· EMll/ Lawrence Smith

FNAS LIGHTNING DETECTION

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Introduction

The follow tasks were completed under this contract:

Following the collection of background information a meeting was held to discuss the format and contents of the proposed documentation. An initial outline was produced and decided upon, a copy of which is included in Quarterly Report No 1 and writing commenced.

Photographs to be included in the brochure were selected. Quotations with respect to printing the document were requested

In the period between 28 March and June 1993 work continued on compiling the text. The Research Co-ordinator traveled to Huntsville to meet with the PI and Dr. Hugh Christian at MSFC. This was an editorial meeting to discuss the contents of the document and finalized the photograph selection. Quotes for the printing of the document were obtained.

Towards the end of this contract, a review of the brochure was undertaken by the technical monitor. Photographs were being revised and additional areas of lightning research were being considered for inclusion into the brochure. Therefore, we submit a copy of the draft (and photographs) which is still being edited by the technical monitor at the time of this report.

INTRODUCTION

Lightning, the thunderbolt of mythology, has long been regarded as an atmospheric spark of supernatural proportions, the greatest weapon of the gods. The Greeks both marveled and feared lightning as it was hurled by Zeus. For the Vikings, lightning was produced by Thor as his hammer striking an anvil, while riding his chariot across the clouds. In the East, early statues of Buddha show him carrying a thunderbolt with arrows at each end. Indian tribes in North America believed that lightning was due to the flashing feathers of a mystical THUNDERBIRD whose flapping wings produced the sound of thunder.

hundreds of people and injuries to several hundred more. It is difficult to obtain accurate statistics on lightning injuries and fatalities since a systematic compilation of information on lightning casualties does not exist. However, many case histories show heart damage. Inflated lungs and brain damage have also been observed from lightning fatalities. Loss of consciousness, amnesia, paralysis and burns are reported from many who have survived. Most fatal lightning casualties are thought to be due to direct lightning strikes to the head or side flashes to the head. In these cases, the current may be discharged through the brain or respiratory center which is located near the back of the neck thereby causing respiratory arrest.

Today the study of lightning is more scientific than mystical, the techniques of investigation more experimental than intuitive. Still, we remain in awe of lightning. Rightly so, as each year, lightning is responsible for the deaths of

Additional deaths and injuries to livestock and other animals, as well as millions of dollars in damage to buildings and thousands of forest and brush fires are also the result of lightning: as are damages to communications systems, power lines and electronic systems.

While these are more than sufficient reasons for NASA to support lightning research, lightning has a direct affect on the day-to-day operation of NASA as well. The effects of lightning strikes on the initial stages of a spacecraft launch as the vehicle climbs through the atmosphere and the success of the mission post-launch rely on accommodating weather.

One major incident involved the launch, in 1969, of the Apollo 12 mission when lightning briefly knocked out vital spacecraft electronics. More recently, the Atlas Centaur 67 which carried a Naval communication satellite was determined to have been struck by a triggered cloud-to-ground lightning flash in 1987. The induced current apparently caused a change in memory in the digital computer. Following launch, the altered memory gave rise to commands which caused an excessive angle of attack, large dynamic load, and ultimately - the breakup of the Atlas Centaur 67 vehicle.

HISTORY

The first study of lightning which could be called scientific was performed during the second half of the Eighteenth century by Benjamin Franklin. Prior to that time, electrical science had developed to the point where positive and negative charges could be separated by electrical machines, rubbing together two different materials and storing the charges on primitive Capacitors called Leyden jars.

While others had previously noted the similarity between laboratory sparks and lightning, Franklin was the first to design an experiment which conclusively proved that lightning was electrical. In his experiment, he proposed that clouds are electrically charged, from which it follows that lightning must also be electrical. The experiment involved Franklin standing on an electrical (THIS NEEDS TO BE DEFINED IN MODERN TERMS) stand, holding an iron rod with one hand to obtain an electrical discharge between the other hand and the ground. If the clouds were electrically charged then sparks would jump between the iron rod and a grounded wire, in this case, held by an insulating wax candle. Obviously, he did not fully appreciate the dangers involved in this experiment for if the iron rod had been directly struck by lightning, he would likely have been killed.

This experiment was successfully performed by Thomas Francois D'Alibard of France in May, 1752 when sparks were observed to jump from the iron rod during a thunderstorm. G.W. Richmann, a Swedish physicist working in Russia in July 1753, proved that thunderclouds contain electrical charge, and was killed by a direct lightning strike. (NOTE: there is another reference which states the apparatus was hit and not Richmann...need to find out for certain.)

Before Franklin got around to performing his original experiment, he thought of a better way to prove his theory - an electrical kite. The kite took the place of the iron rod, since it could reach a greater elevation and could be flown anywhere. During a thunderstorm in 1752 the most famous kite in history flew with sparks jumping from a key tied to the bottom of the kite string to the knuckles of Franklin's hand.

3 x 4 PICTURE of Franklin's Kite

In addition to showing that clouds contain electricity, by measuring the sign o£ the charge delivered, Franklin was able to infer that during thunderstorms overhead, the lower part o£ the thunderstorm was. generally negatively charged.

No further significant progress was made in understanding the behavior and properties of lightning until the late nineteenth century when photography and spectroscopy became diagnostic tools available for lightning research.
Lightning current measurements were made in Germany by Pockels (Full name, date??) who analyzed the magnetic field induced by lightning currents to estimate the current values. Time-resolved photography was used to identify individual lightning strokes that make up a lightning discharge to the ground by many experiments during the late nineteenth century.

Lightning research in modern times can be dated to Wilson, who in England during 1916-1920 invented the cloud chamber to track high energy particles, winning the Nobel Prize.

The first to use electric field measurements in thunderstorms to estimate the structure of the charges involved lightning discharges, Wilson contributed greatly to our present understanding of lightning.

Research continued at a steady pace until the 1970's when lightning research became particularly active. This increased interest was motivated by lightning damage to spacecraft and the vulnerability of the solid-state components of computers and other electronic devices that were becoming much more widely available.

To cite an example of

TYPES OF LIGHTNING DISCHARGES

Lightning strikes come in many forms, descriptions of some are given below:

CLOUD-TO-GROUND LIGHTNING This is the most damaging and dangerous form of lightning. Although not the most common type of lightning discharge, it is the type which is best understood. Most flashes originate near the lower-negative charge center and deliver negative charge to Earth. However, sometimes positive charging occurs in a thunderstorm that is dissipating. In this case, the lower negative charge has been neutralized by the previous discharges and excess positive charge remains at the top of the storm. This discharges between the lower positive-charge area and Earth, thereby directing positive charge Earthwards. Cloud-to-Ground Lightning has a large variation in flash frequency. This variation seems to be due to the latitude of the flash, with a greater percentage occurring at higher latitudes. The variation may also be explained by the temperature and location of the charge center.

INTRA-CLOUD LIGHTNING is the most common type of discharge. This occurs between centers within the same cloud that are oppositely charged. Usually the process takes place within the cloud and looks from the outside of the cloud like a brightening portion which flickers. However, the flash may exit the boundary of the cloud and a bright channel, similar to cloud-to-ground flash, can be visible before it re-enters the cloud.

CLOUD-TO-CLOUD LIGHTNING acts as the name implies, and the charge centers are in two different clouds with the discharge occurring as a bridge in the gap of clear air between them.

CLOUD-TO-AIR LIGHTNING is when the flash exits from a cloud and terminates in clear air . The flash can be heavily branched with the different branches ending in the region of the space charge in the clear air. This type of flash is responsible for the name "Bolt from the Blue" as it usually occurs in a region of fair, blue skies where the cloud responsible for the flash is unobserved.

HEAT LIGHTNING. This is a brightening of clouds caused by other lightning types or an intra-cloud reflection.

SHEET LIGHTNING is a name given to a large illuminated area caused by intra-cloud discharge.

RIBBON LIGHTNING to the observer is seen as several closely-spaced flashes which follow a parallel congruent path to the ground. This is thought to be caused by wind moving the ionized main discharge channel short distances during a number of individual lightning strokes. Because the retina of the eye cannot discriminate between image changes in less than 1/16 of a second in interval, the strokes seem to occur at the same time and all together they look like a bright ribbon.

BEAD LIGHTNING is a flash in which the discharge channel seems to be alternatively bright and faint, even with sections that are non-luminous. Therefore, it looks like a string of bright beads. This is an optical illusion. The flash usually begins as a normal discharge with a high channel. As the channel twists, the observer views different sections with different perspective. If he looks perpendicular to the channel it will seem faint compared with looking along the channel where he sees more particles and thus this section appears brighter.

BALL LIGHTNING is one of the most mysterious atmospheric phenomenon. It is almost always associated with violent thunderstorms, and its variability eludes explanation.(I BELIEVE IT IS ALSO HAS BEEN SEEN PRIOR TO MAJOR EARTHQUAKES??) It appears as a ball ranging in diameter from a few centimeters to a meter or more. Some balls seem to hover in mid-air and remain motionless, while others travel at great speed. Some bounce off conducting surfaces, while others can penetrate through solid material (even glass without shattering it) and can remain inside of aircraft. Some last seconds, some minutes. Some explode, while others quietly fade away. The color is usually yellow or red or bluish white, but purple and green fireballs have been seen as well.

St. ELMO'S FIRE. This name has been given to a form of discharge which occurs in the vicinity of a more or less pointed object. Named after the patron saint of sailors, it applies to the glow around mastheads during

storms. With the increase in electric field which occurs during thunderstorms charge accumulates at points giving rise to a corona discharge. That is, charged particles are accelerated by the electric field and collide with and ionize some molecules. When these electrons and ions recombine, energy is released in the form of visible light.
The length and duration of an individual lightning stroke varies, but the average duration of a discharge is estimated to be about 30 microseconds. (The average power per stroke is about 10^{12} watts.) There is usually an average of four strokes for every lightning flash. Multiply the energy of a stroke then by four and if you use 100 as the number of flashes occurring throughout the world every second, then the global electrical energy produced by lightning per year is about one billion kWH enough to power ?? homes.

THUNDER is the sound that occurs along the length of the lightning channel as the atmosphere is heated by the electrical discharge to over (TEMPERATURE??). This expands and pushes aside the surrounding clear air which in turn collapses immediately following the strike. Although the flash and the resulting thunder occur at essentially the same time, light travels at 186,000 miles in a second. Whereas sound travels at the relatively snail pace of a 1/5th of a mile in the same time. Thus the flash , if not obscured by clouds, is always seen before the thunder is heard. By counting the seconds between the flash and the thunder and dividing by 5 an estimate of the distance of the strike can be made.

WHEN LIGHTNING STRIKES

~' A 5X7 picture

~ goes here which has title on it.

The six most common dangerous activities associated with lightning strikes are:

1. Work or play in open fields.
2. Boating, fishing and swimming.
3. Working on heavy farm or road equipment.
4. Playing golf.
5. Talking on the telephone.
6. Fiddling with electrical appliances.

If caught in the open during a strike and the hair on your head or neck begins to stand on end (this really happens)

3x4 cartoon

go inside the nearest building. If no shelter is available, crouch down immediately in the lowest possible spot and roll up in a ball with feet on the ground. (DO NOT LIE DOWN.)

TREATMENT:

A. Check breathing and pulse .
B. TREAT <u>APPARENTLY</u> DEAD FIRST .
C. Perform mouth-to- mouth resuscitation.
D. Apply cardiopulmonary resuscitation.

OBSERVATIONS FROM HIGH-ALTITUDE AIRCRAFT

Observations from airplanes and balloons long confirmed Wilson's theory that strong electric fields exist over the tops of thunderstorms. The penetrative convective cells which rise above the anvil cause the most intense electrical stresses, as seen from high-altitude aircraft.

Electrical activity taking place above and also within the upper portion of thunderclouds has been studied with the use of a U-2 high altitude aircraft, which can fly at an altitude of 20 km MSL and at speeds of 200 ms(?) over most of the highest thunderstorms.

A new enhanced version, the high-altitude ER-2 is also designed for sustained flight at very high altitudes. Cruising above atmospheric disturbances (65,000 ft+ units??) at consistent (constant?) speeds allows for almost distortion-free data. Providing direct observations of severe thunderstorms and resultant thunderheads, the aircraft employ lasers, infrared and microwave scanners, spectrometers and electric field antennas.

Photography of lightning in clouds is accomplished using an open shutter technique. In this method, the camera is pointed toward the thundercloud with the shutter open. In the dark nocturnal sky, no light falls onto the film until lightning strikes.

With the duration of a lightning flash of about 0.5 sec., luminosity from channel or multiple stroke lightning will result in multiple images placed around 100 m during a flash.

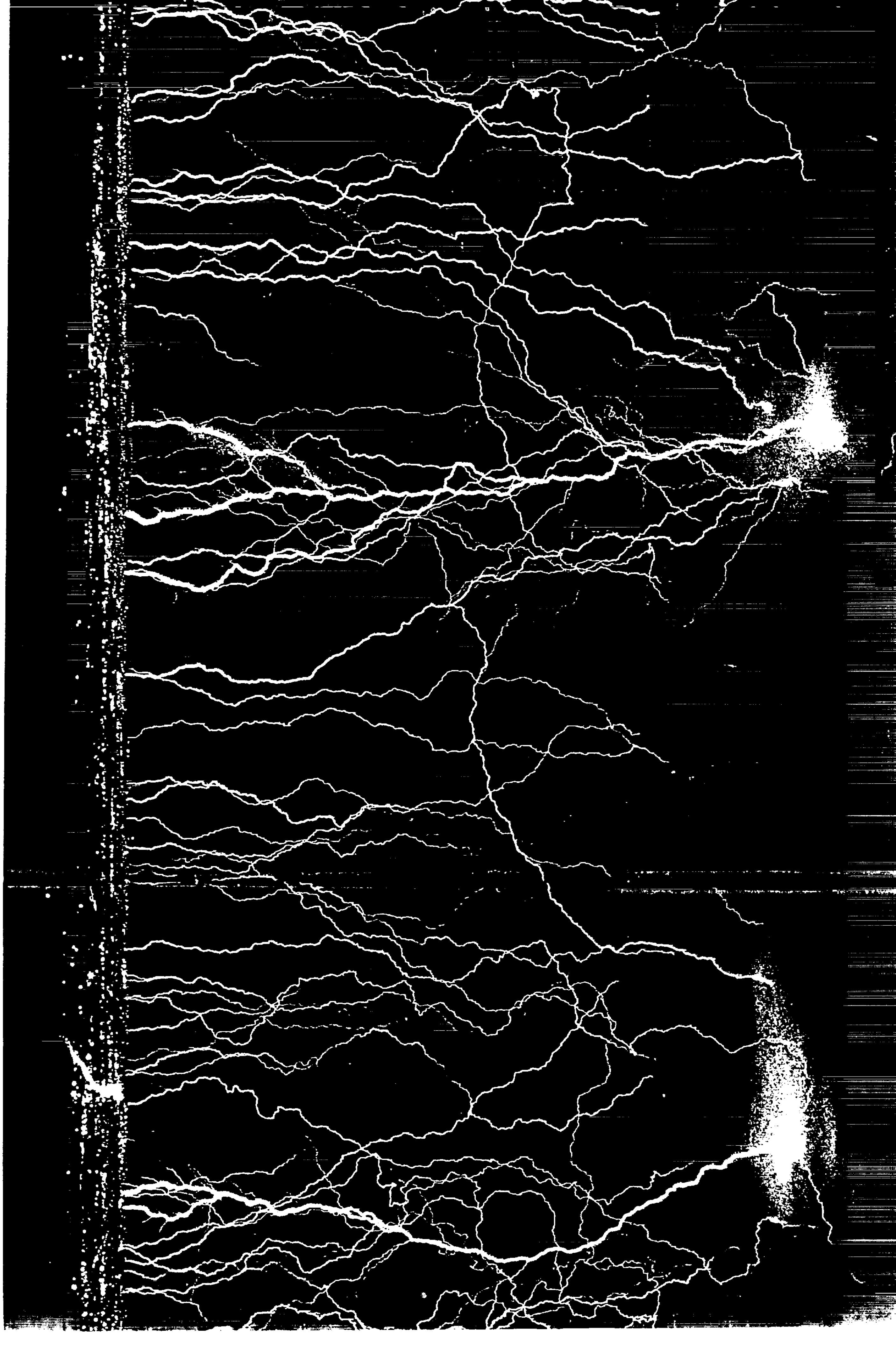
In a typical experiment, an aerial Vinten camera was located in the belly of the U-2 airplane and pointed vertically downward. The 44.5 mm focal length lens (f2.8 aperture) was then left fully open. 70 mm Plus-X Aerographic 2402 film was used to photograph clouds at intermediate altitudes with a coverage of approximately 10 km x 10 km. The film being advanced one frame at a time by the pilot following each flash of lightning. Alternatively, an intervalometer is used to automatically advance the film, frame by frame, at set intervals while the aircraft pass over a thunderstorm.

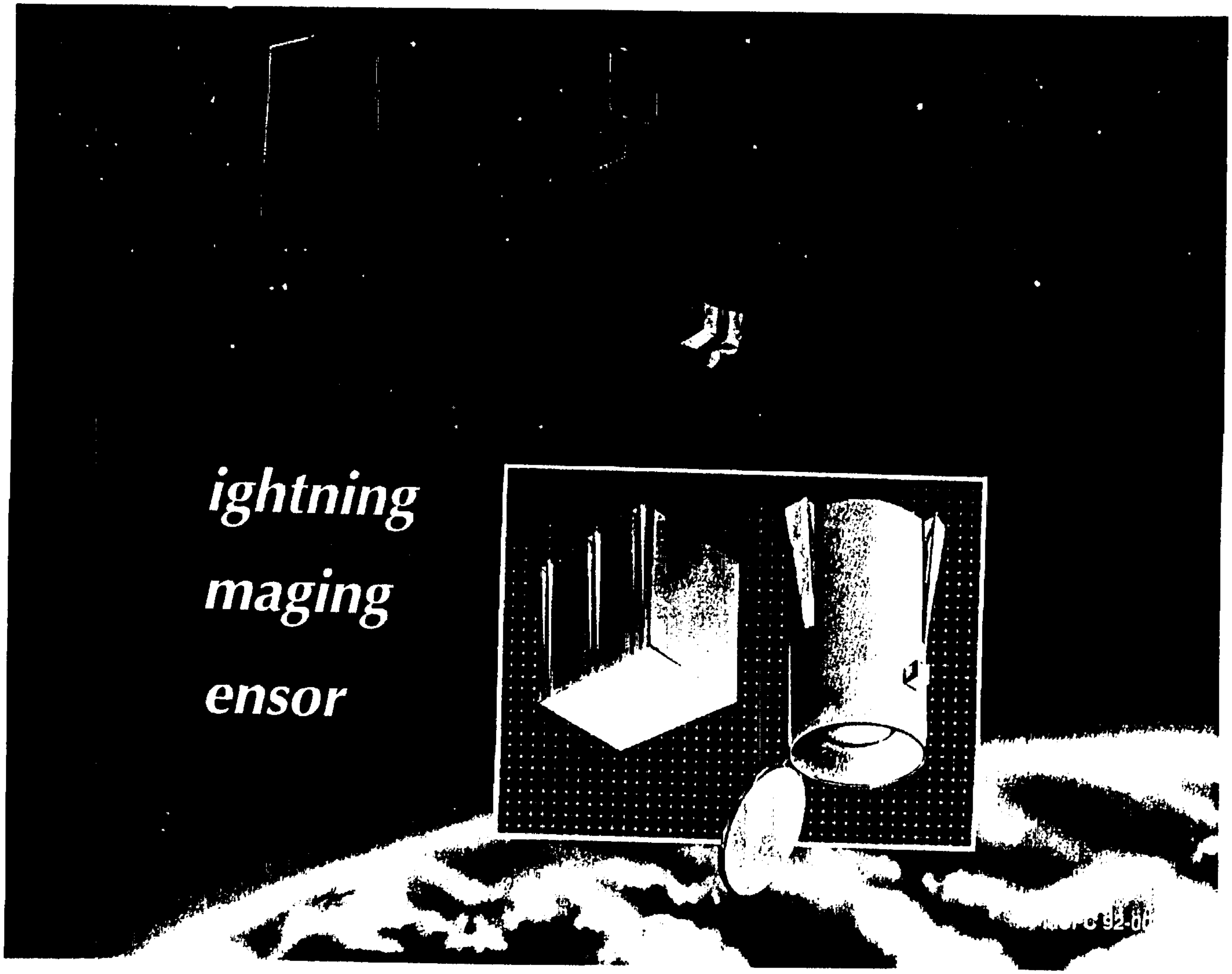
LIGHTNING DETECTION NETWORK

The National Lightning Detection Network (NLDN) which is located in Tucson, Arizona is a network of at least 130 detection finders (Dfs) which encompasses the entire United States. These active sensors act like radio receivers to locate lightning discharges. The location of the lightning discharge is determined by triangulation, with each of these sensors being capable of detecting cloud-to-ground lightning flashes up to 400 km away. This information is transmitted to the Network Control Center (NCC) via computer in the form of a grid map showing lightning across the U.S.

USES OF A LIGHTNING MAPPER

1. Extrapolate highly electrically active cells' motion]
2. More accurate aircraft avoidance advisories
3. Real-time local electrical activity advisories for the shuttle
4. Recreational warning enhancement e.g. golf courses, beaches, marinas.
5. "Infrastructure"? warnings, e.g. power companies, fuel depots, etc.
6. Lightning discharge rate, re - storm development, flood warnings.
7. Specialized display of long-duration flashes, re - forest fire control.
8. Forecast improvement by quantifying lightning data by; time of day, season, location, storm type.
9. Lightning as an indicator of cyclone development.
10. Increasing the understanding of the physics of the Global electric circuit.
11. Increased understanding of lightning-induced wave-particle effects in magnetosphere.
12. Land-sea intensity & frequency differences, solar anomalies etc.
13. O & NO_x generation studies using C-C rates + intensities.
14. Studies of Whistler & other wave propagation phenomena.
15. Research VLF-ELF electromagnetic noise.
16. Radical, oxidant, & HCN formation.
17. Investigate sympathetic lightning.

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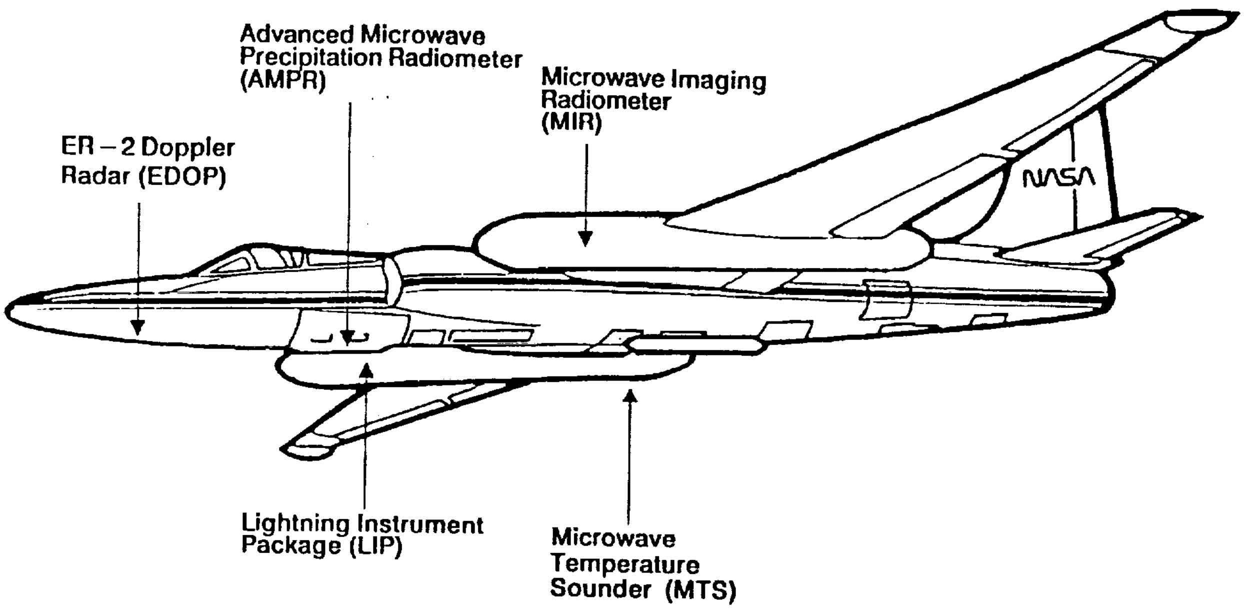
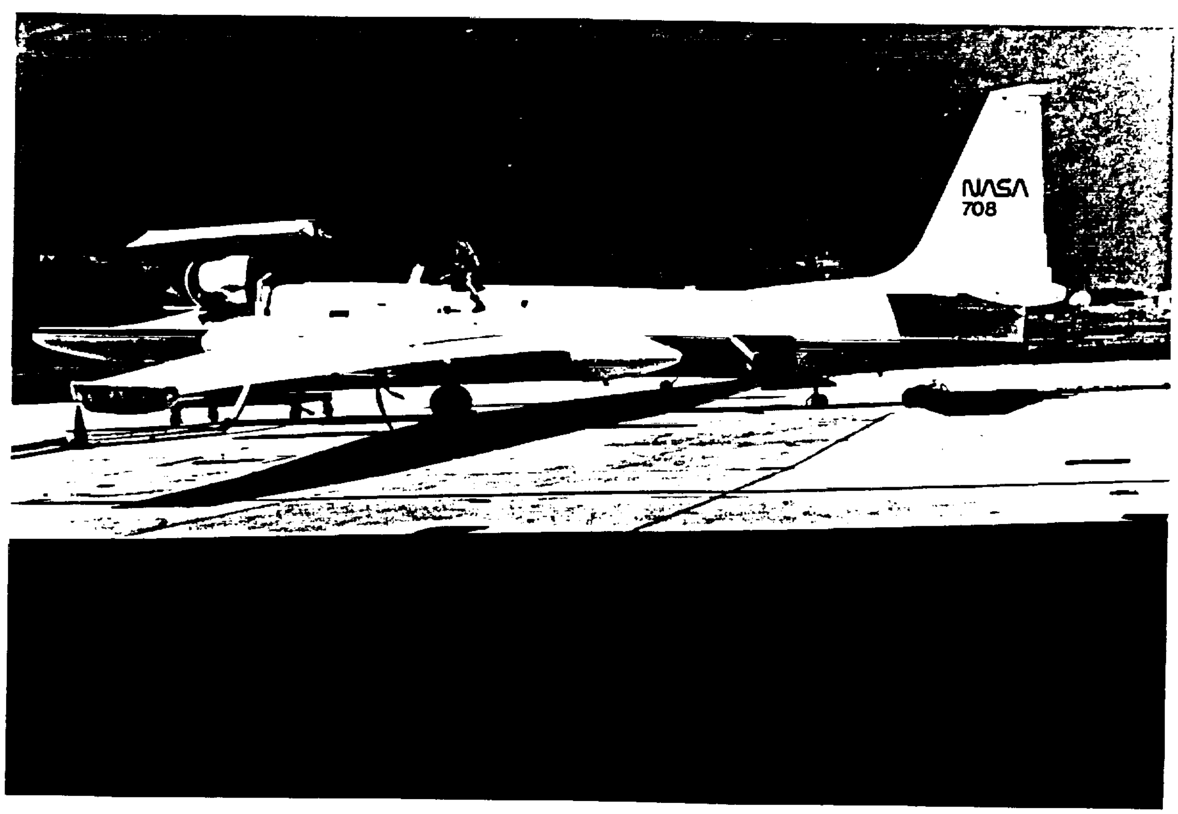
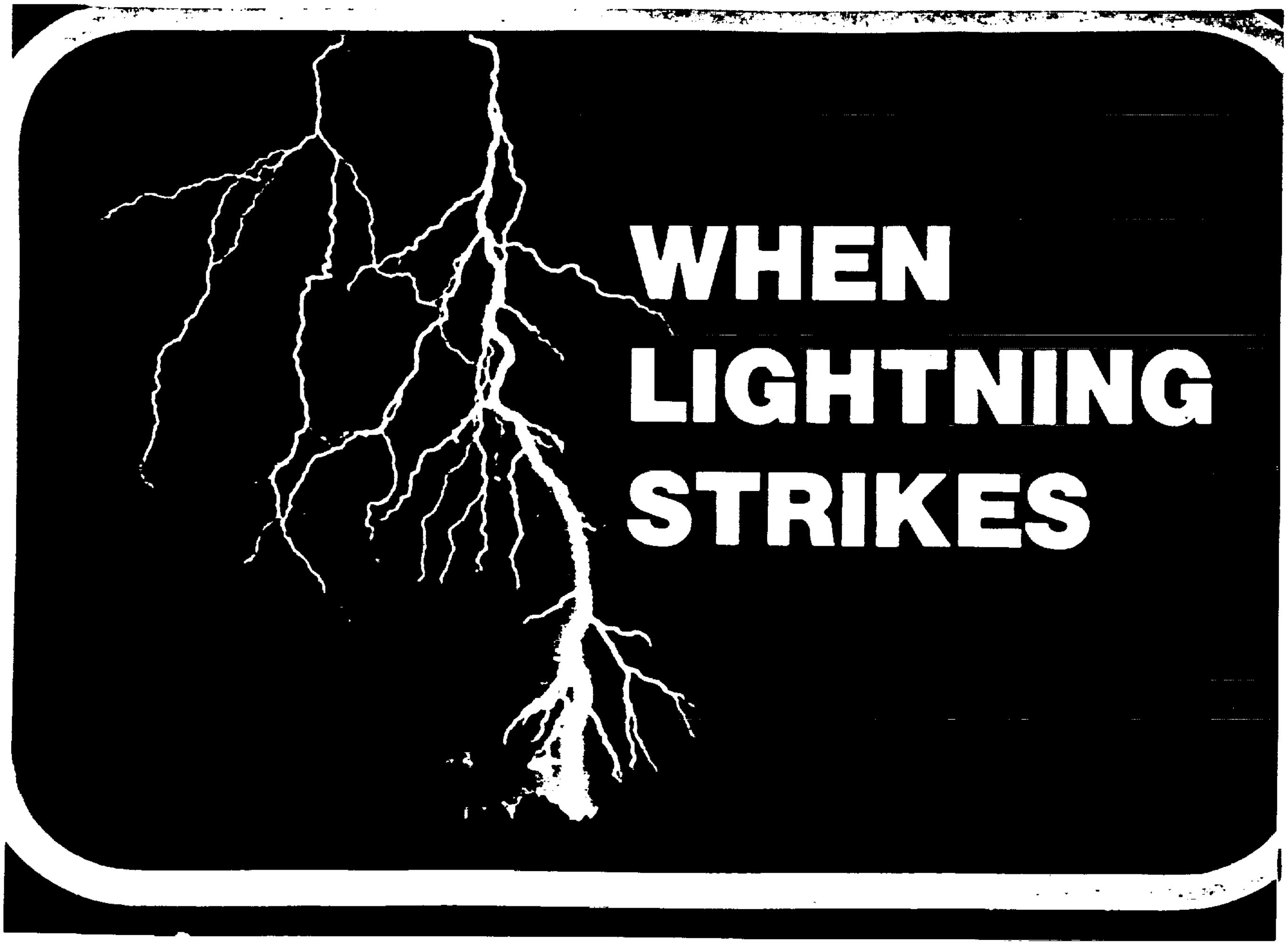


ER – 2 Configuration for Storm Observations



NASA ER-2 HIGH ALTITUDE AIRPLANE DEVELOPED BY LOCKHEED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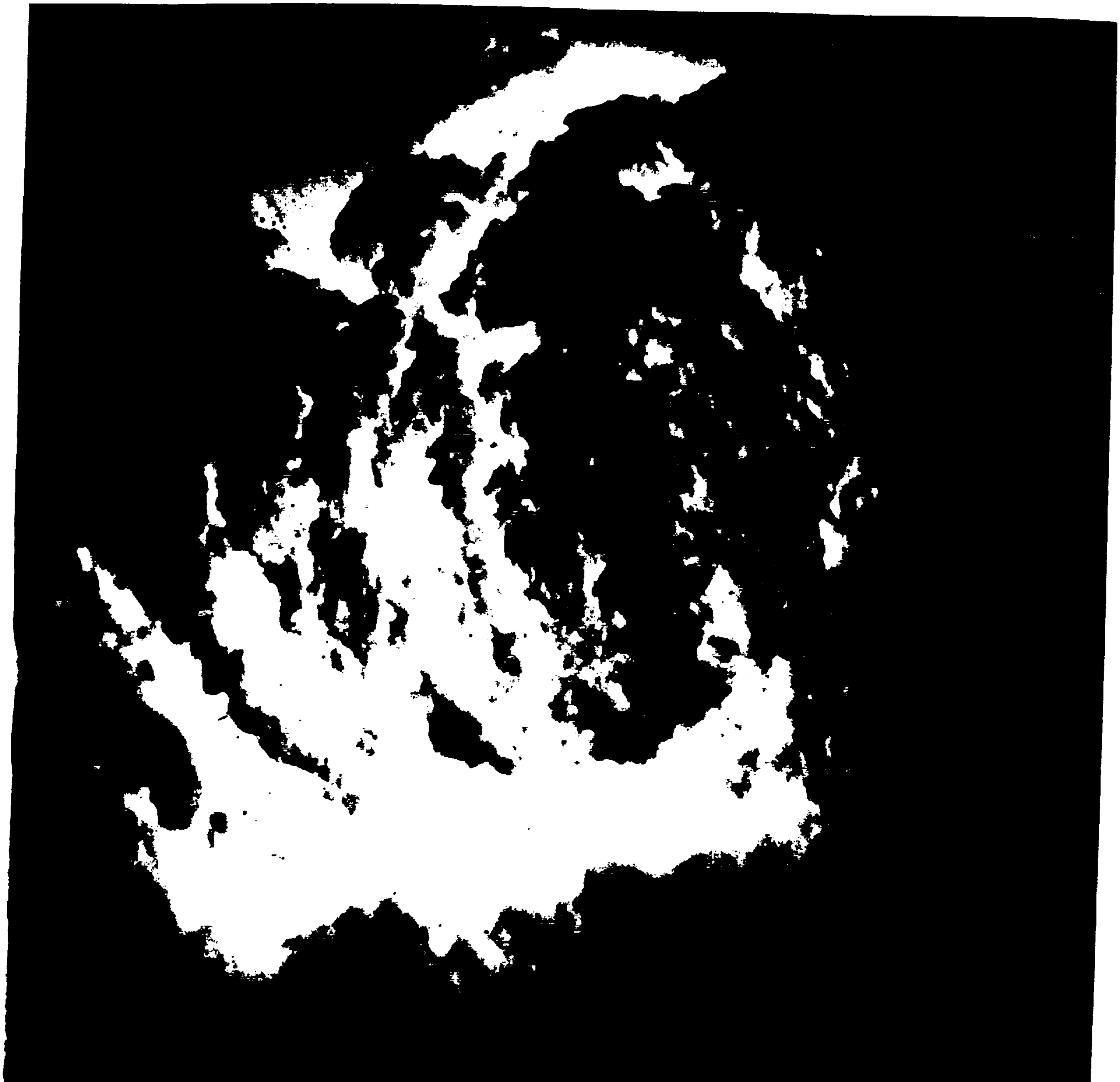

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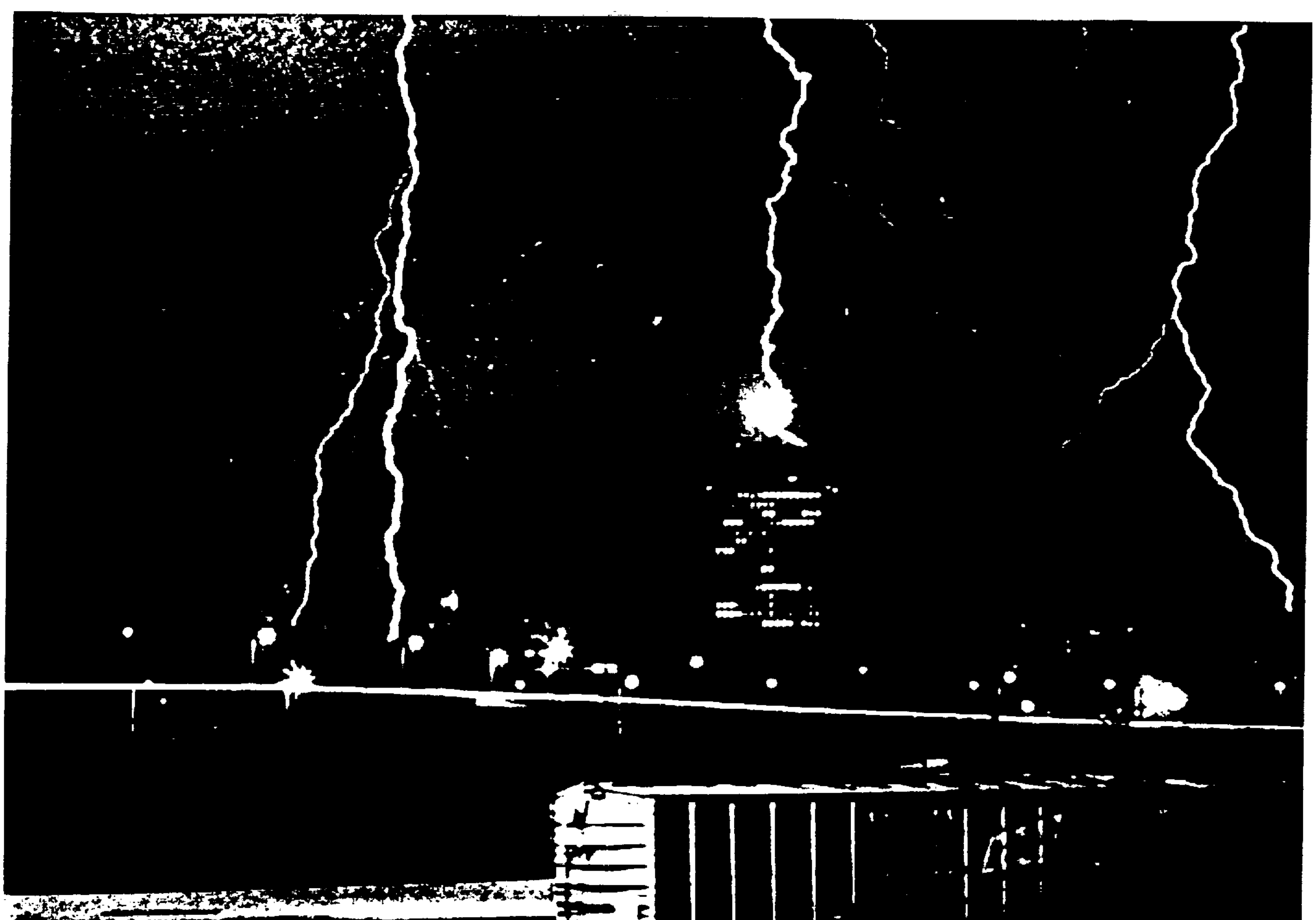

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