# NASA Facts

National Aeronautics and Space Administration

**John F. Kennedy Space Center**
Kennedy Space Center, Florida 32899

FS-2004-02-002-KSC

# Lightning and the Space Program

## KSC lightning protection systems

Kennedy Space Center (KSC) operates extensive lightning protection and detection systems in order to keep its employees, the 184-foot-high Space Shuttle, the launch pads, payloads and processing facilities from harm. The protection systems and the detection systems incorporate equipment and personnel both at KSC and Cape Canaveral Air Force Station (CCAFS), located southeast of KSC.

## Predicting lightning before it reaches KSC

*Air Force 45th Weather Squadron* – The first line of defense for lightning safety is accurately predicting when and where thunderstorms will occur. The Air Force 45th Weather Squadron provides all weather support for KSC/CCAFS operations, except Space Shuttle landings, which are supported by the National Atmospheric and Oceanic Administration (NOAA) Spaceflight Meteorology Group at Johnson Space Center.

Information provided by the 45th Weather Squadron includes lightning advisories and warnings critical for day-to-day Shuttle and payload processing, as well as launch day weather data essential in helping NASA determine when it is safe for the Space Shuttle to lift off. The 45th Weather Squadron has developed several techniques to forecast lightning and has teamed with many universities to improve thunderstorm prediction.

The 45th Weather Squadron operates from Range Weather Operations (RWO) at CCAFS, a center for the forecasting and detection of thunderstorms and other adverse weather conditions. RWO houses the Meteorological Interactive Data Display System, which processes and displays data from the National Centers for Environmental Prediction, weather satellite imagery and local weather sensors to help forecasters provide the most accurate, timely and tailored support possible for KSC operations.

Among the local sources of weather information are two weather radars that can identify and track storms within a 150-mile range of Cape Canaveral, and the Wind Information Display System, a network of towers with wind, temperature and moisture sensors. Wind measurements can reveal some of the conditions that can cause thunderstorm development.

*Lightning Detection Systems* – The Launch Pad Lightning Warning System (LPLWS), Lightning Detection and Ranging (LDAR) system and the Cloud to Ground Lightning Surveillance System (CGLSS) provide data directly to the Range Weather Operations on atmospheric electrical activity. These systems, along with weather radar, are the primary Air Force thunderstorm surveillance tools for evaluating weather conditions that lead to the issuance and termination of lightning warnings.

The LPLWS comprises 31 electric field mills uniformly distributed throughout KSC and Cape Canaveral. They serve as an early warning system for electrical charges building aloft or approaching as part of a storm system. These instruments are ground-level electric field strength monitors. Information from the LPLWS gives forecasters information on trends in electric field potential and the locations of highly charged clouds capable of supporting natural or triggered lightning. The data are valuable in detecting early storm electrification and the threat of triggered lightning for launch vehicles.

This is one of the 31 electric field mills that compose the Launch Pad Lightning Warning System. They are called mills because they have a rotating, four-bladed shield much like arms of a wind mill. The shield contained in the bottom of the round housing alternately exposes and covers metal sensing plates, resulting in an alternating current proportional to the atmospheric electric field.

LDAR, developed by KSC, detects and locates lightning in three dimensions using a "time of arrival" computation on signals received at seven antennas. Each part of the stepped leader of lightning sends out pulses, which LDAR receives at a frequency of 66 MHz (equal to TV channel 3). By knowing the speed of light and the locations of all the antennas, the position of individual steps of a leader can be calculated to within 100-meter accuracy in three dimensions. LDAR provides between one and 1,500 points per flash.

For many years, this was the only system in operational meteorology able to provide detailed information on the vertical and horizontal extent of a lightning flash, rather than just the location of its ground strike. LDAR detects all lightning, including cloud-to-cloud and in-cloud as well as cloud-to-ground.

The CGLSS detects, locates and characterizes cloud-to-ground lightning within approximately 60 miles of the RWO. Electromagnetic radiation emitted from lightning is first detected by the system's six direction finder and time-of-arrival antennas, located in Orange and Brevard Counties. Lightning positions are computed using triangulation and time-of-arrival from as many sensors as possible and relayed to a color display video screen in the RWO. Once lightning-producing cells are identified and located, the forecaster can more easily predict just where the next lightning bolts will hit.

Attached to the wing of a Cessna Ciltation aircraft are cloud physics probes that measure the size, shape and number of ice and water particles in clouds. The plane is also equipped with field mills, used to measure electric fields. The plane is being flown into anvil clouds in the KSC area as part of a study to review and possibly modify lightning launch-commit criteria.

The 45th Weather Squadron also has an extremely active program to educate its customers and the general public on lightning safety.

## KSC lightning policy

KSC pioneered a two-phase lightning warning policy. In Phase I, an advisory is issued that lightning is forecast within five nautical miles of the designated site with a desired lead-time of 30 minutes. The 30-minute warning gives personnel in unprotected areas time to get to protective shelter and gives those working on lightning-sensitive tasks time to secure operations in a safe and orderly manner.

A Phase II advisory is issued when lightning is imminent or occurring within five miles of the designated site. All lightning-sensitive operations are terminated until the Phase II advisory is lifted.

This two-phase policy provides adequate lead-time for sensitive operations without shutting down less sensitive operations until the hazard becomes immediate. Because it is essential that no lightning go unwarned, there is a false-alarm rate of about 40 percent. Improved forecasting tools may enable the false-alarm rate to be reduced without compromising safety.

The Lightning Policy is defined by the KSC Lightning Safety Assessment Committee. This group is also responsible for seeing that all structures at KSC, as well as the Space Shuttle, are adequately protected. Structures that particularly need protection against lightning include those containing ignitable, explosive or flammable materials, and personnel.

## Protection at the pad

Some KSC facilities that incorporate extensive lightning-shielding devices include the service structures at Launch Pads 39A and 39B, the Vehicle Assembly Building (VAB) and the hangar-like Orbiter Processing Facility.

An 80-foot-tall fiberglass mast on top of the Fixed Service Structure at each pad is the most visible means of protecting the structure itself, the Shuttle while it is on the pad, and the enclosed launch equipment. The mast supports a 1-inch stainless steel cable that runs over its top. This cable stretches 1,000 feet in two directions, and each end is anchored and grounded. Its

Space Shuttle Endeavour clears the lightning mast and attached catenary wire as it hurtles into space on mission STS-111 to the International Space Station, June 5, 2002. The mast and wire provide the primary lightning protection system for the orbiter while it is on the pad. Mission STS-111 is the 18th flight of Endeavour and the 110th flight overall in NASAís Space Shuttle program.

appearance is similar to that of a suspension bridge tower and its supporting cables.

A 4-foot-high lightning rod on top of the mast is connected to the cable. The rod's purpose is to prevent lightning current from passing directly through the Space Shuttle and the structures on the pad. Any strikes in this area would be conducted by the cable, called a "catenary wire" because of its shape, to the grounded anchor points.

Other grounding systems in the Launch Complex 39 area include a network of buried, interconnected metal rods called the "counterpoise" that run under the launch pads and surrounding support structures. All structures in the area are grounded, including the VAB.

Additional protection devices at the pads include a grounded overhead shield cable to protect the crew emergency egress slidewires, attached to the Fixed Service Structure. Grounding points on the pad surface connect the pedestals that support the Mobile Launcher Platform (MLP) to the pad counterpoise. The MLP itself has electrical connections in its twin Tail Service Masts that make contact with the Space Shuttle. These connections complete the system that conducts any lightning-related electrical discharges safely away from the space plane. Most other launch pads at CCAFS have similar overhead wire lightning protection systems.

Overhead gridwire systems protect hypergolic fuel and oxidizer storage areas at the pads. The huge 900,000-gallon liquid hydrogen and oxygen tanks at each pad are constructed of metal and do not need overhead protection since they provide their own grounds.

Away from the pad, the Shuttle is well protected from both inclement weather and lightning when it is in the VAB. This 525-foot-high structure, one of the largest in the world, has its own system of 11 lightning conductor towers rising 25-feet high on its roof. When lightning hits the system, wires conduct the charge to the towers, which then direct the current down the VAB's sides and into its foundation pilings that are driven into bedrock.

After leaving the VAB, the Space Shuttle is vulnerable to lightning strikes as it is transported to the launch pad. This trip takes about six hours. The primary method of reducing lightning risk is by scheduling rollout during periods of very low lightning probability – typically in the late night and early morning hours.

## Launch pad detection systems

A lightning measuring system is located at the launch pads so any electrical activity in the immediate area can be continually observed, recorded and assessed. Data gathered by its sensors and cameras is sent directly to the Launch Control Center so NASA personnel can determine when it is safe to launch the Shuttle.

One of the monitors closest to the Shuttle is the Catenary Wire Lightning Instrumentation System (CWLIS). This system senses lightning currents in the wire and evaluates them to see what potential they may have for causing damage to sensitive electrical equipment. The CWLIS current sensors are located at each end of the catenary wire, and they detect and record lightning strikes to provide potential damage assessment data for the CWLIS system.

Another launch pad monitoring system, the Lightning Induced Voltage Instrumentation System (LIVIS), detects and records any transient electrical impulses that might occur in Space Shuttle electronic systems or on the vehicle's skin. LIVIS is installed in the MLP and monitors conditions while the Shuttle is on the way to the launch pad via the crawlerway and at the pad itself. Voltages and currents may be induced by nearby lightning even if the pad is not directly struck.

The electromagnetic fields from the intense lightning currents are enough to cause currents to flow in nearby conductors.

Data recorded by both the CWLIS and LIVIS systems are compiled and sent to the Launch Control Center through the computers of the Lightning and Transients Monitoring System.

A new Sonic Lightning Locator (SOLLO) at the Shuttle launch pads precisely determines the strength and exact location, to within 5 meters, of any lightning strikes within the immediate area of the pad. This helps Shuttle engineers assess the need to conduct additional tests on sensitive systems after nearby lightning events. SOLLO uses an electric field detector and an array of acoustic detectors to locate the lightning contact point with great precision.

Visual detection of lightning activity is also essential. A network of video cameras positioned to observe the Fixed Service Structure's lightning mast and the top of the Shuttle's external tank are linked to television monitors in the Launch Control Center. Any lightning flashes can be seen on the screen and recorded for later analysis. These data, along with the launch pad protection systems, help verify and calibrate the lightning detection systems.

## Does it all work?

The elaborate lightning detection and protection systems at KSC have proven their worth the hard way. The lightning masts at Launch Pads 39A and 39B are struck about five times per year, sometimes with a Space Shuttle on the pad. There has been no damage to any equipment.

In 1983, lightning struck the launch pad with the Shuttle on the pad before three of the four launches. To this date, no NASA-KSC employee has ever been injured by lightning – due in part to the Lightning Protection Policy and education programs.

Thanks to the extensive weather and electric field detection systems, no Space Shuttle has ever been endangered during launch, although several launches have been delayed due to observed and forecast weather conditions.

## Lightning research by NASA, other governmental agencies

Kennedy Space Center needs to protect Space Shuttles and other launch vehicles, payloads, associated ground processing equipment and facilities, and its personnel. Therefore, it has performed extensive research into lightning and its causes, and how to detect and forecast it. This information is applied toward improved lightning warning and protection systems.

For more than 20 years, KSC has hosted international projects to study thunderstorms and atmospheric electricity. The three largest programs have been the Thunderstorm Research International Project (TRIP) conducted in the mid-1970s, the Rocket Triggered Lightning Program (RTLP) conducted from the mid-1980s to 1992 and the Convection and Precipitation/Electrification (CaPE) program of 1991.

Additionally, three programs using aircraft with electric field measurement capability have been conducted at KSC. The first occurred around the time of the Apollo-Soyuz program to safely enhance launch availability for short-launch-window docking missions.

The second was an Airborne Field Mill (ABFM) program in the early 1990s that studied revising our lightning launch-commit criteria, to safely relax them based on better understanding of the actual hazards. It was conducted by NASA's Langley Research Center, Marshall Space Flight Center (MSFC) and KSC, Stanford Research International and New Mexico Technological University.

Finally, the latest ABFM program flew missions in 2000 and 2001. The data from that program is still being analyzed, but has already led to modified lightning launch-commit criteria and improved launch safety.

Many investigators from other governmental agencies, leading universities, utilities and international organizations conducted ground-based and airborne lightning experiments supporting KSC's program. The French government was a major participant in the RTLP and it pioneered this type of research along with the United States.

Other NASA Centers are heavily involved in lightning-related research. NASA-Langley scientists studied aircraft-triggered lightning by flying specially instrumented and weather-hardened aircraft directly through thunderstorms in Virginia and Oklahoma. Much of what we know about this phenomenon was discovered through work with an F-106B fighter airplane.

During eight years of research, the airplane was struck by lightning more than 700 times. Nearly all of these strikes were triggered by the aircraft's motion through the intense thunderstorm-electric field, rather than as the result of intercepting a natural lightning bolt. The FAA and the Air Force have conducted similar experiments to determine how to better protect aircraft electronics.

MSFC, in conjunction with Langley and KSC, measured electric fields aloft in the early 1990s using airborne field mills to assess what weather conditions pose a threat of triggered lightning during space vehicle launches.

Similar measurements were made in 2000 and 2001 by a team led by KSC that included scientists from MSFC, University of North Dakota, the National Center for Atmospheric Research, the National Atmospheric and Oceanic Administration (NOAA) and others.

Scientists from the University of Arizona, New Mexico Tech and other universities are examining KSC/CCAFS ground-based field mill data for additional clues concerning what condi-

Lightning is at once beautiful and fearsome. Here, a cloud-to-ground strike is caught in the act as it zaps a tree.

tions are safe and which are hazardous. This will help design launch rules providing maximum opportunity to launch without compromising safety.

MSFC has investigated thunderstorms by flying over them with U-2 aircraft, and is also investigating lightning via satellite. Its Optical Transient Detector (OTD) is able to detect and locate lightning from orbit over large regions.

The OTD is a highly compact combination of optical and electronic elements that represents a major advance over previous technology by gathering lightning data in daytime as well as night. Some of its most important science results are the first-ever consistent lightning climatology covering most of the globe, and contributing to the use of lightning data in severe weather forecasting.

OTD and its follow-on, the Lightning Mapper, enables more accurate estimates of the energy and current associated with the global electrical circuit.

## Lightning ó One of the most violent forces of nature

At any instant, there are more than 2,000 thunderstorms taking place throughout the world. These storms combine to produce about 100 lightning flashes per second, each one with an average of 300 million volts, currents ranging up to 20,000 amps, and temperatures over 50,000 degrees Fahrenheit. Extreme lightning can reach a billion volts, over 200,000 amps, and over 54,000 degrees Fahrenheit.

A moderate-sized thunderstorm at its peak can generate several hundred megawatts of electrical power, equivalent to the output of a small nuclear power plant. With so much energy being released, there is little wonder that lightning has considerable potential to cause damage.

## Lightning on other planets

These giant electric sparks are not unique to Earth. Among the mystifying and gargantuan storms that rage throughout Jupiter’s atmosphere, one familiar phenomenon – lightning – was captured by cameras on NASA’s Voyager I

An artist's concept of the descent module of NASAís Galileo interplanetary probe shows the probe plunging through Jupiterís atmosphere. The probe carried instruments designed to investigate lightning in the Jovian atmosphere. Launched from KSC Oct. 18, 1989, Galileo arrived at the planet in 1995, and after 8 years of data gathering, disintegrated as it fell toward the surface .

planetary explorer spacecraft. Both Voyager I and II detected electrical signals from Jupiter characteristic of lightning. This discovery was the first hard evidence that such violent electrical discharges take place on other planets. The Galileo spacecraft also photographed what appear to be visible lightning flashes in Jupiter’s atmosphere. Electrostatic discharge detection on Saturn and Uranus by Voyager 2, along with radio signals associated with lightning picked up by the Pioneer Venus orbiter and Russian Venera probe, may indicate that lightning is commonplace in our solar system.

Lightning-like electrostatic discharges in the dust storms of Mars have been hypothesized.

## Lightning helps maintain atmospheric charge, aids plants

Lightning on other planets may be too “far out” for some people. For others, the fearsome flashes and explosions that accompany a mid-summer night's thunderstorm here on Earth often seem a little too close to home.

During a power blackout from a lightning strike, it's hard to remember that some good does come from the powerful bursts of electrical energy. When lightning bolts discharge, they ionize the air and produce nitrogen oxide. According to recent studies, this process could generate more than 50 percent of the usable nitrogen in the atmosphere and soil. Nitrogen is an essential plant fertilizer.

Lightning also plays a critical role in forests' natural cycles by helping generate new growth.

Areas that are burned by lightning-triggered fires are cleared of dead trees so that seedlings have the space and soil to take root. The global array of thunderstorms serves as a worldwide circuit of electrical generators. Through the activity of the lightning they produce, these generators continually maintain and renew the atmosphere's positive electrical charge.

## Nature takes its toll, though

With so many bolts of lightning, it's no wonder that people and structures are hit. Each year, about 100 people are killed and about 245 are injured in the U.S. by the number two storm-related killer.

Lighting-generated fires destroy more than 30,000 buildings at a loss of hundreds of millions of dollars yearly. The average total economic impact of lightning is over $5 billion in the U.S. each year.

Airplanes and spacecraft are subject to the tremendous electrical forces that can build up in the atmosphere. According to the FAA, commercial aircraft are struck an average of once every 3,000 flight hours, or about once a year. However, only one U.S. airliner was confirmed as lost to lightning, in 1963.

Because of an airplane's metal construction, lightning flows along its fuselage rather than penetrating it.

Almost all lightning strikes on aircraft cause only superficial damage, and passengers are protected from injury. With the advent of new composite materials for airframes and digital fly-by-wire control systems, newer aircraft may be more vulnerable than statistics would suggest.

Spacecraft are more vulnerable than aircraft. On March 26, 1987, an Atlas Centaur rocket and its satellite were lost when the unmanned NASA vehicle was struck by lightning that it triggered.

Two earlier triggered strikes that temporarily disabled the electrical systems on the Apollo 12 spacecraft onboard a Saturn V rocket on Nov. 14, 1969, prompted NASA to develop ways to protect its launch vehicles, and to create a better system to predict when and where lightning might strike.

## Reducing lightning damage

NASA, the Department of Defense, NOAA, the FAA, various research and industry groups, and several foreign governments continue to investigate the ways lightning develops, better ways to predict its occurrence, and the means to reduce damage when it does strike.

To attempt to predict where the next strikes will occur, a National Lightning Detection Network (NLDN) has been established across the U.S. The NLDN plots the strike location of each cloud-to-ground flash.

KSC developed a precision three-dimensional Lightning Detection and Ranging (LDAR) system, which was commercialized under a Space Act agreement between NASA and Global Atmospherics, Inc (a Vaisala Inc. subsidiary).

LDAR allows the forecaster to view the height and horizontal extent of each lightning flash and not just the point-of-ground contact. Unlike the NLDN, the system can also detect in-cloud and cloud-to-cloud flashes.

LDAR has contributed much to our understanding of lightning, including the distribution of lightning strike distances, and the use of lightning in severe weather forecasting. Soon, satellites that observe the whole planet will supplement ground detectors to increase coverage of thunderstorm activity.

Meteorologists can use this data to alert people in potential strike areas. The more accurate the prediction of where and when lightning will occur, the better chance of reducing or eliminating the damage it causes. KSC and CCAFS use a two-phase lightning policy (described on page 3).

## Ground equipment needs most protection

Since lightning tends to strike the highest local point, special care must be taken to protect tall structures from direct strikes. These structures are often power lines, microwave relay towers used in telephone communication, buildings filled with sensitive electrical equipment, or even launch pads.

Without protection, a lightning strike can cause power line surges and arcing, electrical fires and electrical or structural damage. The lightning does not have to hit a facility directly to cause damage. Voltages and currents induced by nearby strikes can burn out or damage components of modern electronic circuits.

The National Fire Code standards for lightning protection (NFPA-780) for structures call for a pathway, or conductor, that will safely redirect a lightning bolt's electrical energy to the ground. Circuit breakers, fuses and electrical surge arrestors provide additional protection.

Sometimes even this equipment is not sufficient to prevent damage.

Studies, including results from the RTLP, have shown that lightning strikes result in rapid current surges (reaching an initial peak within a millionth of a second) with such high peak current (over 20,000 amperes on average) that conventional protection methods are unable to save complex electronic systems from damage.

Utilities and high-technology industries, among others, are investigating ways to better protect vital electrical equipment.

## Better protection begins with better knowledge of lightning

Although lightning has been known to be a discharge of electrical energy since Ben Franklin's kite-flying days, the way electrical charges build up and discharge in clouds is still not fully understood, even now in the 21st century. Researchers at KSC and others throughout the world attempt to answer these questions so improved means to detect and measure the charges can be developed.

A lightning bolt is the transfer of an electrical charge between regions inside a cloud, between clouds, from cloud to air, from cloud to the ground, or (more rarely) from the ground to air.

For such a transfer to take place, the two types of charges must be separated so the cloud is electrified. Exactly how the charges become separated and where in the cloud they are located are still not completely clear.

The lightning event begins when lightning strikes the 3,000-foot copper wire being trailed from the 3-foot-tall rocket. The wire is then vaporized as it follows the path to a lightning rod attached to the launcher. As the wire burn dissipates, it creates an effect called ìrosary bead lightning.î This can be the prelude to natural lightning restrikes. The initiation of a wire burn can also induce natural intercloud lightning during the event, as seen in this sequence.

## Is a thundercloud like a generator?

However the details may turn out, it is well understood that thunderstorms separate electrical charges. Usually, a positive charge is pumped aloft while a negative charge accumulates near the lower-middle part of the storm. A small amount of positive charge may collect near the base of the storm cloud. It takes energy to separate the charge, and this energy comes from the rapidly rising air currents in the storm. Thus, like a generator, a thunderstorm converts mechanical energy to electrical energy.

## Convection and thunderstorms

A thunderstorm is a natural heat engine. On a typical summer day over Florida, the air is loaded with moisture and the land surface is hot. As the land heats the air near the surface, it expands, becomes less dense (lighter) and begins to rise.

As it rises, the air expands further, this time due to the lower pressure higher in the atmosphere, rather than due to heating. In fact, as the air expands in the lower pressure, it cools because its internal energy is spread out over a larger volume. When moist air cools enough, it can no longer hold all the water it contained when it was warm. If it were on the ground, dew and fog might form. Aloft, the excess water condenses out as a patch of fog in the sky, which we call a cloud.

When water condenses, it releases heat to its surroundings, just as when it evaporates, it absorbs heat (which is why a wet towel cools you on a hot day). The heat released when a cloud forms makes the air rise even more vigorously until a cloud is thousands of feet high. The cloud can continue to grow as long as it has a good source of warm, moist air at its base. As it grows, it eventually becomes tall enough for the air in the cloud to cool below the freezing point (0° C).

Surprisingly, water in the parts of the cloud cooler than 0° does not actually freeze until it gets considerably colder: -10° C to about -20° C. Liquid water colder than 0° is called "super-cooled" water. At temperatures below -10° to -20°, water vapor condenses directly to ice ("subliming" rather than "condensing"). As we will see, it is the mixture of ice and super-cooled water that probably accounts for most thunderstorm electrification.

Cloud droplets are too small to fall as rain, but turbulence in the cloud causes droplets and ice crystals to collide. Droplets may coalesce, and when a super-cooled droplet collides with an ice crystal, it will freeze to the crystal, thus enlarging it. Soon these larger ice crystals begin to fall through the super-cooled water and collect it, growing as they go. When they have fallen enough for the temperature to rise above 0°, they melt, becoming raindrops.

Sometimes a small ice pellet will become coated with water and be then blown back up higher by a sudden updraft. Later it can fall again and gather even more water. This can happen several times if the updrafts and turbulence are strong enough. Then some really large ice particles can form and they may not melt before hitting the ground. These large ice particles are called hail.

## Precipitation charging theory

The most widely accepted explanation of how thunderstorms separate the charge is based on laboratory experiments and atmospheric observations with aircraft and radar. The tests show that when ice crystals and super-cooled water droplets collide, if they don't coalesce, the pieces that are scattered after the collision are charged. Which pieces get which kind of charge, positive or negative, depends on the temperature. But at temperatures typical of the electrically active part of thunderstorms, the smaller pieces usually get the positive charges. These smaller, lighter fragments will be carried aloft by the updrafts while the negatively charged, larger, heavier remnants fall. This results in charge separation and an upward transport of the positive charge.

## Mechanics of a lightning strike

It is a fact of nature that positive and negative electrical charges attract each other. The strength of this attraction is called the "electric field." When enough charge has been separated, the force of attraction overcomes the electrical resistance of the air and a giant spark (lightning!) can occur.

Most lightning occurs within or between clouds. The destructive cloud-to-ground lightning bolt occurs much less frequently and can carry either a positive or a negative charge. Of the two, negative lightning is the most common type (about 94 percent). The process involved in generating a lightning stroke explains why lightning usually seeks out and strikes the highest point on the surface.

First, a long series of negatively charged branches about 50 yards long, called stepped leaders, emerges from the cloud and approaches the ground. During the approach, the stepped leader causes electric fields on the ground to increase in strength. Positive ions gather around pointed objects as small as pine needles and grass blades, then flow upward toward the stepped leader as several 50-yard sparks, called upward streamers.

When the stepped leader and upward streamer touch, the cloud-ground circuit closes, and a huge, rapid surge of current flows up the ionized stepped leader channel from ground to cloud. The grounded object serves as the focal point of the positive ion flow. That object, such as a tree or a golfer with an upraised club, is considered "struck" by lightning.

The huge upward surge of current is called the return stroke. It heats the channel to over 50,000 degrees Fahrenheit almost instantly. This lights up the channel, which we see as lightning, and generates a large pulse of sound as the super-heated air rapidly expands, which we call thunder. Usually the return stroke doesn't neutralize all the charge in that region of the cloud, and a dart leader races down the lightning channel to the ground, initiating another return stroke.

There are usually three to four return strokes per lightning flash, separated by about a tenth of a second. This is near the limit of human perception and explains why lightning appears to flicker. Lightning with as few as fifty return strokes has been observed. The entire event is called a lightning flash.

Positive lightning carries a positive charge to the ground. It makes up less than 4 percent of a storm's lightning strikes and typically takes place at the end of a storm. However, the positive lightning strike has potential to cause more damage.

It generates current levels up to twice as high and of longer duration than those produced by a negative bolt. It's the long-duration, or "continuing current" components, of lightning that causes heating and burning, and metal punctures. For that reason, scientists are especially interested in developing ways to detect the areas of a thunderstorm that develop positive bolts.

## Triggered lightning ó a bolt from the gray?

The phrase "a bolt from the blue" originated from observations of a seemingly inexplicable phenomenon – a flash of lightning on a day without a storm cloud nearby. This event would be startling under any circumstances, but imagine the shock of seeing such a bolt strike the 363-foot-high Apollo 12/Saturn V rocket while it was more than a mile above KSC (Nov. 14, 1969). Perhaps being in an airliner as it was "zapped" by lightning at 20,000 feet would be more of a scare, though. While not really bolts from the "blue," because they occur inside of clouds, they occur in clouds that otherwise do not contain lightning.

Why are rockets and airplanes struck in these circumstances? It was first thought that they just "got in the way" of a lightning bolt jumping from a positive- to a negative-charged area of a thundercloud. Later research provided evidence that the buildup of strong electric fields at certain points of the aircraft were the culprit.

Such concentrated fields of electrical energy can develop before lightning occurs. When an aircraft or a rocket enters such a high electric field, electrical fields are compressed, and they concentrate around the sharp edges and protuberances of the vehicle.

If the electrical fields around the airplane's sharp and protruding parts build up to where there is an electrical breakdown of the air, lightning leaders form at two or more locations on the airplane. The aircraft also contributes to the conducting path between a positive and a negative electrical field, triggering the resultant lightning bolt.

In the case of Atlas Centaur-67, a lightning strike changed some data in the rocket's computer, which caused it to steer the rocket sideways and begin breaking up in flight. Range Safety then destroyed the out-of-control rocket, March 26, 1986.

## Lightning Safety

Lightning is the second leading cause of storm-caused deaths in the U.S., killing more than tornadoes or hurricanes. Only floods kill more than lightning. Lightning also inflicts life-long debilitating injuries on more than it kills.

Public education is the key to prevention. Lightning safety is best taught as a multi-level process of decreasing levels of protection. No place outside is safe when thunderstorms are within several miles.

The first and best level of lightning safety is to avoid the threat. Use the weather forecast and know your local weather patterns to plan your outdoor activities to avoid the lightning.

Level-2 is to use the "30-30 Rule" while outdoors. If there are 30 seconds or less between lightning and its thunder, go inside. Wait 30 minutes or more after the last thunder before going outside. The safest, most accessible place to avoid lightning is a large, fully enclosed building with wiring and plumbing, such as a typical house. While indoors, avoid using corded telephones, electrical appliances and wiring, and plumbing. If a solid building is not available, a vehicle with a solid metal roof and metal offers some protection.

Level-3 of lightning safety is getting into dangerous territory. If you must be outside and thunderstorms are near, avoid the most at-risk locations or activities. Avoid high elevations or open areas. Do not go under trees to keep dry. Avoid tall, isolated objects. Avoid swimming, boating and fishing. Avoid open-cockpit farm or construction equipment.

Level-4 should be used only as a desperate last resort. If you've made several bad decisions and find yourself outside, in an at-risk location, and thunderstorms are threatening, some procedures can reduce, but not eliminate the threat.

Level-5 is first aid. All lightning deaths result from cardiac arrest or stopped breathing from the cardiac arrest. CPR or rescue breathing is the recommended first aid, respectively.

Further lightning safety information is available at the 45th Weather Squadron Web site, **https://www.patrick.af.mil/45og/45ws/lightningsafety,** and from the National Weather Service lightning safety Web site, **www.lightningsafety.noaa.gov**

## The future of lightning prediction, detection and research

As society becomes more dependent on computers and other electronic devices, more effective ways must be developed to protect this equipment against high-voltage shock. Future aircraft made of non-conductive composite materials, that "fly-by-wire" or by computer command instead of manual hydraulic systems, will need advanced protection systems. As the global population expands, the increase of people and property calls for improved lightning prediction and detection through advanced weather equipment and methods.

As one of the more lightning-sensitive residents of the "lightning capital of the United States," KSC will continue to apply its technical expertise to support these efforts.

COVER PHOTO: A tremendous lightning bolt that appeared to impact Pad A in this dramatic photograph actually smashed into the ground well to the north. If the strike had occurred over the pad, it would have gone to ground through the one-half-inch stainless steel catenary wire, which is suspended over the pad from north to south. The wire is supported by the lightning mast, visible to the left and above the Orbiter Challenger.

National Aeronautics and Space Administration
**John F. Kennedy Space Center**
FS-2004-02-002-KSC