Lightning frequency and importance at the Kennedy Space Center (KSC) and the Eastern Test Range (ETR) are discussed. The lightning detection systems in use and their importance to Space Shuttle operations are presented. Lightning research projects are briefly mentioned.
LIGHTNING AT KENNEDY SPACE CENTER

William C. Gibbons and Billie F. Boyd
Office of the Staff Meteorologist
Eastern Space and Missile Center
Patrick Air Force Base, Florida

William Jafferis
Office of the Directorate of Launch
and Landing Operations
John F. Kennedy Space Center, Florida

ABSTRACT

Lightning frequency and importance at Kennedy Space Center are discussed. Lightning detection systems and research projects are described.

BACKGROUND

The Kennedy Space Center/Cape Canaveral Air Force Station (KSC/CCAFS) area borders the area of highest frequency of thunderstorms in the United States (Fig. 1). Since the majority of the thunderstorms occur in the summer months, lightning frequencies in the area during these months approach the highest level of any location in the world. The mean area density of cloud-to-ground lightning at KSC is 3.9 with a range of 2.4 flashes per square kilometer during June, July, and August. If the lightning strikes were randomly spaced, this would equate to about 10 ± 6 lightnings for each square mile of KSC each month, or a total of about 1400 ± 850 lightning strikes each summer in the KSC area. This high level of frequency presents three major problems: danger to personnel, damage to equipment and property, and loss of time in order to minimize the previous items.

Danger to personnel is very real. Over the period 1959 to 1983 there were 265 deaths in Florida attributed to lightning (approximately ten per year, more than ten percent of the national total). There were 663 lightning related injuries reported in that same period within Florida, which again equals approximately ten percent of the national total of 6,219.

Loss of production time due to lightning occurrence has been a problem since the origin of the space program at KSC/CCAFS. Holmes documented the problem as early as 1964 and Goodman recently discussed the effect of lightning on all phases of Shuttle operations. In preparation for the Shuttle program, the National Aeronautics and Space Administration (NASA) at KSC improved the lightning protection systems for critical work areas and changed their ground safety plans.

The United States Air Force's (USAF) Detachment 11, 2d Weather Squadron of the Air Force Weather Service (AFWS) is constantly working with the various offices of NASA at KSC and the USAF's Eastern Test Range (ETR) and CCAFS to further minimize these problems through improved instrumentation to enhance understanding and forecasting of lightning. NASA has also supported a variety of lightning research projects.

LIGHTNING DETECTION SYSTEMS

Two major lightning detection systems currently in use in the KSC/CCAFS area are the Launch Pad Lightning Warning System (LPLWS) and the Lightning Location and Protection (LLP) system. The Launch Pad Lightning Warning System (LPLWS). The LPLWS was developed as a result of lightning discharges to Apollo 12. The LPLWS enables forecasters to monitor impending and current atmospheric electrical activity. It provides the USAF weather forecasters information on trends in electric field potential and on locations of highly charged clouds and charge centers associated with lightning. This information is used to alert launch complexes and operational areas at KSC to appropriate protective actions can be taken. The LPLWS consists of 34 electric field mills (Fig. 2), computer software for data acquisition and analysis, and a CRT display.

The field mills are placed so the sensor plate is ten inches above the ground. They measure the vertical component of the atmospheric potential gradient at ground level. Each field mill contains eight vertically oriented stator sections which are alternately covered and uncovered as the rotor turns. The differential voltage (volts per meter) between the covered and uncovered stators provides the amplitude and polarity of the electric field. The dynamic range of the sensors is ±15 kilovolts per meter. The data from each field mill are transmitted to a central area where they are digitized at a rate of ten samples per second.
Fig. 1 Mean Annual Thunderstorm Days, 1951-1975.

Fig. 2 Field Mill Locations.

Fig. 3 UV Site Locations.
The LPLWS computer software has a static field mode and a lightning mode. The LPLWS static field program contours the field mill data so the forecasters can determine when the electric field values indicate the threat of lightning is imminent. A map of the CCAPKSC area is drawn and contours of the static field are plotted on a CRT. The static field is calculated from the average electric field value at each millimeter during a 1-minute interval; the forecasters can specify output intervals of 1 to 60 minutes (default is 15 minutes). The average field value for each field mill is printed on the right side of the contour map. During lightning activity the static fields are no longer useful and the lightning mode locates intercloud and cloud-to-ground lightning strikes. In the lightning mode, the LPLWS program outputs the charge centers or source of lightning activity. The program checks for lightning discharge by evaluating data over two one-tenth of a second intervals which is accomplished by extrapolating the slope (assumed to be linear) of the field in the first one tenth of a second interval to a predicted value at the end of the next one tenth of a second interval and comparing this to the measured field at that point. If the difference between these two values is greater than a threshold, a lightning discharge is assumed. The exact time of the strike, the initial and final field, and the position of the strike are each site are displayed. The center of the field change over the network is calculated and this is interpreted as the source of the discharge in the cloud. The first discharge interval is displayed on the CRT. At the end of each minute, the total number of lightning discharges during the preceding one minute interval is output to provide additional information on each storm's lifecycle. After five minutes, the screen is erased, another static field display is output, and the cycle is repeated if more lightning discharges are detected.

The most significant use of the LPLWS is during launch and landing of the Space Shuttle. The intent of these rules is to protect the Shuttle vehicle from lightning strikes (like the Apollo 12 strikes). The LPLWS is used to detect the potential for lightning strikes to the Shuttle during launch or landing. It is an essential instrument for lightning detection at KSC.

### TABLE 1

**SHUTTLE LAUNCH COMMIT CRITERIA RELATED TO LIGHTNING**

<table>
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<tr>
<th>Criteria</th>
<th>Action</th>
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<td>The Shuttle vehicle shall not be launched if the nominal or the return to launch site flight path will carry the vehicle.</td>
<td>a. Through any cloud if a kilovolt per meter or greater ground level electric field contour encompasses the launch or landing site.</td>
</tr>
<tr>
<td></td>
<td>b. Through any cloud if a kilovolt per meter or greater ground level electric field contour encompasses the launch or landing site.</td>
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Lightning Location and Protection (LLP) System.

The LLP system locates cloud-to-ground lightning in the KSC/CCAPKSC area and complements the LPLWS which can locate charge centers. The LLP system has a static mode and a lightning mode. The LLP system has been estimated to have a detection efficiency of about 75 to 80 percent. The LLP system locates lightning to an accuracy of about 500 meters. Lightning strike positions detected by the LLP system are processed through a position analyzer (PA) and a remote display processor (RDP) to be viewed on a color video display unit at the Cape Canaveral Forecast Facility (CCFFF). The LLP system allows the forecasters a variety of maps and modes for displaying the lightning. The lightning strike positions from the LLP system are processed through a separate PA and plotted on a high resolution rectangular plotter at the CCFF. A local data terminal for each system records the time, location, polarity, and number of return strokes for each observed cloud-to-ground lightning strike. The data for each lightning strike is recorded on a Columbia 8-track recorder; the medium gain data is recorded on the Columbia recorder and a Cipher 9-track recorder.

Each DP antenna site uses an orthogonal set of magnetic loop antennas and a flat plate electric field antenna to sense the electromagnetic field radiated by lightning discharges. The bandwidth of the antenna system is broad, approximately 1 kilohertz to 1 megahertz, which preserves the shape and polarity of the lightning waveform. The system processes only those fields that have wave shapes and polarities characteristic of cloud-to-ground lightning. The direction of the incoming field is determined at each DP site from the ratio of the signals on the two orthogonal loops. By measuring the direction at just the time when the return stroke magnetic field reaches its initial peak, errors due to horizontal channel sections are minimized. This time also corresponds to a point where the return stroke is within 1000 meters of the ground, thus giving the location of the actual ground stroke rather than some elevated portion of the stroke. The DF sites communicate to their respective PP via half duplex lines.

The PA is a complete microcomputer that accepts data inputs from the DF sites and automatically reports the locations of the
lightning strikes. The locations are computed by triangulation using the angles measured at two of the DF sites. Lightning which occurs along the baseline of two of the DF sites can be plotted inaccuracy of the small angles involved in the calculation. In the medium gain system, this primary input at each of the other two DF antennas. If a third input is not available (as in the medium gain system), the position is computed by comparing the field amplitude at each DF site as well as each angle.

The USAF forecasters use the medium gain LLP system to determine which echoes on radar are producing lightning and when these, or other storms, will lead to the KSC/CCAFS area. This system helps determine when lightning warnings should be issued so personnel can take proper protective action. For example, the Tethered Aerostat Radar System (TARS) at CCAFS requires a leadtime of 1 hour for thunderstorms within 25 nautical miles of the Shuttle, if it is on the pad, requires 30 minutes of leadtime for lightning within 5 nautical miles of Complex 39A or 39B. The LLP system is also used to determine when lightning warnings should be canceled so as to minimize loss of work time.

RESEARCH PROJECTS

KSC has evolved as an important location in lightning research due to its high frequency of lightning activity in conjunction with aircraft and aerospace vehicles. During the summer of 1983, 36 lightning researches conducted their studies at a facility located about 9 miles north of the KSC Vehicle Assembly Building. Taking part in these research projects were representatives of NASA, the USAF Weight Aeronautical Laboratory, France's Center for Nuclear Studies, American universities, and private industry. Information gained in these studies may be used in the design of advanced lightning protection systems for KSC/CCAFS facilities and also for greater protection of aerospace vehicles containing electronic flight control systems, such as the Shuttle.

The French scientists trigger lightning by launching a small rocket which trails a thin copper wire to an altitude of about 3,000 feet. The wire acts as a trigger, attracting the stroke which vaporizes the wire while traveling down an electrical pathway to the ground. Special instruments and cameras near the launch site record the strike in detail. Triggered lightning provides a degree of control of lightning events occurring at a known ground location thereby providing a laboratory quality set of measurements to correlate with existing operational and scientific instrumentation.

A joint project between the Federal Aviation Administration and the AMM Laboratory continued in 1985. One of the objectives was studying the effects of lightning on flying aircraft using a specially-equipped Convair C-580 airplane; the researchers hoped to position it beneath and after thunderstorms. In the future this may help forecasters predict the start and end of thunderstorms more accurately. A group of researchers from the State University of New York at Albany used a streak camera to determine return stroke velocity.

The Communication and Weather Research Foundation provided support and communication equipment for all phases of these research projects.

SUMMARY

Lightning activity in the KSC/CCAFS area is both a curse and a blessing. The high lightning frequency is a threat to life and slows space vehicle operations. Yet, the presence of numerous lightning researchers as well as sophisticated lightning detection and protection systems make KSC an ideal location for lightning research to perfect lightning detection and protection.

REFERENCES

7. Shuttle Launch Status Criteria and Background, Revision C, 1 Dec 1982, NASA/Jua, pp 1.4-1.4-3, rule 1.4.8.


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