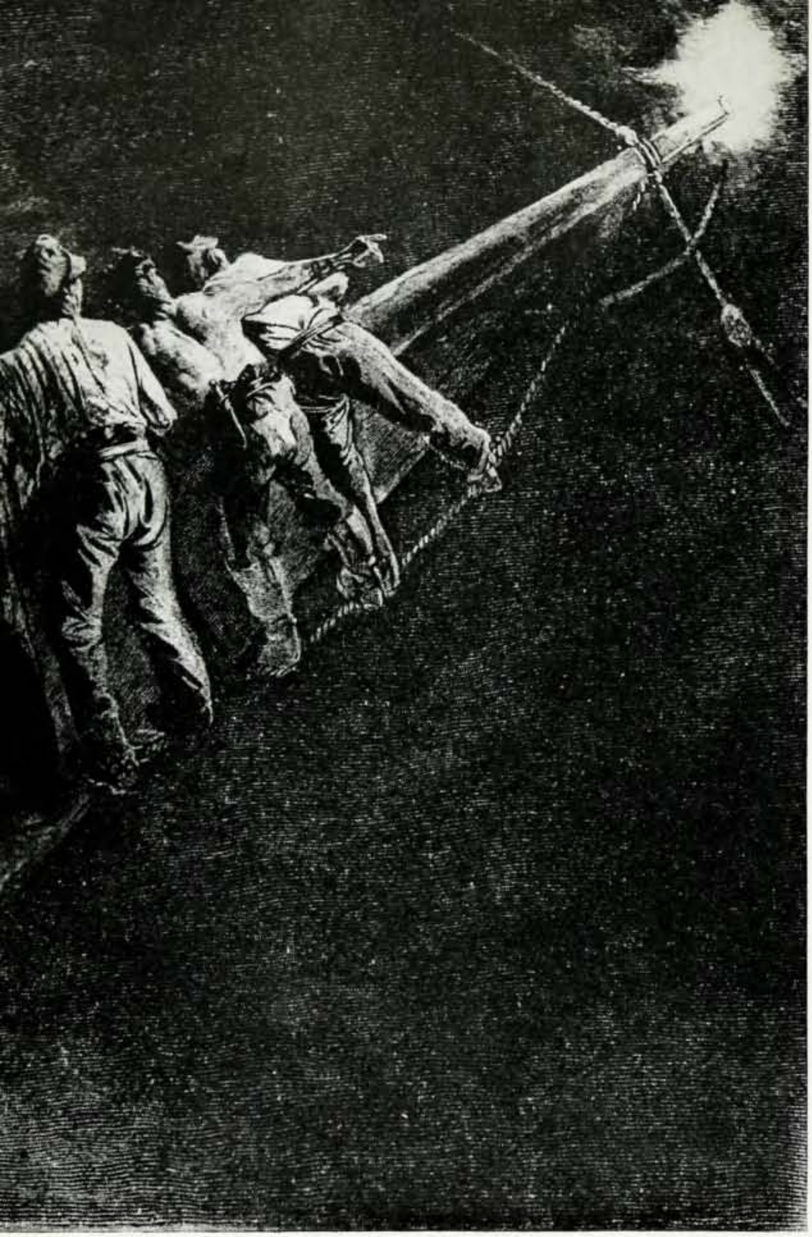


Engineers

and physicists

labored

and brought forth . . .

. . . Pigtails on a Stratoliner

by J. C. Jensen

Above: St. Elmo's Fire electrical phenomenon occurring during storms. Old-entime sailors believed it to be the vision of their patron saint. Engraving by H. Davidson. (Bettmann Archives.)

Right: Thirty-foot spark to suspended and insulated airplane. (From collection of Minneapolis Precipitation Static Laboratory, courtesy of Dr. Ross Gunn.

From the earliest records of sailing the seas in ships come tales of a strange phenomenon known as St. Elmo's fire, a visible discharge from pointed parts of the ship into the atmosphere.

On land, during dust and sand storms, people taking hold of the control wires of metal windmills mounted on wooden towers have received severe electrical shocks because the metal parts had become charged by contact with the flying dust. Radio operators have observed sparks at least half an inch long, jumping from an insulated antenna exposed to dry, wind-driven snow. Gasoline trucks, insulated from the earth by rubber tires, are required by safety regulations to drag along a heavy chain under the truck, to ground accumulated electric charges.

Aircraft, plunging through the atmosphere at high speeds, also develop high electrical potentials. Pilots have often reported tongues of violet or purple fire escaping from propeller tips, the edges of the windshield, or other sharp-edged surfaces when flying in cirrus or alto-cumulus clouds. Similar discharges, sometimes accompanied by a hissing noise, may be observed on the collecting brushes of a Toepler-Holtz, or Wimshurst, static induction machine, or on the high tension wires supplying power to a Coolidge x-ray tube.

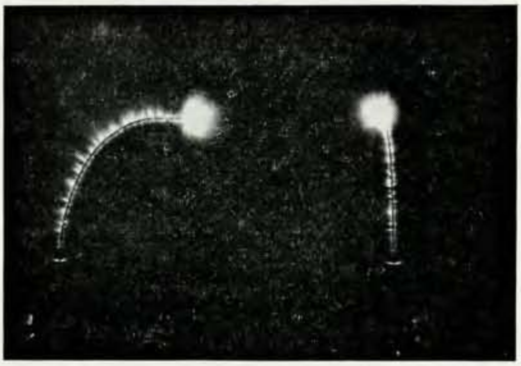
Because the potential gradient is highest around pointed conductors the air around the points becomes ionized first, with a resulting flow of electricity into the gases surrounding them. Due to the higher mobility of the electrons at the negative pole of a charged body than that of the positive ions at the positive terminals, corona begins more readily at negative points; and airplanes, it has been observed, usually collect negative charges rather than positive.

There is no danger to the passengers inside the plane, but these charges, when they escape in more or less visible corona streamers, produce very annoying radio interference originally called "rain static" by Morgan of TWA at Kansas City and by Nakai of Japan, about 1936. The following year Hucke, air safety engineer with the Civil Aeronautics Authority, and his Radio Technical Committee, officially adopted the term "precipitation static." A long series of investigations followed in persistent attempts to remove this serious menace to aerial navigation.

J. C. Jensen, physics professor and dean of men at Nebraska Wesleyan University, wrote his doctor's thesis at the University of Nebraska on the polarity of thunderclouds. During the war he was one of a small group who worked on precipitation static at Curtiss-Wright Research Laboratory. He has published other reports on weather and radio reception, ball lightning, and the relation of ponds and lakes to precipitation from local thunderstorms.

Blots Communication

The interference from precipitation static is not the usual static disturbance we hear on our radios. The crackling noises we hear are called "atmospherics." Atmospherics may originate in lightning discharges in a distant thunderstorm and travel many miles exactly as the amplitude modulated Hertzian waves of a usual radio signal travel. Disturbances produced by x-ray machines, automobile



Corona streamers from the terminals of a Tesla coil. Potential difference about two hundred thousand volts.

ignition systems, or faulty high tension transformers also add to the unwelcome crashes superposed on our radio programs.

Precipitation static, on the other hand, cannot be detected far from the aircraft on which it originates. It usually makes itself known as a crying, squealing sound that obliterates the radio range and radio compass signals on which the pilot must depend when weather conditions require that he fly by instruments alone.

Early Investigations

While many preliminary studies had been made, it was not until 1939 that losses in pilots and planes had mounted to such proportions that large scale research was organized. With World War II, and the rapid expansion in aviation that it brought, these investigations were accelerated and later coordinated under military auspices.

A complex structure like an airplane contains many devices which may contribute to radio interference, or cause it directly, such as engine ignition systems, plate supplies for radio transmitters and receivers, or generators for power and lighting. The early investigators cleaned their machines electrically by improving the insulation and shielding, and by bonding and grounding the metal parts more carefully. They also tried to adapt various limiter circuits, which clip off the high amplitude static peaks of amplitude modulated signals, in the regulation aircraft receivers. Narrow band, highly selective tuners were tried. But none of these efforts gave more than partial relief.

Flight tests by Hucke and his collaborators, by Ayres at Kansas City, and laboratory experiments by Starr of Oregon State College, George of Purdue, and Langmuir and Schaefer of General Electric Company, to mention only a few, established the fact that precipitation static results primarily either from the friction of dry snow, ice spicules, or dust against the plane, or from charges induced on the metallic surfaces when in the vicinity of a thundercloud.

Charging by Friction

The first of these types, called autogenous charging, is much the more serious because it is encountered both summer and winter at high altitudes and high latitudes. Since every change in an electric field is accompanied by the production of Maxwellian, or Hertzian waves with their simultaneous electrostatic and electromagnetic components, the corona discharges from points and sharp edges on an airplane produce electric waves in their vicinity which induce corresponding disturbances on radio antennas and on unshielded radio circuits. The induced potential is proportional to the rate of change of the field, which becomes very large when the ionization of the air develops into the electronic avalanche known as a spark discharge. Spark discharges, by shock excitation of radio circuits, are the source of crashing atmospherics but the less energetic corona discharges produce the crying, howling interference of precipitation static which in severe cases completely drowns out the A and N signals of the radio transmitters on the ground.

"A" in radio code is dot-dash (·—), while "N" is dash-dot (—·). The range transmitter has directional characteristics such that A or N signals predominate in alternate quadrants. When the pilot is "on the beam," on a forty-five degree angle from the axes of adjacent A and N quadrants, he hears a continuous tone (—··—), or rather (————), for the sequence is such that the dot of the A fills in the space between the dash and dot of the N and the dot is in reality just a shorter dash. If the pilot is ten degrees off course, static interference may prevent him from differentiating between their relative intensities, for it is this difference in signal strength which must guide him back to the true course. Since the charging is a frictional effect, found to vary approximately as the cube of the air speed, pilots were instructed to slow down long enough to check their course, when necessary. Wind tunnel tests on model planes of reduced size showed that some of the lacquers and camouflage paints in common use created much more interference than a clean aluminum surface. Consequently the paint program for aircraft was radically revised. Also, a shielded, rotatable loop antenna, in addition to its directional effects, was found to be much quieter than the regulation open wire antenna, and shielded loops were adopted as regular equipment.

Charging by Induction

Exogenous charging, the second type, occurs when an insulated conductor like a flying airplane enters an electrical field such as that which exists between different sections of a thundercloud. The frequent lightning flashes which extend from one part of the storm cloud to the other without going to ground show what large potential differences exist in the cloud itself. An airplane entering such a field may provide a path of low resistance over which lightning may pass to equalize the electrical field between its extremities. Lightning strokes to a plane are rather common and seldom are fatal, but they do blind the pilot temporarily and can put the radio compass and radio receivers out of commission.

Even if this does not happen the airplane is subjected to induced charges of considerable magnitude. The wing tip nearest a positively charged section of cloud becomes strongly negative by attraction of unlike kinds of electricity, while the opposite wing becomes the seat of the repelled positive charge. The crashing or ordinary static in the vicinity of a storm is sufficiently intermittent to permit range signals to get through but when the induced charges produced by adjacent clouds bring the potential above the corona level, typical precipitation static results. Because of this radio interference, and the considerable hazard from turbulent air currents in a cumulo-nimbus cloud, pilots avoid flying through a thunderstorm when they can.

Army and Navy Help

Where the lives of passengers and crew are at stake, as well as property losses running to hundreds of thousands of dollars for a single disaster, large scale research directed by skilled investigators is obviously justified. The earlier experiments, sponsored by aircraft manufacturers and air transport companies, were largely uncorrelated. Resulting observations were incomplete or inconsistent because there was no uniformity in methods of attack or conditions prevailing during the experiments. Even the largest airlines could ill afford to load down scheduled planes with heavy equipment and scientist supercargo particularly when the pilots had orders to run away from, not into, the storms that loomed on the horizon. And so it came about that the Army and Navy Air Services joined forces in what became a large research project.

The central laboratory for both flight and ground testing was a specially designed hangar at the Wold-Chamberlain Field at Minneapolis. Here a B–25 and a B–17 were fitted out as flying laboratories with full complements of electrical and aeronautical instruments. They were manned by pilots and observers who went out looking for trouble in all kinds of weather. For stationary tests under controlled conditions, the B–25 was suspended inside the hangar on high tension insulators and charged to potentials as high as 1.2 million volts using a high voltage generator developed at the University of Minnesota. Dr. Ross Gunn of the Naval Research Laboratory in Washington was technical director of the project, while staff members included capable men from civilian ranks and the armed forces, such as Captain Cleveland of Wright Field, Dayton, Ohio.

Special Instruments

Among the unique instruments used effectively in field tests were an electric field meter developed by Gunn, and an artificial charger first used by Ayres. In the charging device an atomized spray of liquid was passed through a strong electrostatic field before being released in the slipstream of passing air. The droplets thus carried away with them electricity of one sign while they left behind an equal amount of the opposite sign. It was possible to charge a B–17 to five hundred thousand volts, either positive or negative, using seventy-five gallons of water per hour.

Some of the results obtained in these tests seem startling. For example, the electrostatic capacity of a B–17 in flight is only about eight hundred micro-microfarads. At a charging rate of one hundred fifty microamperes the potential of the craft would increase at the rate of about two hundred thousand volts per second. Most aircraft break into corona at two hundred thousand volts, or less, so that a charger which is able to hold the potential well below the critical value even for a few minutes would be valuable in emergencies. However, the most important application of the artificial charger was to produce on a plane in fair weather a sufficient charge to test all kinds of devices under controlled, steady conditions. Clouds are far from being homogeneous in structure, hence a plane flying through them gives the observer little opportunity to obtain consistent data. For everyday flying the charging equipment and liquid add too much weight to be practical.

Earlier experiments, notably by Bendix engineers, had shown that a fine wire ten to twenty feet long, and connected through a resistance of half a megohm to the tail of the plane and thus removed as far as possible from the radio antenna, would facilitate silent discharge under precipitation static conditions. The fine wire is equivalent to a series of points and the high resistance reduces the discharge current to a small, nearly steady flow which produces very faint Hertzian waves. But such a device is an intolerable nuisance in operation, trailing behind the plane with a weight at its outer end, particularly for fighter craft in wartime. Polished steel needles and other pointed devices, with or without dissipating resistors, had given some hope of a favorable solution, as had also a chemically treated cloth fringe attached to trailing edges of wings and rudders. With the facilities of the Wold-Chamberlain hangar for insulating the planes from the ground and charging them easily beyond the corona point, every conceivable appliance could be put to crucial tests under identical conditions.

The Pigtail Discharger

In 1944 the Navy had developed a discharger consisting of a cotton wick saturated with a glycerine compound, which was mounted in an aluminum tube that extended downwards and backwards from the lower side of wings and stabilizers. Flight and laboratory tests were all favorable, but the tube projected down like a sore thumb and was constantly getting knocked off. It was obviously not the long-sought solution but out of it grew a discharger which has now become standard aircraft equipment. The aluminum tube has been replaced by one of a flexible plastic material and the cotton cords have been sufficiently mineralized to become mildly conducting. An airplane equipped with an array of pigtails (three each on the outer trailing edges of the wings) can maintain radio communication through interference conditions several times as bad as one not thus protected. But the problem is not yet wholly solved because reducing the charge on the plane is not the whole trick.

Other Aids

Corona currents of only five or six microamperes from antenna wires interfere seriously with the radio receivers to which they are connected. To try out improved forms of antenna hardware and the effects of a variety of paints and lacquers, the B–17 at Minneapolis and its counterpart at Kansas City flew through numerous Minnesota and Kansas thunderstorms during the seasons of 1944–47. From their experiences tee-splices and masts of approved aerodynamic design were produced. Larger antenna wires, covered with a plastic dielectric, are used regularly where snow is constantly being encountered, but the plastic sometimes punctures and becomes worthless when exposed to the large induced potentials caused by thunderclouds. Surface coatings which develop, in autogenous charging, positive potentials to counteract the preponderant negative are available, but they are ineffective against exogenous charging.

The radio range signals are in the two-hundred-to-five-hundred-kilocycle band, just below the broadcast band. The recent tests have corroborated earlier reports that shock excitation from corona discharges is much less troublesome at frequencies of one hundred megacycles or more. However, ultra-high frequency transmissions are seriously limited in their range just as FM and television signals are. A change to higher frequencies for radio range work will be an involved and costly process unless the future brings forth new techniques.

An important by-product of these experimental flights into storm clouds is that meteorologists now know much more than they did about the velocities of air currents there and the distribution of their electric charges.

For security reasons many of the findings of the research workers have not been included in the published reports. Applications of radar and loran to safety in flight have already been made and are becoming increasingly important. Frequency modulation at intermediate frequencies, and a larger number of transmitters, properly spaced, would solve the interference problem for overland flight but they could not span the distances involved in transoceanic travel. Ultra-high frequency telephone communication around airports is in daily use for conveying orders from the signal tower to incoming and departing planes. This service should be even more efficient with frequency modulation.

The more-or-less ionized exhaust gases from the engines may eventually be used for artificial charging but thus far such efforts have met with little success. Continued improvements may be anticipated in airplane design and in the use of paints, lacquers, and plastic coverings. In peace or war, the aircraft industry must of necessity keep abreast of the hazards presented by four-motored streamliners and by supersonic flight.

So far, the singular remedy for precipitation static, devised through the cooperative efforts of scores of skilled engineers and physicists, is a little black pigtail with a fuzzy tip—but it works.