from a charge on the skin. Fuel systems are well grounded and designed to prevent sparking, and modern fuels are also formulated to produce less explosive vapors.

Acting as a "Faraday Cage," metal skins and frames help shield interior electronics and passengers from lightning. Nonmetallic skins often contain a layer of conductive material for the same purpose.

While an aircraft's skin and frame will serve to channel the energy from a lightning strike away from occupants and critical internal systems, there remain a few places on an aircraft that are susceptible to damage from strikes. Just about every aircraft has communications equipment and electronic navigation avionics that rely on external antennae. An antenna can be a direct route into an aircraft's electronics. While this wiring is heavily shielded and equipped with circuit breakers and surge suppressors, a direct hit on an antenna has the potential to knock those systems out of operation. On larger aircraft, radar and communications antennae are housed behind nonconductive nacelles or radomes to which lightning strips have been bonded in order to channel a strike away from the transceivers within.

Another area in which an aircraft remains prone to lightning damage is if there is a direct strike to any of the control surface linkages. Depending on the aircraft, a lightning strike to a control rod, hydraulic piston or electronic servo or its wires could potentially knock it out of commission, making control of the aircraft difficult. Fortunately, accident statistics show a relatively low probability of this sort of event.

The one area of lightning protection over which aircraft designers have little control is the potential for a strike to disorient the pilot. Temporary blindness and possible temporary hearing loss can easily lead to loss of equilibrium and situational awareness. At low altitudes, such as during takeoff or landing, this debilitation could prove disastrous.

Pilots have long been told to avoid thunderstorms by at least 20 miles, due to the fact that a storm can generate strong turbulence and throw hail several miles from a storm. But in addition, lightning often passes between thunderstorms, and may also emanate from the positively-charged anvil top that extends miles downwind from the storm's core. In fact, such bolts "from the blue" are often the strongest of all lightning strokes, due to the large distances they must travel.

Several avionics products are available to locate and help you steer clear of areas of heavy lightning activity. Stormscope, Strikefinder, many other weather avionics and even older ADF receivers can all provide information on the location and proximity of lightning strikes. Subscribers to satellite or cellular-based weather uplink services may also receive lightning information from a surface-based detection network. Some GA pilots even still carry an AM radio to help them determine if there is lightning nearby.

When flying through an area where lightning is either occurring or is a likely possibility, it's a good idea to have a crewmember looking only at instruments. In single-pilot operations in lightning, the pilot should only glance outside briefly to maintain situational awareness unless greater visual attention is warranted. In addition, unless otherwise recommended by your POH, you might choose to disengage any noncritical electrical systems by opening the circuit breakers, reducing the possibility of electrical damage to those systems. Just remember to close the breakers again when the danger has passed.

Getting struck

Should your aircraft happen to experience a lightning strike your first priority is to fly the aircraft. If you are having difficulty seeing or maintaining your equilibrium, check to see if your autopilot can still help (although, if it's operating, make sure it's working properly before you rely on it). When you feel able and safe to do so, make sure that all your aircraft's essential systems are in working order. All aircraft should have a post-strike checklist pilots can follow to ensure nothing critical is overlooked. At the least, check the operation of all control surfaces and all communications and navigation systems. (Many pilots carry a handheld nav/com unit for just such emergencies.) Ensure that the fuel delivery and propulsion systems are functioning normally, check pressurization, and check that you'll be able to deploy your landing gear and flaps when the time comes to land. If you'll be landing at night, check your aircraft lighting as well.

It should be noted that the wide open spaces with metal hangars, aircraft and towers make airports ideal spots for lightning strikes as well. If there is lightning near the airport it's wise to remain indoors and not use any electronic equipment. Even telephones and crew showers should be avoided until the storms have passed. If you are stuck outdoors, crouch on the balls of your feet to minimize the chance of being struck. If you notice someone get struck by lightning, provide medical attention immediately, as long as you are not placing yourself in danger. While there can be a danger of additional strikes, there is no danger of a lingering electrical current.

Regardless of whether your aircraft has been struck, once the lightning danger has passed, file a Pirep to alert ATC and other pilots to the potential for lightning strikes. After landing, do a thorough walkaround of the aircraft to look for any external damage. (You may not even have noticed a lightning strike.) If a lightning strike is even suspected, the aircraft should be thoroughly examined by a mechanic to identify (and, if needed, repair) any strike damage before your next flight.

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