The tremendous electrical surge of a lightning bolt is safely drawn to a grounding point that is a part of Space Shuttle Launch Pad 39A's extensive lightning protection system at Kennedy Space Center. This strike took place prior to mission STS-8 in August 1983, with the orbiter Challenger at the pad. The 80-foot lightning mast atop the pad's fixed Service Structure can be seen to the left of and above Challenger.
Lightning Research by NASA, other Governmental Agencies

Kennedy Space Center is one of the major lightning research centers in the country. The Federal Aviation Agency (FAA), the U.S. Air Force, NASA's Langley Research Center and New Mexico Technological University have conducted aircraft-based lightning experiments at KSC as a part of the facility's ongoing Rocket Triggered Lightning Research Program. Many other investigators from other governmental agencies, leading universities, utilities and international organizations have conducted ground-based and airborne lightning experiments as a part of this program that began in 1984. The French government has an ongoing involvement with the KSC program, since it pioneered this type of research along with the United States.

NASA Langley scientists have studied aircraft-triggered lightning by flying specially instrumented and weather-hardened aircraft right through thunderstorms in Virginia and Oklahoma. Much of what is known about this phenomenon was discovered through work with a F-106B fighter
airplane. During eight years of research, this airplane was struck by lightning more than 700 times. It was found that nearly all these strikes were the result of its presence in an electrical field rather than being in the path of an already-formed bolt. Both the FAA and the Air Force have conducted similar experiments to determine how to better protect aircraft electronics.

Lightning — Nature's most Violent Force

At any given instant, there are more than 2,000 thunderstorms taking place throughout the world. All these storms combine to produce about 100 lightning flashes per second, each one with a strength of up to a billion volts and temperatures of more than 54,000 degrees Fahrenheit. At the height of a moderate-sized thunderstorm, it can generate several hundred megawatts of electrical power, or the output of a small nuclear power plant. With so much energy waiting to be released, it's 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, cameras on NASA's Voyager I planetary explorer spacecraft found one familiar phenomenon — lightning. This discovery was the first hard evidence that such violent electrical discharges take place on other planets. Detection of electrostatic discharges on Saturn and Uranus by Voyager 2, along with radio signals associated with lightning picked up by the Pioneer Venus orbiter, may indicate that lightning is commonplace on planets with an atmosphere in our solar system.

Lightning Helps Maintain an Atmospheric Charge, Aids Plant Growth

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

The global chain of thunderstorms serves as a worldwide circuit of recharging batteries. Through the activity of the lightning they produce, these batteries continually recharge and maintain the atmosphere's positive electric charge. Some researchers also think that the Earth's negative charge is maintained by electric fields in thunderstorm clouds.

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 the natural cycle of forests 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.

Nature Takes its Toll, Though

With so many bolts of lightning, it's no wonder that people and structures get hit. Each year an average of 100 persons are killed and about 245 injured by nature's number one weather-related
killer. Lighting-generated fires also destroy more than 30,000 buildings at a loss of hundreds of millions of dollars every year.

Airplanes and spacecraft are also vulnerable to the tremendous electrical forces that can build up in the atmosphere. According to the FAA, commercial aircraft are struck on the average of once every 3,000 flight hours, or about once a year. However, only one U.S. airliner has been confirmed as lost to lightning. Because of an airplane’s metal construction, lightning flows along and away from its fuselage. Almost all lightning strikes on aircraft cause only superficial damage, and passengers are protected from injury.

On March 26, 1987, however, an Atlas/Centaur rocket and its satellite were lost when the unmanned NASA vehicle was struck by lightning. But it was an earlier strike, one that temporarily disabled the electrical systems on the Apollo 12 spacecraft onboard a Saturn V rocket on November 14, 1969, that prompted NASA to develop ways to protect its launch vehicles and launch support equipment from lightning. Today, the agency continues to research thunderstorm activity and atmospheric electrical fields to find better ways to predict when and where lightning might strike.

Detection and Research are Keys to Reducing Lightning Damage

In addition to NASA, the National Oceanic and Atmospheric Administration (NOAA), the FAA, various research and industry groups and the governments of several foreign countries continue to investigate just how lightning develops, better ways to predict its occurrence and means to reduce property damage when it does strike. To attempt to predict where the next strikes will occur, a National Lightning Detection Network has been established across the country. During the 1980’s, satellites that can observe the whole planet will supplement the ground detectors of this system to increase its coverage of thunderstorm activity. Meteorologists can use this data to provide an alert to those people in potential strike areas. The more accurate the prediction of where and when lightning will occur, the better chance there is of lessening or eliminating the damage it causes.

Ground Equipment Needs the Most Protection

Since lightning tends to strike the highest point in any given area, special care must be taken to protect tall structures from these high-voltage bolts. These structures are often power lines, microwave relay towers used in telephone communication or buildings filled with sensitive electrical equipment. Without some sort of protection, a lightning strike could and sometimes does cause power line arcing, electrical fires and structural damage.

The U.S. Lightning Protection Code (NFPA-78) for structures calls for a pathway, or conductor, that will safely lead a lightning bolt’s electrical energy to the ground. Additional protection is provided by circuit breakers, fuses and electrical surge arrestors. But sometimes even this equipment is not enough to prevent damage. New studies have shown that lightning strikes so fast (within one-millionth of a second) and with such a high peak current (about 200,000 amperes) that conventional protection methods are unable to save complex electronic systems from damage. Utilities and high-technology industries, among others, are researching ways to find better means to 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 storm clouds build up an electrical charge is still not fully understood. Researchers at Kennedy Space Center and other facilities throughout the world are attempting to answer this and other questions so that improved means to detect these charges can be developed.

What is known is that a lightning bolt is the transfer of either a positive or negative electrical charge from one region of a cloud to another or between the cloud and the Earth. For such a transfer to take place, the two types of charges must be separate, or polarized, for the cloud to become electrified. But exactly how the charges separate themselves and what parts of the cloud they exist in are still not clear.

Is a Thundercloud Just Like a Battery?

Two traditional and still current hypotheses concerning cloud electrification and polarization assume that thunderclouds are bipolar like a battery, with the positive charges accumulating on top and the negative charges forming at the bottom. These theories employ the mechanisms of either convection or precipitation. Other researchers not advocating either means feel that both of these processes are involved, since both are present in thunderstorm clouds.
Convection and the Formation of Thunderstorms

Convection, or the rising of warm air currents, actually causes local thunderstorms to develop. This storm is the type that typically appears over Central Florida and KSC during a hot summer midafternoon. It begins with the rising of bubbles of warm moist air. The higher the bubbles rise, the cooler the air they pass through gets and the lower the atmospheric pressure. These two conditions cause cooling and condensation of the bubbles' moisture and the expansion of the bubbles to form white cumulus clouds.

These small clouds then merge into larger ones, which continue to grow and rise. At a certain height, the water droplets in the clouds become too large and heavy for the the clouds' updraft of air to support them. That's when the droplets begin to fall as rain. At the same time, lighter, smaller droplets continue to rise until they reach a height where atmospheric temperatures cause them to freeze into ice particles.

The ice particles then fall back into the clouds, accumulating water droplets that freeze to them. When the particles reach air temperatures above freezing, they melt and join the raindrops. If they instead strike the colder air of a temperature inversion on the way down, they fall as hail.

According to the convection theory, the thunderstorm's rising warm air currents carry positive electrical charges from the Earth's surface to the top of the cloud. Downdrafts in the cloud are presumed to carry negative charges to its bottom.

The Precipitation Theory

According to the precipitation theory, heavy raindrops, hailstones and ice particles called graupel in the thunderstorm are pulled down past smaller suspended water droplets and ice crystals. Collisions between the graupel and the stationary particles are thought to transfer positive charges to the suspended particles and a negative charge to the larger falling ones. The process...
of changing a particle's electric charge means that its atoms gain or lose electrons.

**Thunderclouds Contain a Complex Mix of Positive and Negative Charges**

Current research indicates that there are large separate areas of positive and negative charges in a thunderstorm cloud, along with a complex mix of other, smaller charged areas of both types. It's thought that this mix develops because of the charge transfer between graupel particles and ice crystals, an activity originally part of the precipitation hypothesis, and action of wind currents within the cloud. Since many variations of this mix have been observed, research on the actual electrical make-up of a thundercloud continues to be conducted to develop a model cloud structure.

**The Mechanics of a Lightning Strike**

Once a thundercloud's electrical charges have built up to the point where they exceed those in the surrounding atmospheric electric field, the gap between the cloud's positive and negative electric fields then can be jumped by the spark of a lightning bolt. Most lightning consists of intracloud or cloud-to-cloud discharges.

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 90 percent) in a storm. The process involved in generating this type of lightning stroke explains why lightning always seeks out and strikes the highest point on the surface.

First, a negatively charged stepped leader from the cloud approaches the ground. During the approach, the leader's tip causes positive electric fields on the ground to increase in strength. Positive ions gather around pointed objects as small as pine needles and grass blades and then flow in streams towards the leader. When they get close enough, closure of the cloud-ground circuit takes place and the leader is neutralized. Now a much more powerful return stroke flows from the ground to the cloud through the grounded object selected as the focal point of the positive ion flow. That object, from tree to golfer with an uprighted club,

Two of the 3-foot-high sounding rockets that are fired into thunderstorms at the KSC Rocket Triggered Lightning launch site are hoisted into position, along with a simulated aerospace vehicle. The rockets trail copper wire which is hit by lightning when fired into thunderstorms. The wire then carries this electrical charge to the mock expendable vehicle.
is considered “struck” by lightning. The whole process, from leader approach to discharge, takes place in less than a second.

The return stroke is the one visible to the human eye, with the brightness of more than 100 million light bulbs. Actually, this bolt may have traveled back and forth between the cloud and the ground more than a dozen times — all in less than a second. The entire event is called a lightning flash.

Positive lightning carries a positive charge to the ground. It makes up less than 10 percent of a storm’s lightning strikes and takes place at the end of the warm-weather storm or during one that accompanies a cold front. However, the positive lightning strike has the potential to cause more damage, since this type of bolt 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, burning and metal punctures. This phenomenon is known as “hot” lightning. For that reason, scientists are especially interested in developing ways to detect the areas of a thunderstorm that develops positive bolts.

Triggered Lightning — A Bolt from the Blue

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-long Apollo 12/Saturn V rocket while it was more than a mile above KSC. Perhaps being in an airliner while it was “zapped” by lightning at 20,000 feet would be more of a scare, though.

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

Such concentrated fields of electrical energy can develop before clouds actually form. When an aircraft or a rocket enters such a field, electrical charges are compressed and 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 negative electrical field, triggering the resultant lightning bolt.

In the case of Atlas/Centaur-67, a lightning strike caused the rocket’s computer to upset and issue an extreme yaw command that led to the vehicle’s breakup in flight. The area struck was where the greatest amount of electrical charge developed as the rocket flew through a highly charged atmospheric electrical field.
KSC's Rocket-Triggered Lightning Program

The Rocket Triggered Lightning Program developed as part of research conducted at KSC to discover methods of improving lightning protection systems for Space Shuttle launch support facilities. Since KSC is located in the region with the second-highest number of lightning strikes in the country, the area is a logical choice for extensive research on this phenomenon.

In order to properly study lightning, it must be observed first-hand and monitored with instruments. Unfortunately, due to lightning's capricious nature, it is extremely difficult to predict just when and where a lightning strike will occur. Some method was needed to cause a lightning strike to take place where it can be studied, like an experiment created in a laboratory.

A modern-day method of triggering cloud-to-ground lightning involves the use of three-foot-high sounding rockets attached to long copper wires. When a rocket is launched into a thunderstorm, lightning strikes it, vaporizes the trailing wire and follows its path to the ground. The strikes are measured and analyzed, along with the electric fields they come from, so that researchers can learn more about this insidious force.

The KSC Lightning Protection System

KSC operates extensive lightning protection and detection systems in order to keep its employees, the 184-foot Space Shuttle, the launch pads and processing facilities from harm. While the protection system is exclusively on KSC property, the detection system incorporates equipment and personnel both at the space center and Cape Canaveral Air Force Station (CCAFS) located just east of the Space Shuttle facility.

Predicting Lightning Before It Reaches KSC

U.S. Air Force Weather Group — The first line of defense for lightning detection is accurate prediction of when and where thunderstorms will occur. The Air Force Weather Group provides all weather information for the KSC/CCAFS area. This information includes lightning advisories that are critical for day-to-day Shuttle processing, as well as launch day weather data essential in helping NASA determine when it is safe for the Space Shuttle to lift off. An Air Force staff meteorologist is permanently assigned to the NASA/KSC test director's office. He is also in the Launch Control Center during Space Shuttle launch preparations and countdown.

KSC operations and Air Force weather personnel have worked closely for several years to develop The Cape Canaveral Forecast Facility (CCFF), a center for the forecasting and detection of thunderstorms and other adverse weather conditions. The CCFF houses the Meteorological Interactive Data Display System (MIDDS), which analyzes data from the National Meteorological Center, weather satellite imagery and local weather stations to assist in putting KSC area weather forecasts together. Two sources of local weather information are a weather radar that can identify and track storms occurring within a 150-mile range of Cape Canaveral and the Wind Information Display System (WINDS) a network of wind, temperature and moisture sensors. Wind measurements can reveal the updrafts and downdrafts that can lead to thunderstorm development.

Lightning Detection Systems — The Launch Pad Lightning Warning System (LPLWS) and the LLP Lightning Surveillance System provide data directly to the CCFF 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 of lightning warnings.

The LPLWS is made up of 31 electric field mills uniformly distributed throughout KSC and Cape Canaveral and serves as an early warning system for electrical charges building aloft or approaching as part of a storm system. These structures are ground-level electrical field strength monitors. Information from the LPLWS gives forecasters information on trends in electrical field potential and the locations of highly charged clouds associated with lightning. The data is valuable in detecting early storm electrification and the threat of triggered lightning for launch vehicles. Plans exist for supplementing this system with airborne field mills to improve its predictive accuracy.

The LLP detects, locates and characterizes negative cloud-to-ground lightning within approximately 60 miles of the CCFF. Electromagnetic radiation emitted from lightning is first detected by the system's three direction finder antennas located at Melbourne, Orlando and in the northern area of KSC. Lightning positions are computed using triangulation from two of the sites and relayed to a color display video screen in the CCFF. Once a lightning strike pattern evolves on a map, it becomes easier for the forecaster to predict just where the next lightning bolts will hit.

KSC's Lightning Policy

When the Air Force weather staff reports the potential for lightning within five miles of desig-
nated KSC areas, a policy to enhance the safety of both the Space Shuttle and employees from lightning bolts or electrical shocks will go into effect. When the lightning policy is announced through a public address system at KSC, orbiter movement outside buildings is restricted, hazardous operations such as the loading of rocket fuel are not initiated, certain equipment is moved into covered facilities and work personnel are required to take shelter.

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 strikes are those that contain ignitable, explosive or flammable materials, and personnel.

Protection at the Pad

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

An 80-foot 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 to where each end is anchored and grounded. Its 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 spaceplane.

Overhead gridwire systems protect hypergolic fuel storage areas at the pads. The huge 900,000-gallon liquid hydrogen and oxygen tanks also 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 eleven 25-foot-high lightning conductor towers 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 on its way to the launch pad, there is a possibility that the Space Shuttle's external tank could be struck by lightning while on the crawlerway. In this unlikely event, however, shielding and electronic circuit protection devices throughout the spaceplane are designed to keep its computers and other electrical equipment from serious damage.

Launch Pad Detection Systems

A lightning measuring system is located at the launch pads so that any electrical activity in the

The screen for the Meteorological Interactive Data Display System (MDDS) in the Cape Canaveral Forecast Facility nearby KSC provides a synopsis of weather information from weather satellite imagery as well as local weather stations. The lighter areas on the screen show intense rain showers at 10,000 feet above the KSC area. The Air Force provides continuous weather data for NASA before and during Space Shuttle launches.
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 that NASA personnel can determine when it is safe to launch the spaceplane.

One of the monitors closest to the Shuttle is the Catenary Wire Lightning Instrumentation System (CWLIS). This system senses any 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 detect and record lightning flashes 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 charges that might exist in Space Shuttle electronic systems or on the vehicle's skin. This system 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. Two additional LIVIS sensors monitor the induced effects of any lightning activity in the Payload Changeout Room inside the Rotating Service Structure.

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 (LATMOS).

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.

**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 have been struck at least five times with a Space Shuttle on the pad — with 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. Thanks to the extensive weather and electrical field detection systems, no Space Shuttle has ever been endangered during launch, although several launches have been delayed due to reported weather conditions.

To make sure that this track record continues, KSC plans to periodically check out the lightning protection systems of various structures with a recent high-tech acquisition — a lightning simulator. This device generates a high-voltage electromagnetic field. Its use will also help to verify the accuracy of the lightning detection systems at KSC and Cape Canaveral Air Force Station and to verify the adequacy of facility lightning protection.

**The Future of Lightning Prediction, Detection and Research**

**KSC System Additions**

Improvements to the KSC area lightning prediction and detection system are to be made in the near future through a 5-year weather forecasting...
accurate severe storm warnings over a large area of the planet.

**Lightning Research Must Continue**

As society becomes more dependent on computers and other electronic devices, more effective ways must be developed to protect this equipment against such high-voltage shock. Future aircraft constructed of non-conductive composite materials and 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. To help meet these needs, NASA and other agencies have pledged to continue lightning research far into the future.

A 40-mile-wide flash of lightning appears in the lower left of a video image recorded by a television camera in the orbiter Challenger’s payload bay during mission STS-8. The image is similar to those captured during Mesoscale Lightning experiments conducted from the Space Shuttle while in orbit. The lights of Tampa Bay, Florida, area cities are in the middle, while the limb of the Earth can be seen on the right.