ASOS Research Brief

Research Request:

What atmospheric conditions are more conducive for lightening strikes other than the obvious (i.e. thunderstorms and severe weather)?

Research Response:

Lightning Development

It is common knowledge that lightning is generated in electrically charged storm systems. How lightning initially forms is still not conclusively determined. Scientists have studied root causes ranging from atmospheric perturbations (wind, humidity and atmospheric pressure) to the impact of solar wind and accumulation of charged solar particles. Ice inside a cloud is suspected to be a key element in lightning development, and may cause a forcible separation of positive and negative charges within the cloud, helping to create conditions favorable for the formation of lightning.

In an electrical storm, the **storm clouds are charged** like giant capacitors in the sky. The upper portion of the cloud is positive and the lower portion is negative. How the cloud acquires this charge is still not agreed upon within the scientific community.

When there is a charge separation in a cloud, there is also an **electric field** that is associated with the separation. Like the cloud, this field is negative in the lower region and positive in the upper region.

The strength or intensity of the electric field is directly related to the amount of charge buildup in the cloud. As the water droplet collisions and freezing continue to occur and the charges at the top and bottom of the cloud increase, the electric field becomes more and more intense -- so intense, in fact, that the electrons at the earth's surface are repelled deeper into the earth by the strong negative charge at the lower portion of the cloud. This **repulsion of electrons** causes the earth's surface to acquire a strong positive charge.

Aviation Research Group/U.S. Inc
U.S., Inc. 212 W. 8th Street Cincinnati, OH. 45202
215-345-6782

In-Flight Aircraft Lightning Strikes

Edward J. Rupke, senior engineer at Lightning Technologies, Inc., (LTI) in Pittsfield, Mass., provides the following explanation:

It is estimated that on average, each airplane in the U.S. commercial fleet is struck lightly by lightning more than once each year. In fact, aircraft often trigger lightning when flying through a heavily charged region of a cloud. In these instances, the lightning flash originates at the airplane and extends away in opposite directions. Although record keeping is poor, smaller business and private airplanes are thought to be struck less frequently because of their small size and because they often can avoid weather that is conducive to lightning strikes.

Aircraft lightning strike phenomenon

In-flight experiments have shown that there are two types of aircraft lightning strikes. The most frequent case (90% of events) is lightning triggered by the intrusion of an aircraft in a region with an intense electrostatic field. The other case is the interception of a branch of a natural lightning by an aircraft. Electric currents associated with the luminous brightening are probably in the range of 1,000 to 4,000 amperes. Strikes to aircraft exhibit peak currents of only a few thousand amperes, about an order of magnitude less than currents in ground flashes—though sometimes the peak currents are large.

Some Heavy Science

For lightning triggered by an aircraft, the main chronological sequence of events can be investigated by using the typical E-field variation measured on all E-field aircraft sensors. These measurements show that there are two phases in the lightning strike to aircraft. The first phase is characterized by the bi-directional leader inception and development. This phase begins when an aircraft flies into a region of a thunderstorm in which the electrostatic field reaches a critical value in the range of 50-100 kV/m. An electrical discharge (positive leader) is initiated from the aircraft and propagates in the direction of the ambient field. During the development of this leader, a negative charge is injected into the aircraft, producing a positive variation of the E-field on the aircraft surface. Consequently, a few milliseconds later, the electrical conditions for the inception of a negative-stepped leader are reached. It develops from the aircraft and propagates in the opposite direction of the ambient field vector and positive discharge.

Lightning Characteristics

Step Leaders

Once the ionization process begins and plasma forms, a path is not created instantaneously. In fact, there are usually many separate paths of ionized air stemming from the cloud. These paths are typically referred to as **step leaders**.

The step leaders propagate toward the earth in stages, which do not have to result in a straight line to the earth. The air may not ionize equally in all directions. Dust or impurities (any object) in the air may cause the air to break down more easily in one direction, giving a better chance that the step leader will reach the earth faster in that direction. Also, the shape of the electric field can greatly affect the ionization path. This shape depends on the location of the charged particles, which in this case are located at the bottom of the cloud and the earth's surface. If the cloud is parallel to the earth's surface, and the area is small enough that the curvature of the earth is negligible, the two charge locations will behave as two charged parallel plates. The lines of force (**electric flux**) generated by the charge separation will be perpendicular to the cloud and earth.

Flux lines always radiate perpendicularly from the charge surface before moving toward their destination (opposite charge location). Given this knowledge, we can say that if the lower surface of the cloud is not straight, the flux lines will not be uniform. Try this: Draw two points on opposite ends of a basketball. Next, draw a line on the basketball that connects the two points. The curvature of the line is analogous to the flux lines in a non-uniform electric field. The lack of uniform force can cause the step leaders to follow a path that is not a straight line to the earth.

Considering these possibilities, it becomes obvious that there are various factors that affect the direction of the step leader. We are taught that the shortest distance between two points is a straight line; but in the case of electric fields, the lines of force (flux lines) may not follow the shortest distance, as the shortest distance does not always represent the path of least resistance.

So now we have an electrically charged cloud with ever-growing step leaders stretching out toward the earth in stages. These leaders are faintly illuminated in a purplish glow and may sprout other leaders in areas where the original leaders bend or turn. Once begun, the leader will remain until the current flows, regardless of whether or not it is the leader that reaches the ground first. The leader basically has two possibilities: continue to grow in stages of growing plasma or wait patiently in its present plasma condition until another leader hits a target.

Positive lightning

Positive lightning, also known colloquially as a "bolt from the blue" makes up less than 5% of all lightning. It occurs when the leader forms at the positively charged cloud tops, with the consequence that a negatively charged *streamer* issues from the ground. The overall effect is a discharge of positive charges to the ground. Research carried out after the discovery of positive lightning in the 1970s showed that positive lightning bolts are typically six to ten times more powerful than negative bolts, last around ten times longer, and can strike tens of miles from the clouds. The voltage difference for positive lightning must be considerably higher, due to the tens of thousands of additional feet the strike must travel. During a positive lightning strike, huge quantities of ELF and VLF radio waves are generated.

Positive lightning has also been shown to trigger the occurrence of upper atmosphere lightning. It tends to occur more frequently in winter storms and at the end of a thunderstorm.

Anvil-to-ground

Another type of cloud-to-ground lightning is anvil-to-ground lightning. It is a form of positive lightning, since it emanates from the anvil top of a cumulonimbus cloud where the ice crystals are positively charged. The leader stroke issues forth in a nearly horizontal direction until it veers toward the ground. These usually occur miles from (often ahead) of the main storm and will sometimes strike without warning on a sunny day. An anvil-to-ground lightning bolt is a sign of an approaching storm, and may occur in a largely clear sky.

Cloud-to-cloud

Lightning discharges may occur between areas of cloud having different potentials without contacting the ground. These are most common between the anvil and lower reaches of a given thunderstorm. This lightning can sometimes be observed at great distances at night as so-called "heat lightning". In such instances, the observer may see only a flash of light without thunder. The "heat" portion of the term is a folk association between locally-experienced warmth and the distant lightning flashes.

Another term associated with cloud-cloud or cloud-cloud-ground lightning is "Anvil Crawler", due to the habit of the charge typically originating from beneath or within the anvil and scrambling through the upper cloud layers of a thunderstorm, normally generating multiple branch strokes. These are usually seen as a thunderstorm passes over you or begins to decay. The most vivid crawler behavior occurs in well developed thunderstorms that feature extensive rear anvil shearing.

Dry lightning

Dry lightning is a folk misnomer in common usage in the United States for thunderstorms which produce no precipitation at the surface. This type of lightning is the most common natural cause of wildfires.

Cloud-to-ground

Cloud-to-ground lightning is a great lightning discharge between a cumulonimbus cloud and the ground initiated by the downward-moving leader stroke. This is the second most common type of lightning, and poses the greatest threat to life and property of all known types.

Ground-to-cloud lightning

Ground-to-cloud lightning is a lightning discharge between the ground and a cumulonimbus cloud from an upward-moving leader stroke.

Sample Lightning Strike Reports from the ASRS Database

Narrative

MAJOR **LIGHTNING** STRIKE ON NOSE OF ACFT ENCOUNTERED WHILE CLBING THROUGH BACKSIDE OF HVY PRECIP AREA W OF CLE. ENCOUNTER OCCURRED AT APPROX 10000 FT MSL. APPARENT **LIGHTNING** AND DISCHARGE ACCOMPANIED BY LOUD BANG SEEN BY ALL OCCUPANTS OF ACFT. MANY EXTERIOR SURFACES OF ACFT SEEN ARCING AND EMITTING STATIC OR GENUINE ELECTRICAL DISCHARGE. CLB STOPPED AT 15000 FT MSL AFTER STRIKE. SPD REDUCED FROM 280 KIAS TO 250 KIAS. ACFT SYS, STRUCTURE AND HANDLING FULLY EVALUATED BY CREW. ONLY AFFECTED ONBOARD SYS WAS THE APU'S FIRE DETECTION SYS. POSTFLT MAINT INSPECTION REVEALED NO DAMAGE TO ACFT EXCEPT FOR 50% OF STATIC WICK AT TOP OF VERT STABILIZER MISSING.

Synopsis

B737-800 IS VICTIM OF **LIGHTNING** STRIKE DURING CLBOUT FROM CLE.

Narrative

AT FL270 WE SAW WX ON THE RADAR 30 MI AHEAD AND ASKED FOR A 20 DEGS R DEV FROM ATC. SOON AFTER WE TURNED TO THE NEW HDG WE RECEIVED A NEAR **LIGHTNING** STRIKE CAUSING OUR #2 ENG TO ROLL BACK. CONTINUOUS IGNITION WAS SELECTED 'ON' AND QRH PROCS WERE ACCOMPLISHED. WE CAME OUT INTO VMC AND TURNED BACK L ON COURSE. WE WERE TOLD BY ATC THAT WE WERE 400 FT LOW, 26600 FT MSL. I REQUESTED FL250 AND WAS TOLD, 'UNABLE.' EVEN WITH MAX CONTINUOUS THRUST WE WERE UNABLE TO ACCELERATE AND CLB BACK UP TO FL270. SO, I DECLARED AN EMER AND TOLD ATC WE NEEDED A COURSE TO STAY OUT OF THE WX AND NEEDED A LOWER ALT. WE WERE GIVEN FL190 AND 030 DEG HDG. THE AUTOPLT HAD BEEN REENGAGED AND THE FO HAD THE CTLS AND RADIOS. I PERFORMED THE XBLEED AIR START QRH PROC. ALL PARAMETERS WERE NORMAL AFTER THE START. THE EMER WAS CANCELED AND ZZZ WAS STILL OUR NEAREST ARPT IN POINT OF TIME.

Synopsis

CRJ200 FLT CREW HAS A **LIGHTNING** STRIKE AND ENG FAILURE, DECLARES AN EMER.

Narrative

AT THE TIME OF THE STRIKE, MULTIPLE **LIGHTNING** FLASHES WERE OBSERVED IN THE AREA, BUT THE WX RADAR INDICATED NO CELLS INSIDE THE 25 NM RING. 2-3 CELLS WERE OBSERVED OUTSIDE THE RING.

Synopsis

AN E145 FLT RECEIVES A **LIGHTNING** STRIKE AT 10800 FT ON THEIR CLBOUT 40 MI E OF PLL, IL.

Narrative

WHILE GETTING VECTORED FOR APCH, WE BELIEVE THAT WE EXPERIENCED A **LIGHTNING** STRIKE TO THE ACFT. WE WERE IN LIGHT TO MODERATE RAIN WITH LIGHT TURB AND CLR OF ALL RED RADAR RETURNS WHEN WE SAW A **LIGHTNING** BOLT MOVING THROUGH THE CLOUD IN FRONT OF US THAT APPEARED TO ENTER THE ACFT'S NOSE ON THE R-HAND SIDE. SIMULTANEOUSLY, WE HEARD A LOUD BANG. WE DID NOT EXPERIENCE ANY RADIO ANOMALIES AND ALL GAUGES CONTINUED TO INDICATE NORMALLY. AFTER LNDG, SEVERAL PAX IN THE AFT CABIN ON THE ACFT R RPTED SEEING FLASHES OF FIRE (SPARKS) COMING FROM THE R WING. SOME EVEN SAID THERE WAS A BURN MARK ON THE TOP OF THE WING. WE COMPLETED AN EXTERIOR POSTFLT INSPECTION AND DID NOT FIND ANY AREAS OF DAMAGE FROM **LIGHTNING** STRIKE. WE FOUND THE BLACK MARK ON TOP OF THE #4 SPOILER PANEL ON THE R-HAND SIDE TO BE REMAINS OF A BIRD. WE HAD NO INDICATIONS OF HITTING A BIRD OTHER THAN THE REMAINS DISCOVERED ON THE POSTFLT INSPECTION.

Synopsis

A320 FLT CREW ENCOUNTERS WX, A **LIGHTNING** STRIKE AND BIRD STRIKE DURING APCH FOR LNDG AT ORD.

Narrative

IN IMC, WE WERE FLYING ALONG AT FL340, AND WE SAW A TSTM AHEAD ON RADAR. WE ASKED TO TURN AND WE WERE CLRED TO DEV. WHILE AT LEAST 25 MI FROM THE STORM, WE WERE HIT BY **LIGHTNING**. COMRDO #2 WAS HIT BY **LIGHTNING** AND STOPPED WORKING. COM #1 RADIO WAS ONLY WORKING TEMPORARILY. AT THE SAME TIME, THE PRESSURIZATION SYS SHOWED A CLB OF 3000 FPM. AT THE TIME, WE WERE NOT SURE IF WE HAD BEEN HIT BY **LIGHTNING** AND IF ANY SYS WERE AFFECTED. SO WE PUT ON THE MASKS AND STARTED A DSCNT TO FL250. WITH LIMITED COMS, IT WAS DIFFICULT TO GET IN TOUCH WITH ATC TO GET THIS CLRNC. AT FL250 WE WERE ABLE TO COM WITH ATC THROUGH ANOTHER ACFT. ATC THEN TOLD US TO MAINTAIN FL250. THE PRESSURIZATION STABILIZED AND WE CONTINUED TO ZZZ1. AS SOON AS WE WERE ABLE TO COM WITH ZZZ APCH, WE HAD FULL CTL OVER COM #1. ON INSPECTION AFTER LNDG, WE DISCOVERED COM #2 BLOWN APART AND BURN MARKS ON THE FLAPS AND TAIL.

Synopsis

AN EMB145 IN CRUISE AT FL340 EXPERIENCED A **LIGHTNING** STRIKE INCURRING DAMAGE TO THE #2 COM AND LIMITED USE OF #1 COM.

Narrative

AT FL380, APPROX 40-50 MI E OF A LINE OF TSTMS, DEVIATING IN AREA THAT HAD RPTED DEVS IN ONLY LIGHT CHOP WITH LIGHT PRECIP IN CLOUD TOPS. NO CONVECTIVE ACTIVITY WAS PAINTING ALONG OUR FLT PATH. THROUGHOUT THIS AREA WE HAD INTERMITTENT LIGHT CHOP WITH ONLY A FEW MODERATE BUMPS. NEARLY SIMULTANEOUSLY WE HAD FLASH OF **LIGHTNING** WITH CLAP OF THUNDER AND AN UNUSUAL 20C-25C RISE IN OUTSIDE AIR TEMP TO APPROX -32 DEGS C. WE ASSUMED THAT WE HAD BEEN STRUCK BY **LIGHTNING,** IT CERTAINLY WASN'T A CLASSIC **LIGHTNING** STRIKE IF, IN FACT, IT WAS A STRIKE AT ALL. THE UNUSUAL TEMP RISE AT FL380 MIGHT HAVE GENERATED SOME PROBE ICING THAT TRIGGERED THESE EVENTS AND THE **LIGHTNING** MAY HAVE BEEN NOTHING MORE THAN A DISTR. NOT THE USUAL **LIGHTNING** STRIKE AS THE NOISE WAS NOT EXTREMELY LOUD AND IT WAS DOUBTED THAT IN FACT IT WAS A STRIKE. ON THE GND, THE **LIGHTNING** STRIKE WAS VERI-

FIED AS MAINT FOUND BURNED DISCHARGE SPOTS ON THE AFT CARGO DOOR THAT REQUIRED BURNISHING AND REPAINTING.

Synopsis

AN A319 IN CRUISE AT FL380 40-50 MI FROM A LINE OF TSTMS INCURRED A **LIGHTNING** STRIKE. HAD ENG #1 AND ENG #2 'EPR MODE FAULT' ECAM WARNINGS.

Narrative

TKOF WAS TO THE E BECAUSE OF WINDS AT LAX. TOOK RADAR VECTORS TO THE E, S, AND EVENTUALLY BACK TO THE W. HAD RADAR ON BECAUSE OF RAIN AND RECENT THUNDERSHOWERS. WHEN TURNED W, WE PAINTED SEVERAL SMALL CELLS IN FRONT OF US. CAPT ASKED FOR TURN TO R, TO AVOID WX. ATC SAID UNABLE BECAUSE OF TFC TO OUR R. CAPT ASKED FOR AS FAR R A TURN AS POSSIBLE AND ATC GAVE IT. AFTER TURN, IT APPEARED AS THOUGH WE WOULD GO THROUGH SOME YELLOW ON THE RADAR, BUT AVOID THE RED. AT ABOUT 8000 FT MSL, WE BROKE OUT OF THE CLOUDS INTO A CLRING, THE SIZE OF WHICH I COULD NOT TELL. THERE APPEARED TO BE MANY SPARKLERS, LIKE KIDS' SPARKLERS USED ON THE 4TH OF JULY. ALL OF A SUDDEN, WE WERE HIT BY **LIGHTNING**, ON THE L SIDE OF THE ACFT, JUST BELOW CAPT'S FEET. THERE WAS A VERY LOUD BOOM ASSOCIATED WITH THE STRIKE. MOMENTARILY, WE BROKE OUT OF THE CLOUDS INTO CLR AIR.

Synopsis

A B747-400 WAS STRUCK BY **LIGHTNING** DEPARTING LAX. UPON ARR, 30 RIVETS POPPED DISCOVERED FROM CAPT'S WINDOW ALONG UPPER DECK.

Narrative

WHILE BEING VECTORED ON APCH AT 12000 FT, TO ATL, WENT INTO GREEN WX AREA ON RADAR AND ENCOUNTERED 2 **LIGHTNING** STRIKES. FIRST MILD, SECOND APPROX 20 SECONDS LATER, SHOOK AIRPLANE. SPARKS OBSERVED IN FRONT OF ACFT. (LATER FLT ATTENDANTS RPTED SEEING ON R SIDE OF ACFT.) AFTER FLT AT GATE, FOUND NUMEROUS BURN HOLES ON OUTSIDE OF R ENG COWL.

Synopsis

B767 FLT CREW ENCOUNTERS TURB AND **LIGHTNING** STRIKES DURING APCH TO ATL.

Narrative

EMER LNDG DUE SMOKE IN CABIN. NORMAL S DEP RWY 19 IN LIGHT RAIN WINDS 210 DEGS AT 8 KTS CLBING THROUGH 9000-10000 FT WITH ANTI-ICE ON AND RADAR SHOWING ONLY LIGHT RAIN WITH SMALL POCKETS OF MODERATE PRECIP. ST ELMOS FIRE APPEARED ON BOTH WINDSCREENS FOLLOWED SHORTLY BY A BRIGHT FLASH OF **LIGHTNING** OFF THE L SIDE OF THE ACFT WITH A MUFFLED RUMBLE AND A MINOR AIRFRAME BUMP. THERE WERE NO INDICATIONS OF ANY ELECTRICAL PROBS WITH THE ACFT. SOON AFTER THE DISCHARGE, I BEGAN TO SMELL HOT ELECTRICAL WIRES AND THE #1 FLT ATTENDANT RPTED SMOKE FROM OVERHEAD FLUORESCENT LIGHT. SUSPECTING A BALLAST FIRE, I ASKED HER TO TURN OFF THE LIGHTS. SHORTLY AFTER SHE RPTED THE SMOKE DISSIPATING, MOMENTS LATER SHE RPTED SMOKE WAS INCREASING IN THE COACH CABIN. I DECLARED AN EMER, REQUESTED FIRE SUPPORT AND VECTORS TO DULLES. ON 22 MI FINAL, THE FLT ATTENDANTS RPTED THE CEILING IN COACH WAS MELTING AND THEY WERE USING THE FIRE EXTINGUISHERS. AT THIS TIME I ADVISED THE #1 FLT ATTENDANT THAT WE WOULD BE EVACING ON THE RWY.

Synopsis

MD80 CREW HAD A **LIGHTNING** STRIKE IN IAD CLASS B AIRSPACE.

NASA Storm Hazards Program Research

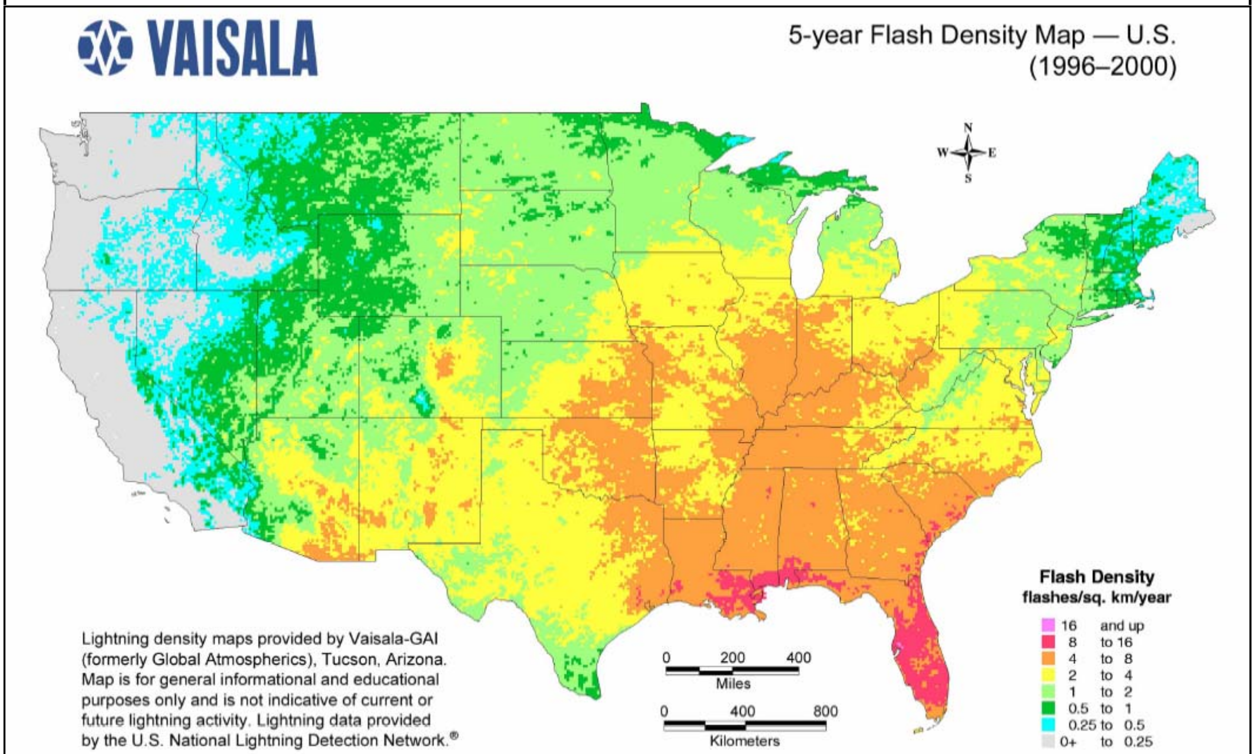
Source: Jack D Chapdelaine/NASA

Recent experimental flights designed to determine probabilities and causes of aircraft lightning strikes have provided some new information related to a pilot's chances of receiving an in-flight encounter with lightning bolts. Although there have been several recent studies, the bulk of the new information comes from two research projects: a USAF/FAA study which involved the use of a Convair 580 specially instrumented transport aircraft which flew for 42 hours and experienced 21 lightning strikes; and from a NASA Storm Hazards Program, which involved the use of a specially instrumented F-106B aircraft which made 1,154 thunderstorm penetrations and received 637 lightning strikes. These studies showed:

1. The majority of strikes (greater than 90 percent) were triggered by the aircraft itself.
2. The probability of an aircraft triggering a lightning discharge in a thunderstorm increased with altitude.
3. The probability of a lightning strike to an aircraft flying in a thunderstorm increased from a minimum at the thunderstorm base to a maximum at the 36,000- to 40,000-foot level. The temperature at this level was from -40 degrees C to 45 degrees C. The strike rate encountered at these high altitudes was two strikes per minute of penetration time. At 18,000 feet, the frequency was one strike every 20 minutes. An average of only one aircraft strike every 3 hours was encountered when flying below active thunderstorms.
4. Lightning strikes at high altitudes generally resulted in greater total charge transfer than strikes at lower altitude; however, the low altitude strikes sometimes produced greater instantaneous discharge.
5. The entire surface of the aircraft may be susceptible to lightning attachment even though strikes are more probable to particular areas such as the aircraft extremities (nose, wingtips, tail) and composite surfaces.
6. During penetration of thunderstorms at low levels, lightning strikes were found to occur in areas of moderate or greater turbulence at the edge of and within large downdrafts. Conversely, lightning strikes experienced in the upper areas of thunderstorms and in the vicinity of decaying thunderstorms most frequently occurred under conditions of little turbulence or precipitation.

It should be remembered that prior to this research it was thought that an aircraft had to fly into the path of naturally occurring lightning to get struck, and the altitudes near the freezing level (0 degrees C) were considered the most probable location for this to happen. The research data, however, seem to conflict with previous statistics. This does not mean that the old rules do not apply any longer. What it does mean is that we are learning more about the behavior of lightning and its effects on aircraft. Many of the old rules are still valid, and several new rules are being developed which we will be able to apply in the future.

Test Pilot Bruce Fisher during a lightning strike


VAISALA
5-year Flash Density Map — U.S.
(1996–2000)
N
W
E
S
Flash Density
flashes/sq. km/year
16 and up
8 to 16
4 to 8
2 to 4
1 to 2
0.5 to 1
0.25 to 0.5
0+ to 0.25
0 200 400
Miles
0 400 800
Kilometers
Lightning density maps provided by Vaisala-GAI (formerly Global Atmospherics), Tucson, Arizona. Map is for general informational and educational purposes only and is not indicative of current or future lightning activity. Lightning data provided by the U.S. National Lightning Detection Network.®