AD A135 318 DATA ACQUISITION FOR EVALUATION OF AN AIRBORNE LIGHTNING DETECTION SYSTEM(U) AIR FORCE WRIGHT AERONAUTICAL LABS WRIGHT-PATTERSON AFB OH 1/1

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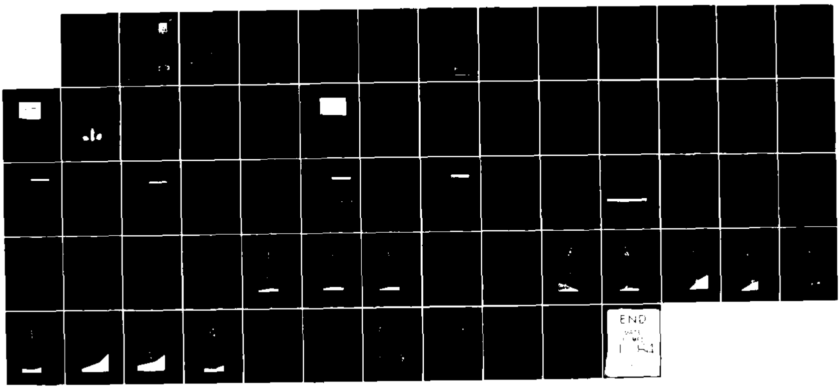

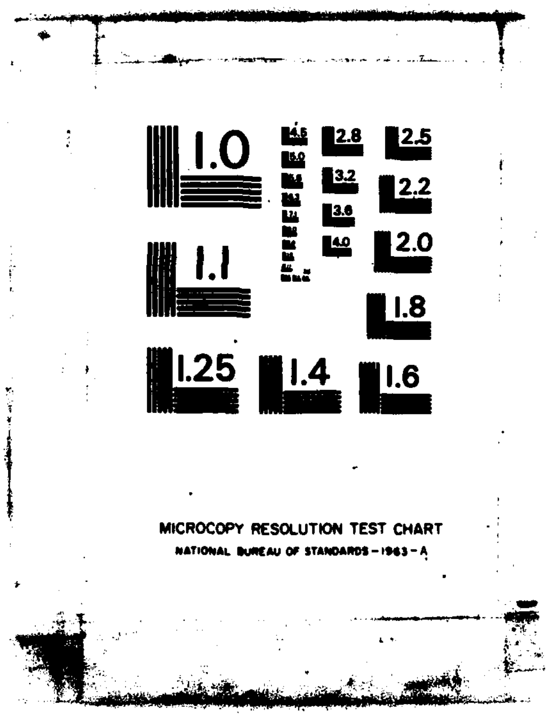
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AFWAL-TR-83-3083

DATA ACQUISITION FOR EVALUATION OF AN AIRBORNE LIGHTNING DETECTION SYSTEM

AD-A135 318

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September 1983

Final Report for Period June 1981 - August 1981

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This technical report has been reviewed and is approved for publication.

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A data acquisition system was flown on a WC-130 aircraft to acquire data for evaluation of the Ryan Stormscope for potential use of such a system on USAF aircraft. The data acquisition system consisted of an instrument panel containing the Stormscope display, an aircraft weather radar display, an IRIG-B time display, and video recording system. Data were acquired during the summer of 1981 in the Florida area during a

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20. program conducted jointly by the Air Force Wright Aeronautical Laboratories and the National Oceanographic and Atmospheric Administration for the airborne characterization of lightning. The IRIG-B time reference permitted correlating of the Stormscope data, airborne and ground weather radar data, and electromagnetic measurement data from the lightning characterization program. Typical data acquired are presented along with corresponding data from electromagnetic sensors. A comparative discussion of the data from the various systems is presented. The data will undergo further analysis sponsored by the Warner Robins Air Logistics Center.

FOREWORD

This report presents and discusses data acquired for the Warner Robins Air Logistics Center (WR-ALC) during an Airborne Lightning Characterization Program (ALCP) conducted jointly by the Air Force Wright Aeronautical Laboratories (AFWAL) and the National Oceanic and Atmospheric Administration (NOAA). The work was performed under the direction of the Atmospheric Electricity Hazards Group (AFWAL/FIESL) under Subtask 2, "Lightning Characterization," Work Unit 24020223, "Atmospheric Electricity Hazard Assessment for Aircraft."

Data collection took place in the Florida peninsula area during the summer of 1981. The instrumentation systems were provided by AFWAL/FIESL. A Model WX-10 Ryan Stormscope* was supplied by 3M along with technical assistance for installation and calibration. Airborne radar information was provided by the National Hurricane Research Laboratory. The WC-130 aircraft and airborne weather radar information were provided by NOAA. Funding for the installation, data acquisition, and documentation was provided by WR-ALC.

The AFWAL/FIESL project engineer was Mr. Lawrence C. Walko. The WR-ALC project engineer was Mr. Clifford H. Mashburn. Mr. Roger Ryan was the technical representative for 3M Ryan Stormscope. Dr. Frank D. Marks, Jr. served as the technical contact from the National Hurricane Research Laboratory and was instrumental in the timely acquisition of airborne weather radar computer plots. Capt. Norman C. Buss (USAF) of AFWAL/WEF provided expert interpretation of weather radar information. The system installation was performed by Technology/Scientific Services, Inc. (T/SSI). During the flight missions, the system was operated by Lt. Brian P. Kuhlman (USAF) of AFWAL/FIESL, and M. Jean Reazer and Martin D. Risley of T/SSI. Ms. Reazer was also responsible for the processing, analysis, and presentation of the data. Douglas Benner of T/SSI assisted with the data processing and presentation.

*Ryan Stormscope is a registered trademark of the Safety and Security Division of the 3M Company.

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SECTION I

INTRODUCTION

The 3M/Ryan Stormscope WX-10 Weather Mapping System is described by the manufacturer as an airborne solid state receiving system which provides bearing and range information to electrical discharges. These data provide a display which can be used by the flight crew to avoid electrically active convective storms and thus the lightning, turbulence, wind shear, hail and ice which accompany them.

A previous model of the Stormscope, the WX-7A, was evaluated by the Air Force Flight Dynamics Laboratory and the 4950th Test Wing in 1980 [illegible] the Stormscope's ability to identify thunderstorm activity with sufficient accuracy to permit use as an in-flight lightning and severe weather avoidance [illegible] This report concluded that the [illegible] electrical activity [illegible] for the purpose of [illegible] air-craft. [illegible] indications with weather radar [illegible] there were some discrepancies [illegible] electrical activity which did [illegible] indications or [illegible]

[illegible]

vicinity of lightning activity. Johnson (Reference 3) evaluated the ability of the Stormscope and other systems to detect approaching thunderstorms that might trigger explosives in mines.

Because lightning continues to present a threat to Air Force aircraft of all types, the Warner Robins Air Logistics Center, Robins AFB, Georgia, provided funds to obtain information for further evaluation of the Stormscope. This project was included as part of the AFWAL/FIESL Lightning Characterization Program which was conducted in Florida during the period June to August, 1981.

Since some readers of this report may be unfamiliar with basic lightning terminology, the following discussion provides a brief review. Most of it is taken from the book Lightning by Martin A. Uman (Reference 4).

Lightning is generally the result of electric charge separation in a cumulonimbus cloud. More than half of these discharges occur within the cloud and therefore are known as intra-cloud discharges. Cloud-to-ground lightning also occurs frequently, while cloud-to-cloud and cloud-to-air discharges are less common.

A typical cloud-to-ground lightning flash lasts about 0.5 second (s). It consists of several high current pulses called return strokes, each lasting about 1 millisecond (ms) with 40-80 ms between them. The flash begins with a preliminary breakdown in the cloud which produces a leader, a movement of negative charge toward the ground in a series of luminous steps. The preliminary breakdown and charge movements produce an electric field change with a duration of a few to a few hundred milliseconds. Also, as the leader steps towards the ground, it produces individual rapid charge movements which generate electric and magnetic fields over short intervals.

When the leader (which may be one of several leaders) nears the ground, upward moving streamers produced by the large electric field make contact with it, connecting it to ground potential. This produces a return stroke characterized by a fast rise to a high current level, then a slow decay. More leaders may then propagate down the channel, followed by subsequent return strokes. Continuing currents also may occur when there is direct charge transfer from cloud-to-ground. A Polaroid oscillograph of the electric field for a typical lightning flash is shown in Figure 1.

The rapid movement of charge from ground-to-cloud during the return stroke produces a fast changing magnetic field which will in turn induce a current in a loop. If two loops oriented 90° to each other are in the path of the magnetic field, the arctangent of the peak current values will give the azimuth of the stroke from the loop location with a 180° ambiguity. A typical plot of the magnetic field produced during a return stroke is shown in Figure 2.

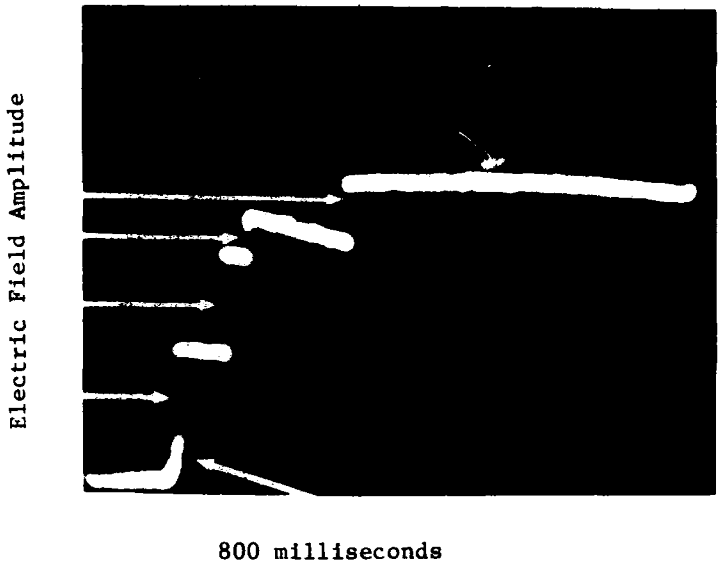


Figure 1. Electric Field Time History of a Four-Stroke Lightning Flash.

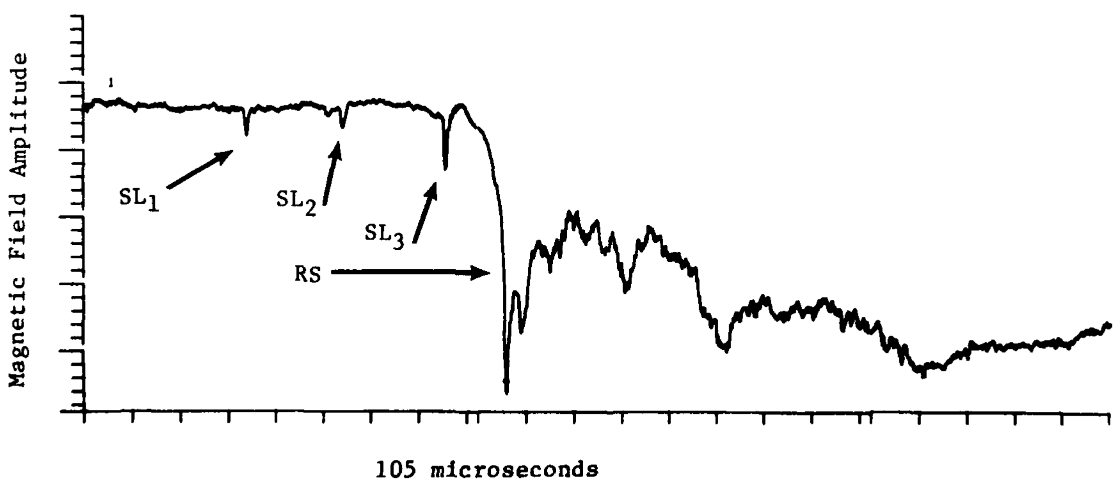


Figure 2. Magnetic Field Time History for the First Return Stroke (RS) of a Lightning Flash (Three Stepped Leaders (SL's) Precede the Return Stroke.

SECTION II

DESCRIPTION OF THE STORMSCOPE MODEL WX-10

The WX-10 Model used in this test is the newest Stormscope available, with features including 25, 50, 100, and 200 nautical mile (nmi) range displays, selectable fields of view of full 360° or forward looking 120° segment, a 256 dot memory capacity, and twice the resolution of previous models. All operational controls are in the panel mounted display. A microprocessor unit is included in the package but can be located anywhere in the aircraft. A flat pack ADF-type antenna must be mounted in an electrically noise-free area of the aircraft. The WX-10 display, microprocessor, and antenna are pictured in Figure 3.

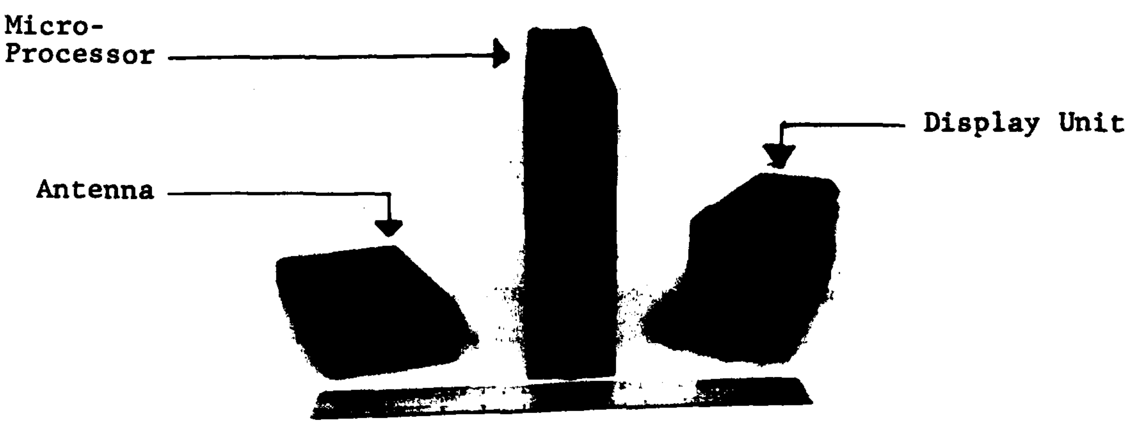


Figure 3. Stormscope Model WX-10 System Components

The Stormscope is represented by the manufacturer as a device which detects electrical activity associated with turbulence, allowing the pilot to deviate around severe weather by avoiding areas of high electrical activity. The azimuth and range of this activity are plotted in polar form over a 360° scan out to 200 nmi. The Stormscope can be operated in the air or on the ground.

The magnetic and electric field components of the electrical discharge radiation are detected by crossed loops and a sense antenna, respectively, in the flat pack unit. These signals are routed to the central processing unit for determination of discharge location. Azimuth of the discharge is determined from the ratio of the two crossed loop antenna inputs. Inherent azimuth ambiguity is resolved by the sense antenna input. Range of the discharge is also derived from the crossed loop antenna inputs, based on the assumptions that in the far-field region (i.e., observation distance much greater than lightning channel length), the magnetic field intensity is relatively constant from discharge to discharge and is inversely proportional to distance from the discharge. The time domain signature of the magnetic field (i.e., risetime, decay time) is used to modify the basic range computation, reducing error caused by intensity variations from discharge to discharge. To enhance noise rejection capability, the processor unit performs a correlation of the electric and magnetic field waveforms, a high correlation being characteristic of valid far-field discharge radiation.

Each discharge is stored in one of the 256 memory locations and is subsequently displayed on the CRT display. When the 257th event occurs, the oldest event is erased from memory and the newest takes its place.

The display has an overlay consisting of a compass rose, two concentric range circles, and a small aircraft outline in the center. The range can be varied so that the two circles represent 12.5 and 25, 25 and 50, 50 and 100, and 100 and 200 nautical miles, respectively. (In other words, when the Stormscope is described as on the 50 nmi range, the inner circle represents 25 nmi and the outer circle 50 nmi.) Data displayed can be erased at any time by pushing the clear button.

Since the location of each electrical discharge is displayed relative to the aircraft as stored in the memory, the information is displayed in the same location until the memory is erased. Changes in aircraft heading and location will not affect those dots already displayed; consequently, periodic clearing is necessary to maintain an accurate presentation with respect to the changing position of the aircraft in flight, particularly if the electrical activity is low.

SECTION III

TEST SETUP AND METHOD

1. STORMSCOPE SYSTEM

The Stormscope was installed on a WC-130 aircraft and flown for approximately 30 hours on 12 flights in the vicinity of southern Florida summer thunderstorms. A video monitor with a weather radar display was mounted beside the Stormscope so that the two outputs could be photographed simultaneously. An IRIG-B time code signal and crew conversations were also recorded for later correlation with other data and visual lightning sightings from the cockpit (Figure 4). The microprocessor was mounted on the aft, left bulkhead near the lower cargo doors. After reviewing a noise map of the aircraft, the antenna was mounted under the beaver tail just behind the cargo doors (Figure 5). Measurements by Stormscope personnel verified that this should be an electrically quiet location.

During the test program,the Stormscope was used to detect electrical activity approximately 100-200 nmi distant, fly to the area, then remain in the vicinity of the electrical activity while recording data. Generally, the Stormscope observations consisted of recording simultaneous Stormscope and radar displays on video tape, then comparing Stormscope video presentations with visual lightning observations from the cockpit and records of data obtained at the times when data were recorded by the lightning characterization instrumentation system.

2. LIGHTNING CHARACTERIZATION INSTRUMENTATION SYSTEM

The instrumentation installed on the upper fuselage of the aircraft included two magnetic field sensors mounted at right angles to each other and an electric field sensor. The sensors were manufactured by EG&G Washington Analytical Services Center, Inc. The sensors respond to the rate of change of the magnetic

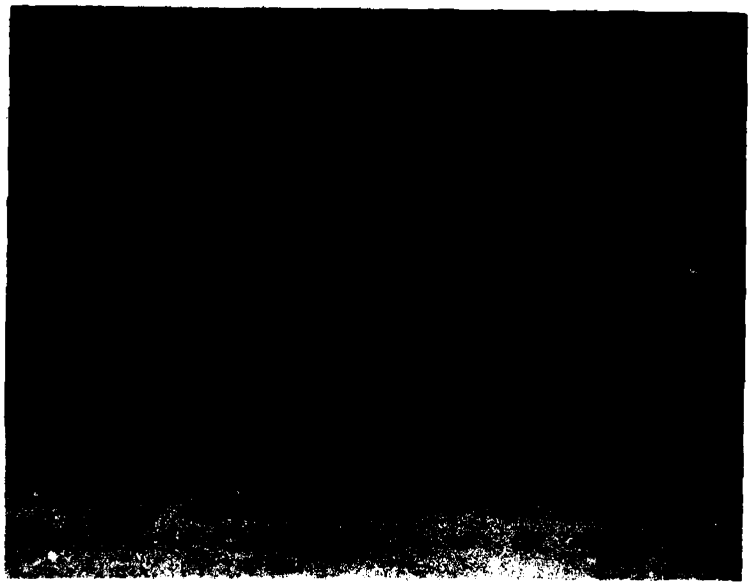


Figure 4. Stormscope, Radar Display, and Time Code Reader Panel

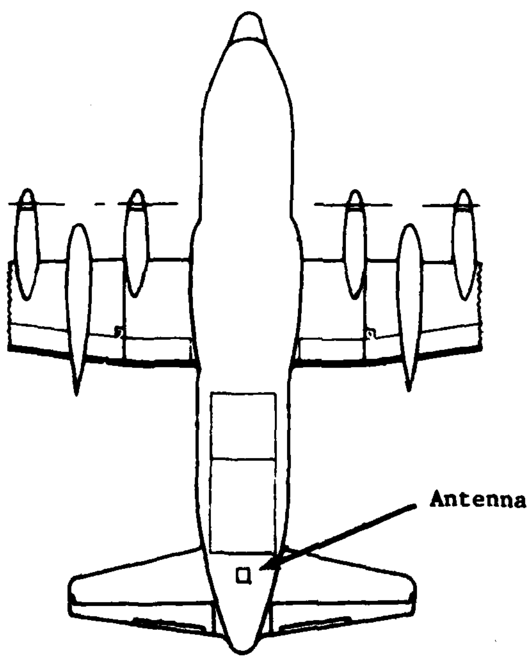
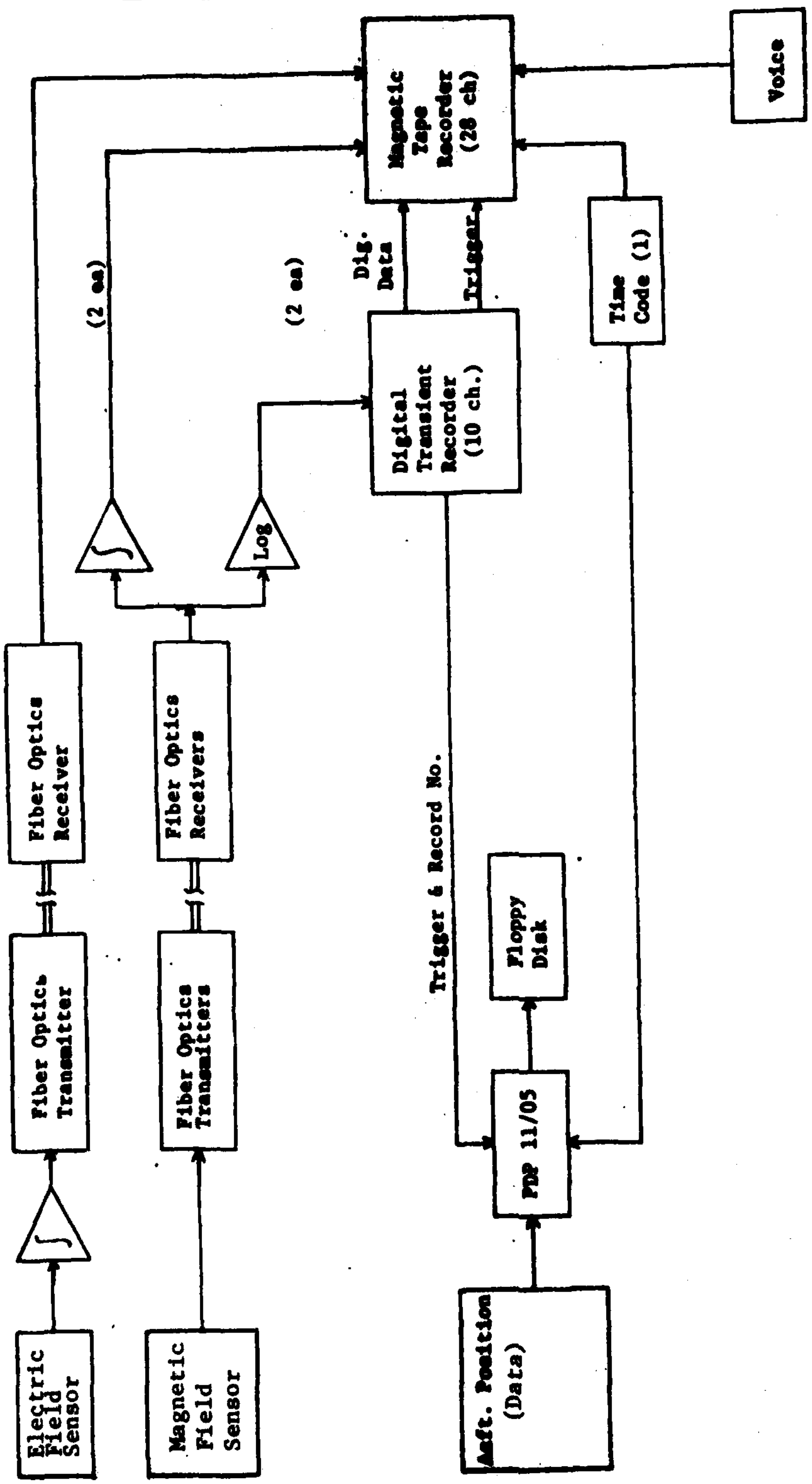


Figure 5. Location of Flat Pack Antenna

and electric fields. Consequently, integrating circuits were included in the instrumentation to permit recording of actual fields rather than their rate of change. The sensor outputs were relayed via fiber optic data links for recording on a Honeywell H101 instrumentation recorder. The magnetic field data into the recorder had a frequency response from 1 kHz to 15 MHz. These data were direct recorded resulting in a bandwidth of 1 kHz to 2 MHz. The electric field data into the recorder had a frequency response of 1 Hz to 15 MHz and were FM recorded resulting in a bandwidth of 1 Hz to 500 kHz. The magnetic field sensors measure the magnetic field components relative to the fuselage and wings of the aircraft; and, as previously stated, the arctangent of their ratio at peak gives the azimuth with respect to the aircraft with a 180^{o} ambiguity. The electric field data provides an overall time history of the lightning flash, including relative amplitude of the strokes and time interval between strokes.

The instrumentation system was designed so that a lightning flash would trigger a ten-channel transient recorder. Each channel of the transient recorder contains a fast analog-to-digital (A/D) converter which can digitize the input data at rates up to 50 MHz (20 nanosecond sample rate) into an 8K memory. The input amplifier of the A/D converter has a bandwidth of 20 MHz. This resulted in a digital data record with 20 MHz bandwidth corresponding to 164 microseconds of the flash. The data from each channel's memory were then transferred to the H101 recorder for storage at a rate of two records per second. These digitized data were not integrated by the instrumentation. The time at which the transient recorder was triggered and the aircraft location (latitude, longitude, heading, and altitude) were simultaneously recorded on a floppy disc by a PDP-11 computer system. A pulse corresponding to the time of the trigger was also recorded on one channel of the instrumentation recorder. The IRIG-B time code was also recorded on one channel of the instrumentation recorder. Thus, all the data recorded on the instrumentation recorder and floppy disc could be time correlated with the Stormscope and weather radar data recorded on video tape. Figure 6 is a diagram of the part of the instrumentation system pertaining to the Stormscope study. A more detailed description of the system is included in Reference 5.



Note 1. IRIG-B synchronized to WWV

Figure 6. Airborne Instrumentation Block Diagram

SECTION IV

RESULTS

The Stormscope was operating during 12 flights averaging 3 hours each between 9 July 1981 and 27 August 1981. It was generally used to direct the aircraft to the nearest lightning activity, and to supplement airborne weather radar indications to keep the aircraft as close to the lightning activity as possible, consistent with safety considerations. For the purposes of this study, verbal observations on the Stormscope's operation were recorded whenever possible on the analog recorder. A total of eight 15 minute video tapes of the Stormscope and weather radar were recorded on several different flights.

1. CORRELATION OF STORMSCOPE DATA WITH LIGHTNING CHARACTERIZATION DATA

Five of the eight video tapes were recorded while the aircraft instrumentation system was collecting data. There were more than 200 lightning events that triggered the transient recorder which could be correlated with Stormscope displayed activity. These results are detailed in Table 1.

TABLE 1

Date of Video Tape	Start/Stop Time	No. of Transient Recorder Events	No. of Stormscope Events
17 Jul 81	17:16:49-17:21:43	19	18
31 Jul 81	17:07:13-17:28:03	28	24
7 Aug 81	16:38:01-17:15:26	85	78
25 Aug 81	14:14:07-14:28:08	52	50
	15:19:20-15:27:36	48	41
		232	211

Approximately 90% of the lightning events recorded by the aircraft instrumentation system were also recorded by Stormscope. The actual percentage may be slightly higher since it is possible for a subsequent dot input on the Stormscope to plot directly over a previous input, making it impossible to detect on the display.

Whenever possible, an observer stationed in the cockpit and/or an aircraft crew member in the cockpit recorded observations of lightning flashes (visuals) on the voice channel. If Stormscope acquired data and/or the instrumentation system showed a trigger, this was also noted on the voice channel. Out of 27 visuals reported on four flights, 24 were recorded by Stormscope and 25 by the instrumentation system. Azimuth indications agreed with crew observations within 10-20° in all but two cases in which there was no correlation.

The pattern of dots produced by the Stormscope when a visual occurred varied from a single dot to 14 dots. The multidot patterns seemed to occur more frequently on the shorter ranges. Usually the dots appeared on the same radial on the 200, 100, and 50 nmi ranges but on the 25 nmi range they often were scattered over many degrees of azimuth. Samples of these dot patterns are shown in Figure 7.

On two tapes, during one flight, the Stormscope was cleared after each event to allow separate recording of each of the dot patterns for later correlation with the low frequency electric field data and the traces from the magnetic field sensors. Several of these correlations have been performed for this report.

To understand how the correlation was done, it is necessary to know how the video system records and displays information. The ensuing discussion applies to both the sensing (or recording) and playback (or display) process.

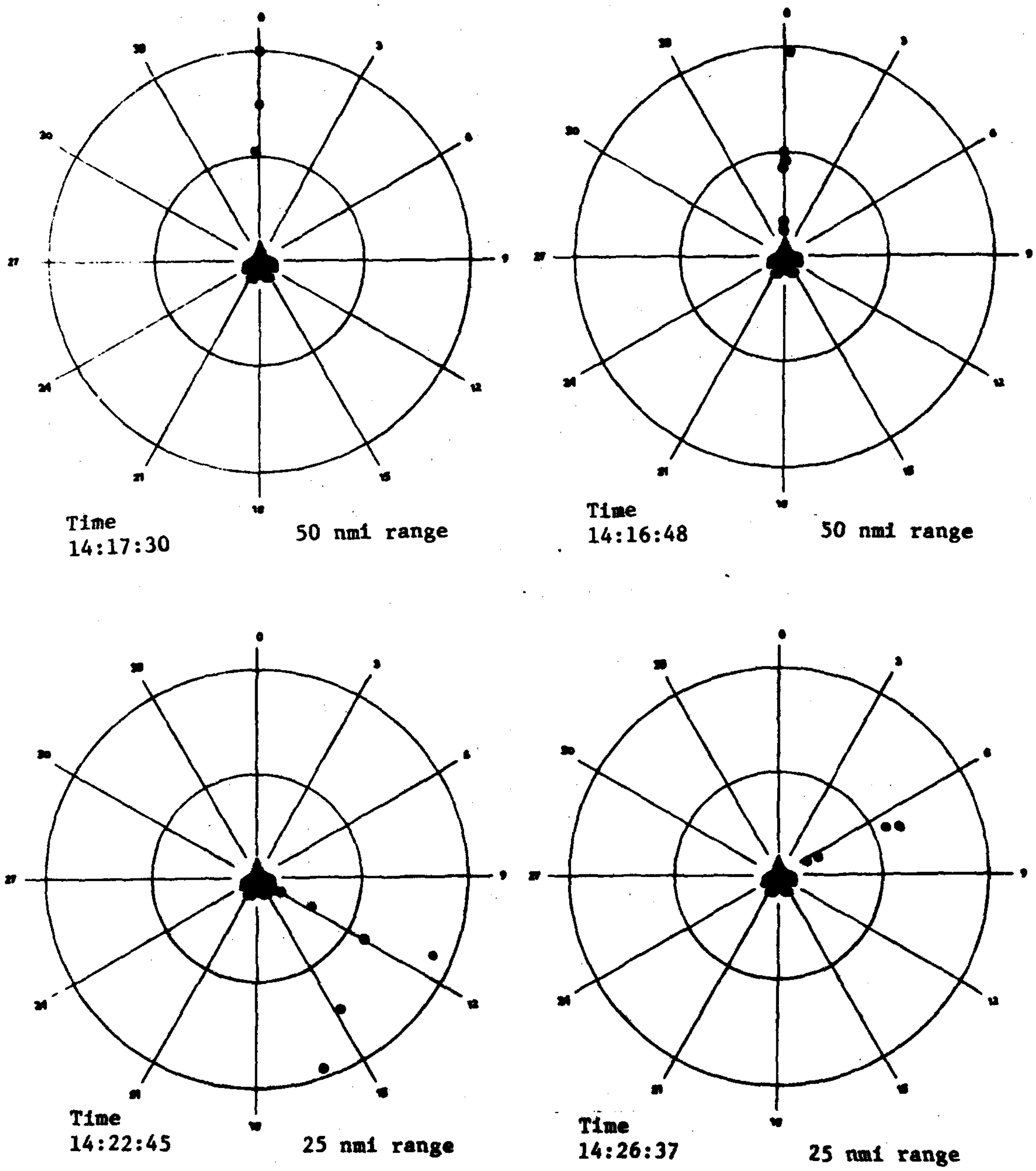


Figure 7. Typical Stormscope Display Patterns During a Storm on 25 August 1981

The image area is scanned twice to obtain or display the video information. The image area is scanned horizontally with 262 lines from top to bottom. After the first scan, the image area is scanned with another 262 lines between the lines of the first scan. Each set of 262 lines is called a "field" and two fields consititute a "frame ". One line is used during the retraces from the bottom of the viewing area to the top. This procedure is called "interlacing ". Each field requires 16 2/3 ms to complete so that a frame requires 33 1/3 ms. During normal playback and display this process is continuous. For analysis, the process is stopped by "freezing" a single frame. This is done by displaying a set of two interlaced fields over and over as long as desired. When viewing the Stormscope display with a video system, if a spot was on the display during the first field, it will be enhanced during the second field. Thus it will appear brighter than a spot that is placed on the Stormscope display after the area was scanned by the first field. By analyzing the video data frame by frame, it is therefore possible to time correlate each Stormscope dot to within 16 2/3 ms. This technique allowed the analyst to determine time intervals between Stormscope dots and was used in subsequent analyses.

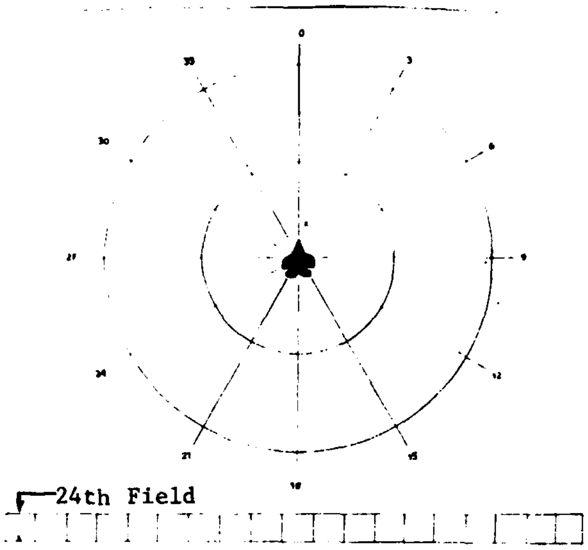
A technique involving line by line analysis would result in definition of time intervals to within two or three lines and would result in an uncertainty of about 2 milliseconds. This is due to the fact that it takes 63.5 microseconds to scan one line.

To perform the data correlation, the following three sets of records were used: (1) the video recording of the Stormscope and time code displays, (2) electric field and time code data recorded on magnetic tape, and (3) magnetic field data from the two sensors also recorded on magnetic tape.

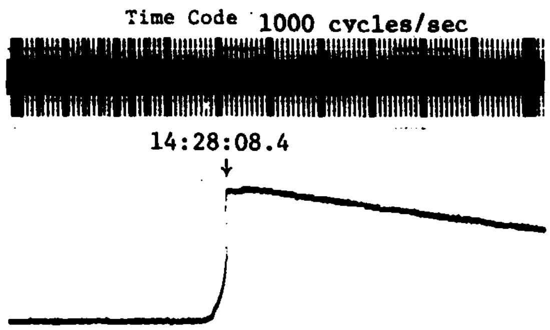
First, the Stormscope data were analyzed frame by frame until the first dot appeared. Since the time code display updates every second, the number of frames after the last time update can be determined by counting back to the last time update. Then, for the one second period covering the Stormscope event, the electric field data and IRIG B time code were plotted on strip chart. Finally, the magnetic field data were also plotted on a strip chart.

a. Correlation of a One Stroke Flash

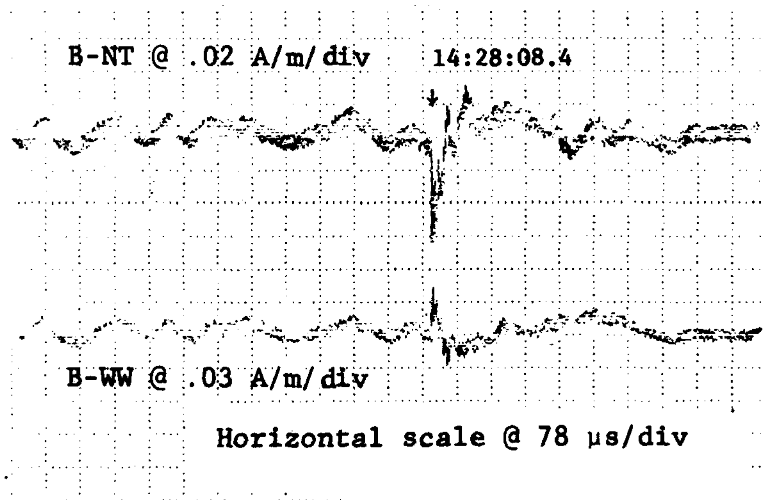
Figure 8 illustrates this process. In (a), the x in the first block below the Stormscope display facsimile depicts the first dot that occurred in the time interval between 14:28:08 and 14:28:09. Each block indicates a field or an interval of about 16.6 ms. The position of the dot on the Stormscope is plotted on the display facsimile as it appeared on the actual display. If another dot had appeared on the display within the subsequent 18 fields, the dot would have been plotted using a different symbol on the appropriate block and the facsimile. The dot shown appeared during the twelveth frame after the 14:28:08 update. The dot brightness indicated that it occurred during the second field of the frame, or at time 14:28:08.4. There were no subsequent dots that appeared within the 1 second interval. In (b), the electric field for the same time interval shows a fast change in the electric field, characteristic of a cloud-to-ground strike, that occurred at time 14:28:08.4. The fact that there were no other Stormscope dots or electric field excursions indicates that these two sets of data correspond to the same event. In (c), the magnetic field data is plotted using an expanded time scale so that amplitude measurements can be obtained. First, a zero reference is defined on each trace by averaging the random (noise) oscillations in the trace and positioning the selected average upon one of the horizontal grids. Then the maximum deflections from these references were measured and scaled to the correct engineering units. Taking the ratio of the resulting values from the wing-to-wing (B_{WW}) and the nose-to-tail (B_{NT}) sensors (0.018 and 0.06, respectively),



a. Stormscope Display at Time Interval 14:28:08 - 14:28:09



b. Electric Field Record at Time Interval 14:28:08 - 14:28:09



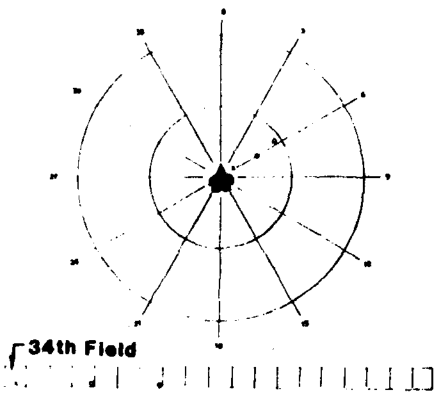
c. Magnetic Field Records from Nose-to-Tail (B-NT) and Wing-to-Wing (B-WW) Sensors

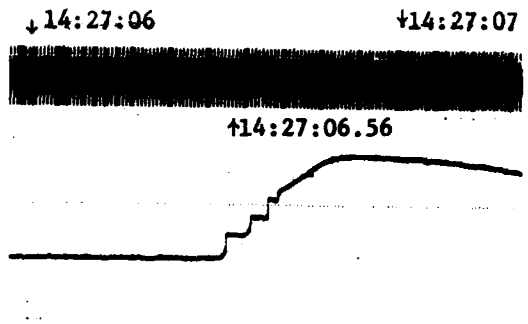
Figure 8. Correlation of One Stroke Flash at 14:28:08.4 on 25 August 1981

and calculating the arctangent of the ratio, an azimuth of about 17° is obtained. This azimuth is in agreement with the approximate 15° azimuth on the Stormscope display.

b. Correlation of a Three Stroke Flash

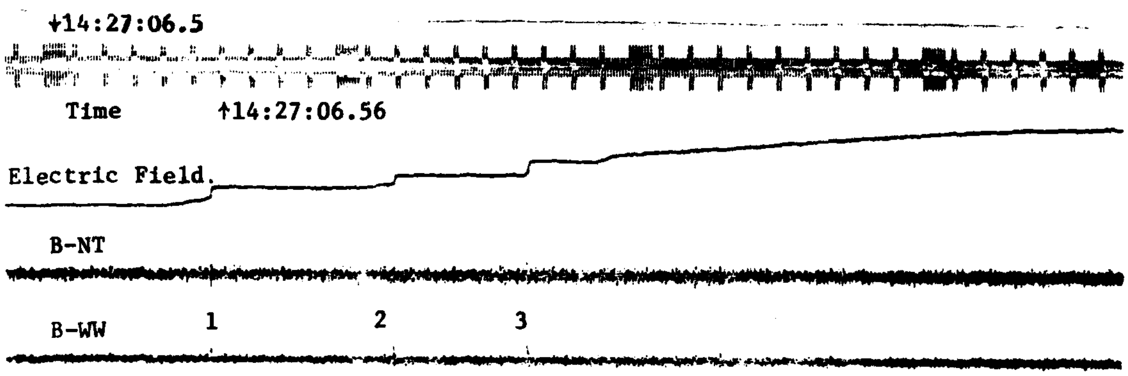
Figure 9 illustrates correlation of a three-stroke flash that occurred during the first field of the 17th frame after the 14:27:06 time update. The Stormscope display had three dots as shown in (a). Frame-by-frame analysis revealed the sequence in which the dots appeared and the approximate time interval between them. The first dot (x) was bright, indicating its presence during both field scans. The second (o) and third (•) dots were dim, indicating their appearance after the first field of their respective frames. Thus, the second dot appeared at least three fields (≈50 ms), but less than four fields (≈67 ms), after the first dot. Similarly, the third dot appeared at least two fields (≈33.3 ms), but less than three fields (≈50 ms), after the second dot. Referring to (b) in the figure, during the time interval between 14:27:06 and 14:27:07, the electric field trace shows an interval of about 60 ms between the first and second, and about 45 ms between the second and third events. This electric field trace indicates a three stroke cloud-to-ground flash at 17:27:06, also followed by a slower field variation which might be related to intracloud processes or continuing current. In (c) of the figure, both magnetic field traces are shown along with the electric field trace and the time code using an expanded time scale. From the B_{WW} trace, the interval between the events is shown to be about 62.5 ms and 45 ms. In Figure 10, the magnetic field traces for each of the three strokes are shown using an expanded time scale. By the process already explained, the azimuths for the three events were calculated to be 71°, 64°, and 67°, respectively, as compared to values of 60°, 55°, and 60° from the Stormscope display data.





a. Stormscope Display at Time Interval 14:27:06 - 14:27:07

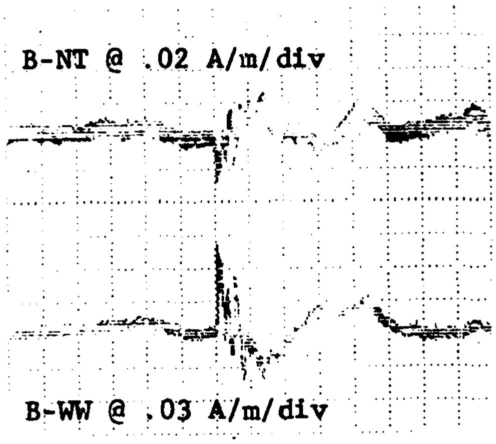
b. Electric Field Record at Time Interval 14:27:06 - 14:27:07



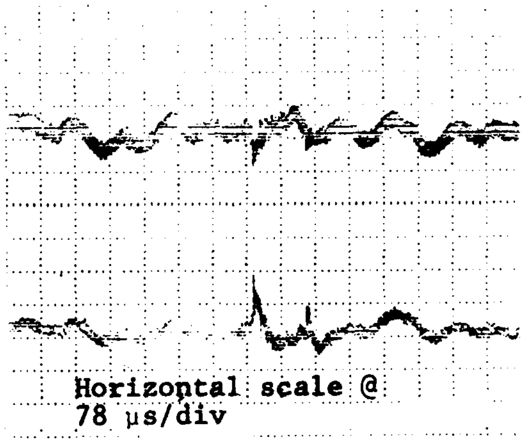
Horizontal scale @
5 ms/div

c. Electric and Magnetic Field Records

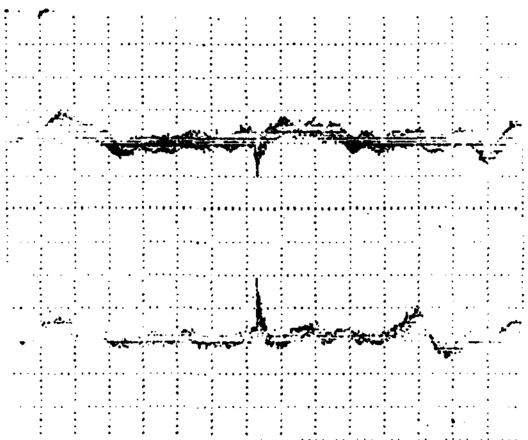
Figure 9. Correlation of a Three Stroke Flash at 14:27:06.56 On 25 August 1981



a. First Stroke



b. Second Stroke



c. Third Stroke

Figure 10. Time Expansion of Magnetic Field Records Shown in Figure 9c.

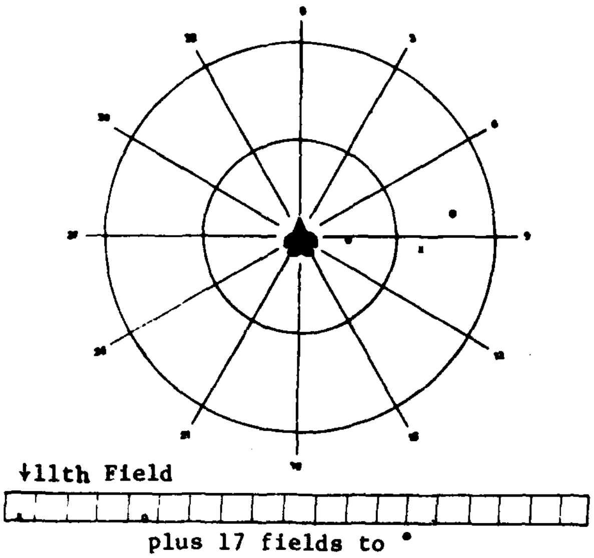
c. Correlation of a Second Three Stroke Flash

A third example occurred after the 14:27:49 time update on 25 August 1981, when the display was on the 25 nmi range and is shown in Figure 11. In this case three dots appeared on the Stormscope display (a). The first two occurred within a short interval, while the third occurred a relatively long time later. The first dot appeared 11 fields after the time update (≈14:27:49.18). The second dot appeared four fields, or about 66.7 ms, later. The final dot appeared about 284 ms (17 fields) later.

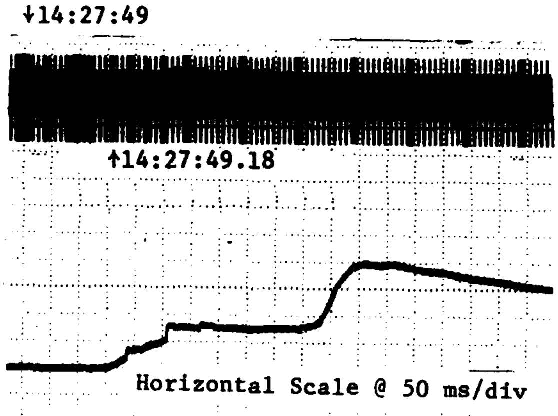
The electric field record (b) in the time interval between 14:27:49 and 14:27:50, indicated a two stroke cloud-to-ground flash. The initial stroke occurred at 14:27:49.18 while the second occurred about 70 ms later. A third stroke was not readily evident in the electric field record. However, when the magnetic field data were plotted with an expanded time scale, a distinct event was present at about 300 ms after the second stroke. In terms of azimuth, the Stormscope events were at 95°, 98°, and 77°, while those derived from magnetic field data were at 100°, 90°, and 77°. Figure 12 shows the magnetic field traces used for the azimuth determinations of each of the three strokes.

d. Correlation of a Multi-Stroke Flash

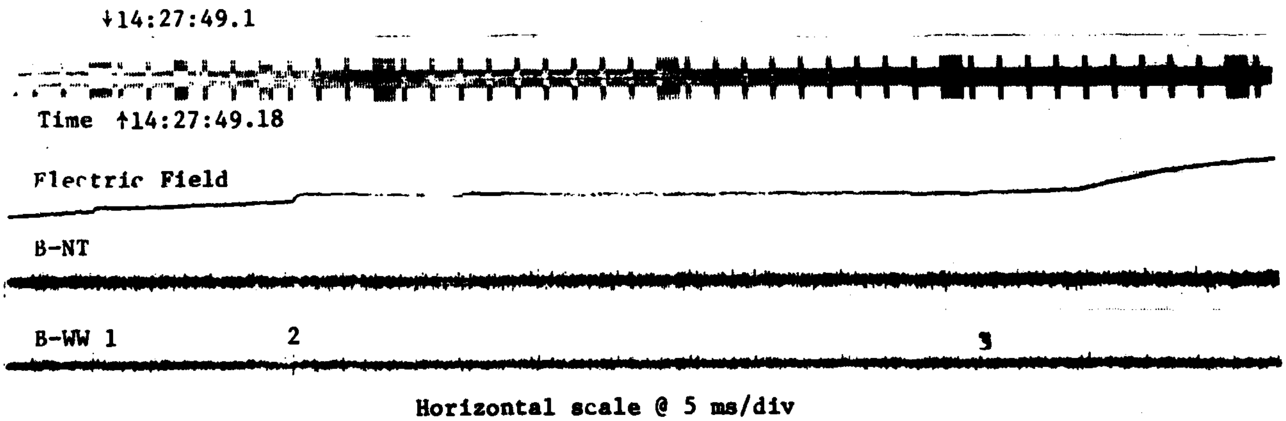
A multi-stroke flash was recorded during the time interval between 14:18:56 and 14:18:57 as shown in Figure 13. The Stormscope display was set to the 25 nmi range. The first dot in (a) appeared 32 fields after the time update at an estimated time of 14:18:56.53. Additional dots appeared 2, 3, 6, and 14 fields later. In the later case, two dots appeared during the same field resulting in a total of six dots. The electric field change as seen in (b) and (c) is of small amplitude for the second dot and the corresponding magnetic field traces in Figure 14(b) indicated a relatively slow rise time when compared to the other events. Fast rise times as shown in 14(a), (c), (d), and (e) are characteristic of cloud-to-ground strokes while slow



a. Stormscope Display at Time Interval 14:27:49 - 14:27:50

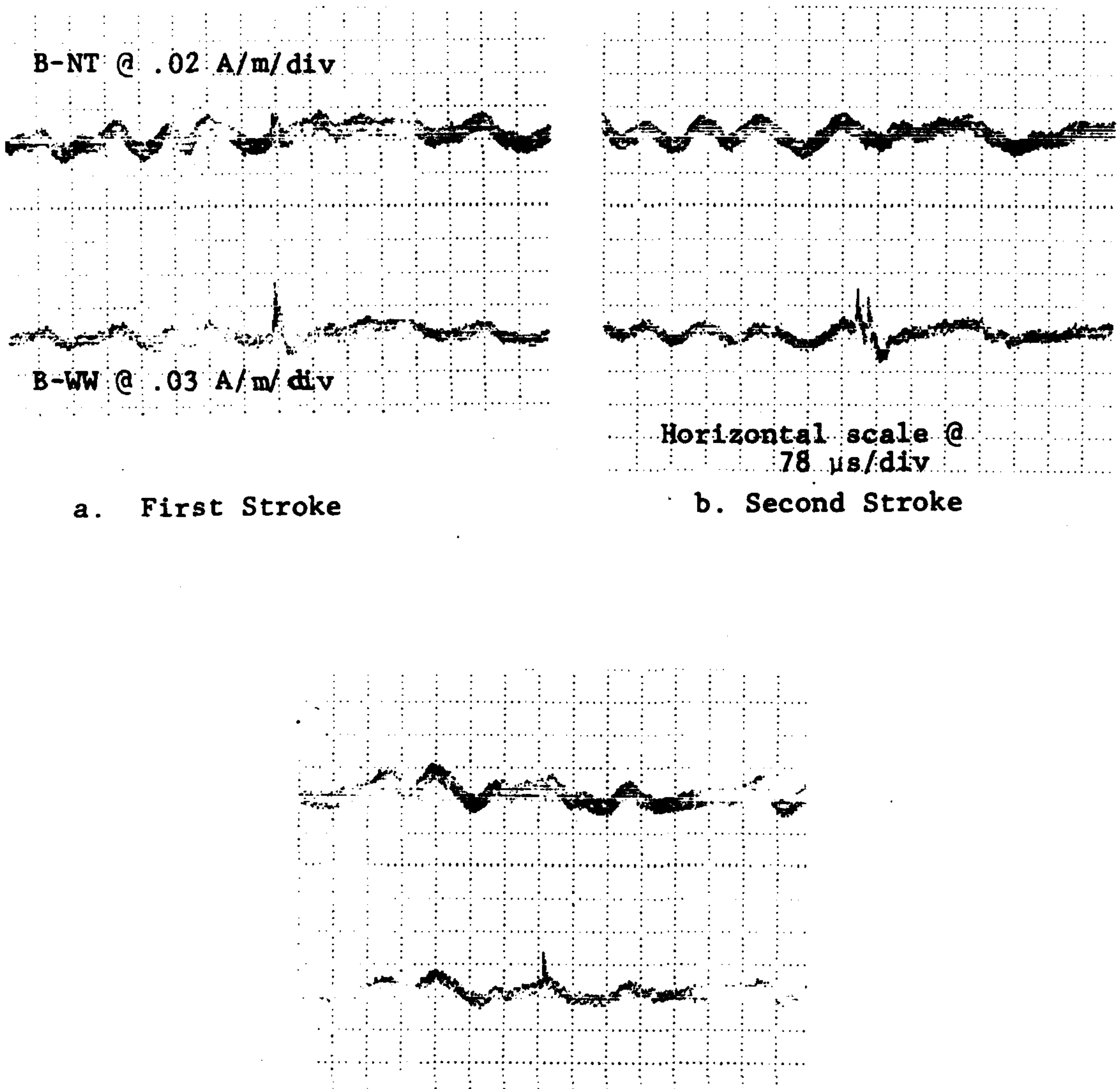


b. Electric Field Record at Time Interval 14:27:49 - 14:27:50



c. Electric and Magnetic Field

Figure 11. Correlation of a Three Stroke Flash at 14:27:49.18 On 25 August 1981

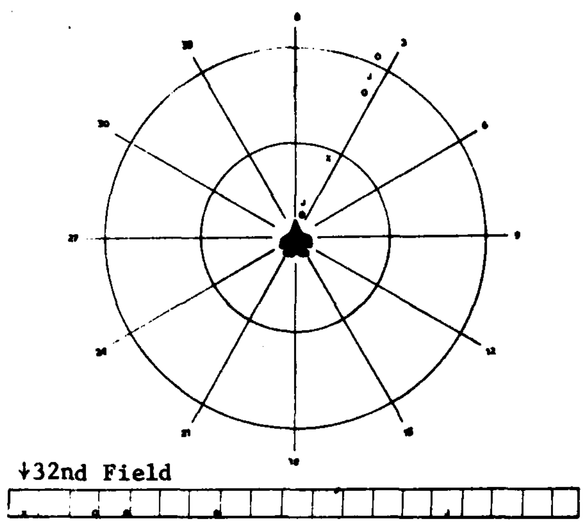


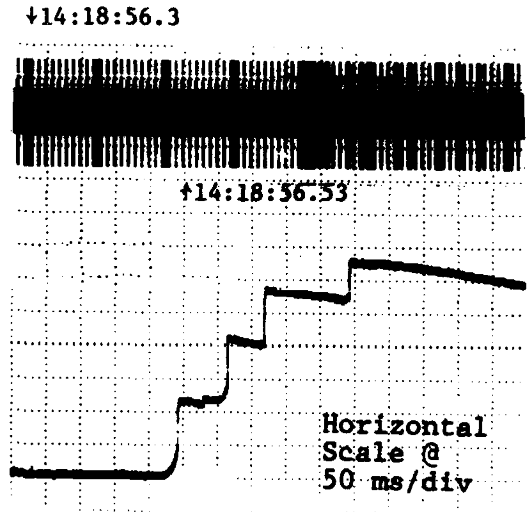
a. First Stroke

b. Second Stroke

c. Third Stroke

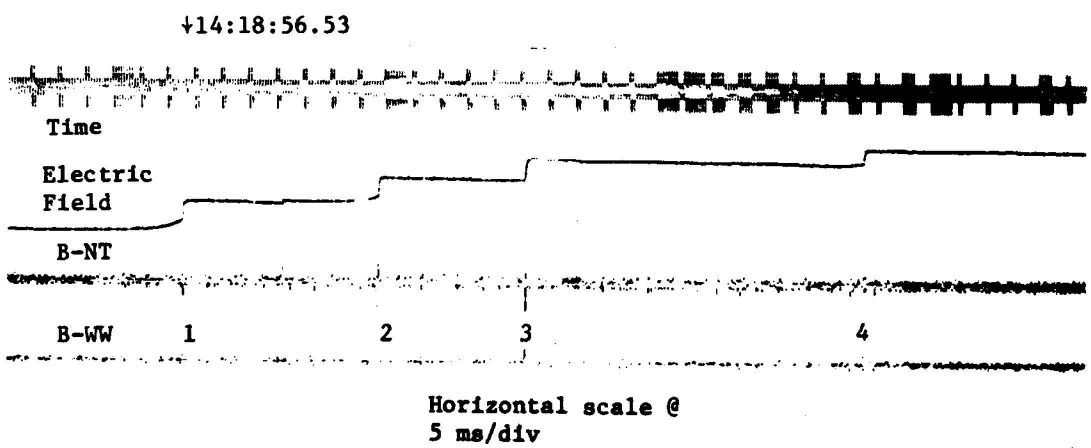
Figure 12. Time Expansion of Magnetic Field Records Shown in Figure 11c





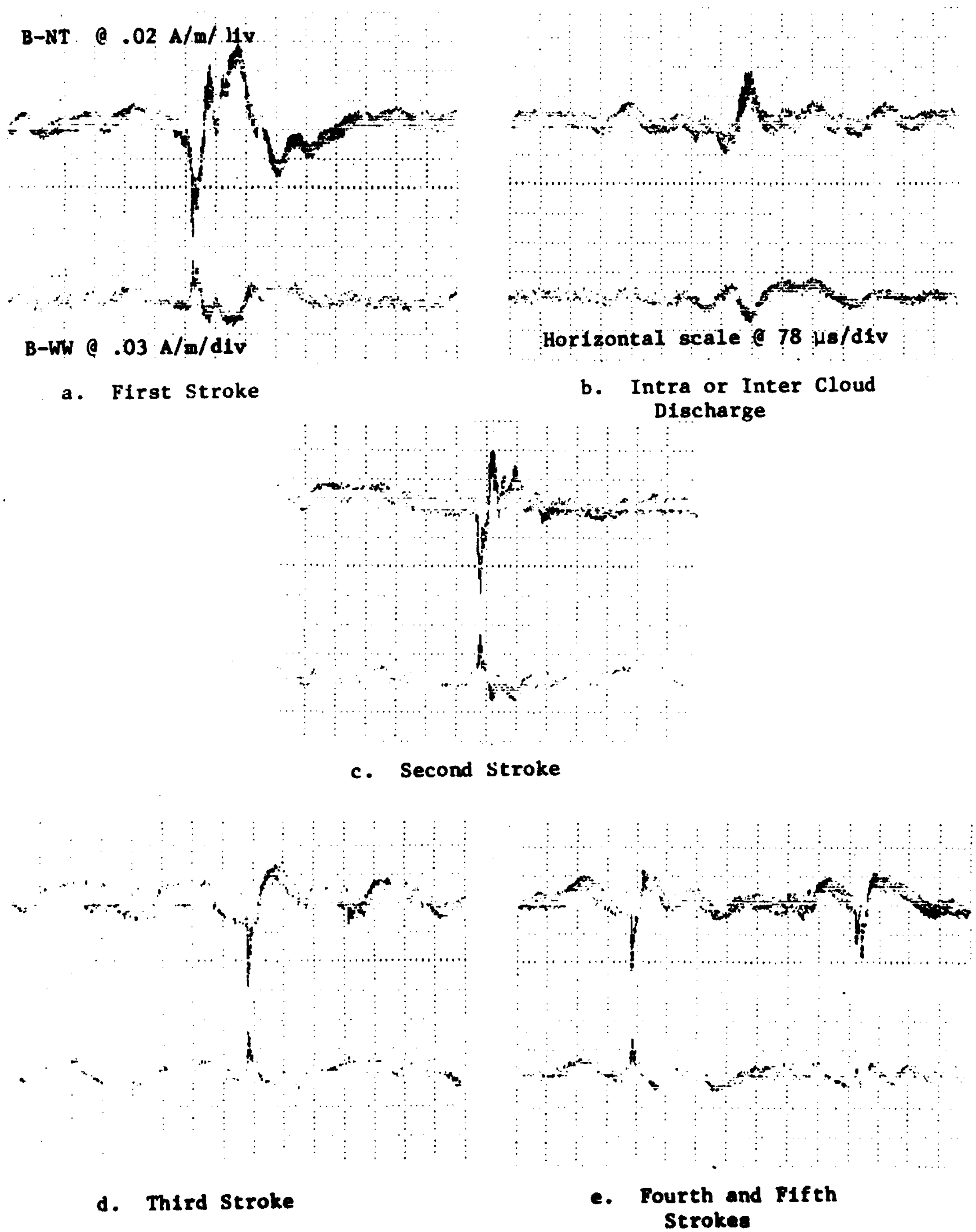
a. Stormscope Display at Time Interval 14:18:56 - 14:18:57

b. Electric Field Record at Time Interval 14:18:56 - 14:18:57



c. Electric and Magnetic Field

Figure 13. Correlation of a Multi-Stroke Flash at 14:18:56



a. First Stroke

b. Intra or Inter Cloud Discharge

c. Second Stroke

d. Third Stroke

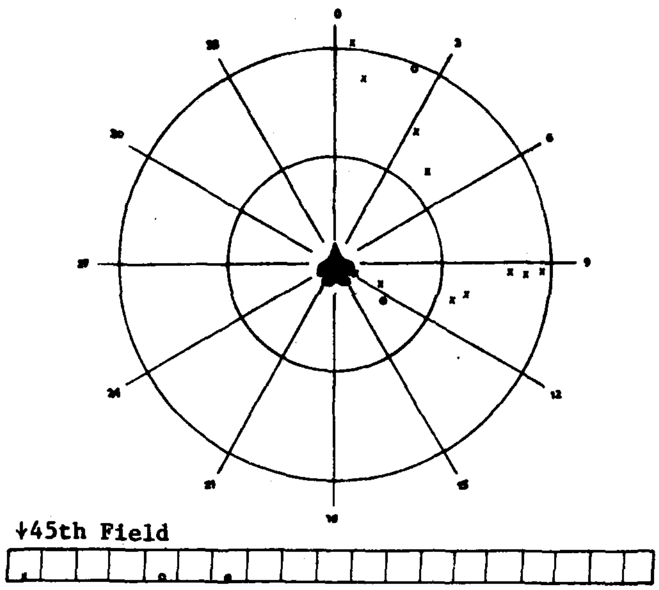
e. Fourth and Fifth Strokes

Figure 14. Time Expansions of Magnetic Field Records Shown in Figure 13c

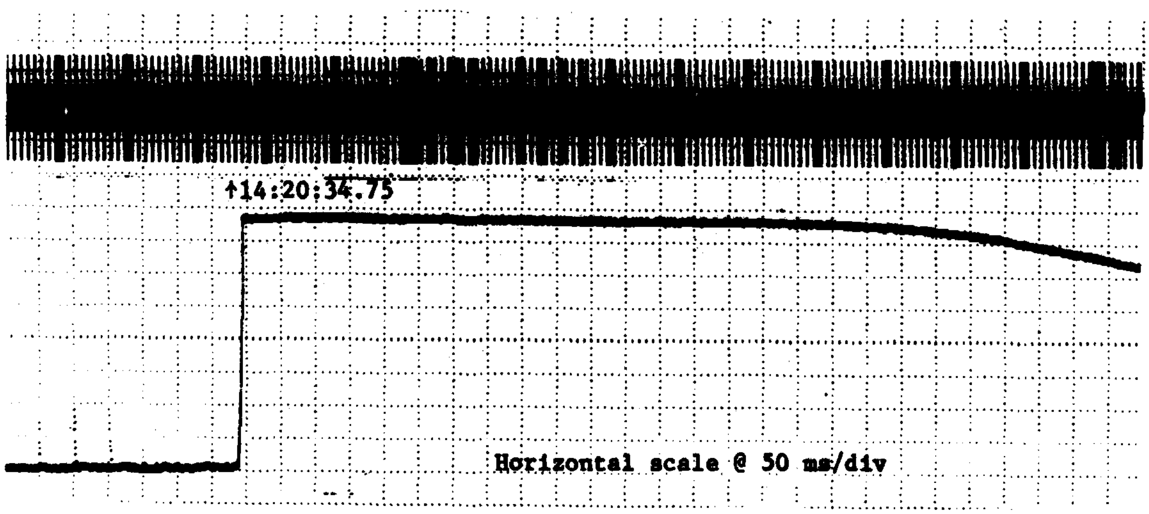
rise times are characteristic of other processes such as cloud-to-cloud or intra-cloud discharges. The last two dots, which appeared during the same field, are not separately discernible in the electric field traces shown in Figure 13(b) and (c). However, in the expanded time scale of Figure 14(e), it can be seen that there were two pulses which occurred within a 0.6 ms interval. Comparison of the time intervals between the dots in 13(a) and the intervals between electric field changes in 13(b) shows the correspondence between the two sets of data. The Stormscope azimuth for all the dots is about 25° while the calculated azimuths (Figure 14) using magnetic field data were in the range of 32° - 35°.

e. Correlation of a Nearby Cloud-to-Ground Flash

During the time interval of 14:20:34 - 14:20:35, a very interesting flash was recorded. The weather radar indicated a storm cell at about 5 kilometers off the right wing. The Stormscope was set on the 25 nmi range. Forty five fields (≈14:20:34.75) after the time update, eleven dots appeared within the same field (Figure 15(a)). These were followed by single dots four and six fields later. The large amplitude of the electric field sensor (Figure 15(b)) exceeded the dynamic range of the data channel so that direct comparison of Stormscope data with electric field data was not possible except for the start of the flash. The Stormscope pattern included data within a 90° quadrant forward and to the right of the aircraft with eight of the 13 dots off of the right wing. Figure 16 shows the electric and magnetic field traces on an expanded time scale. The electric field shows an initial rate of rise with an abrupt transition to a faster (steeper) rate of rise. The initial rate of rise is generally attributed to the rapidly approaching leader while the faster rise is attributed to the cloud-to-ground stroke. Subsequent strokes along the same



a. Stormscope Display at Time Interval
14:20:34 - 14:20:35



b. Electric Field Record

Figure 15. Correlation of a Nearby Strike at 14:20:34.75 on 25 August 1981

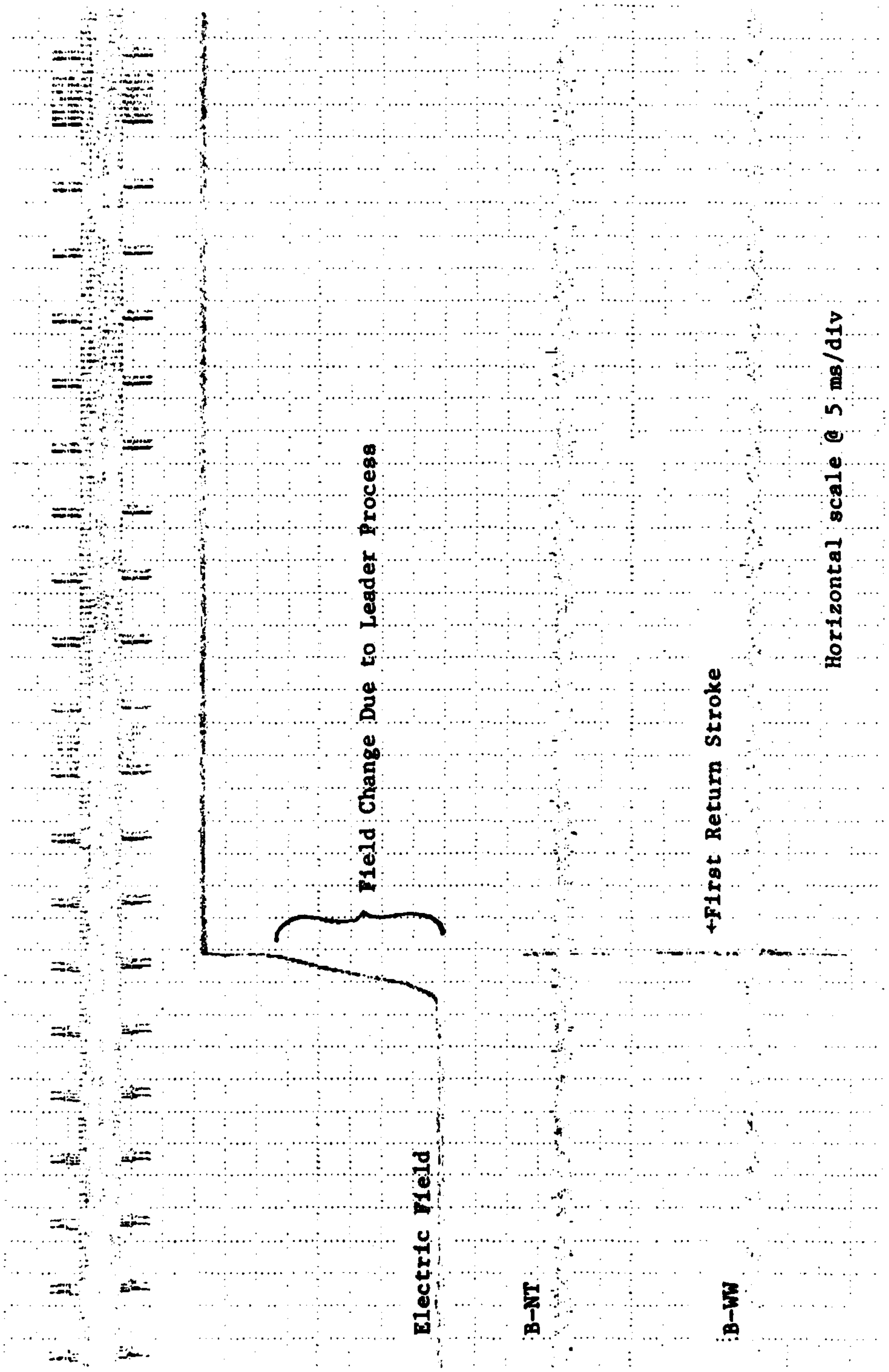


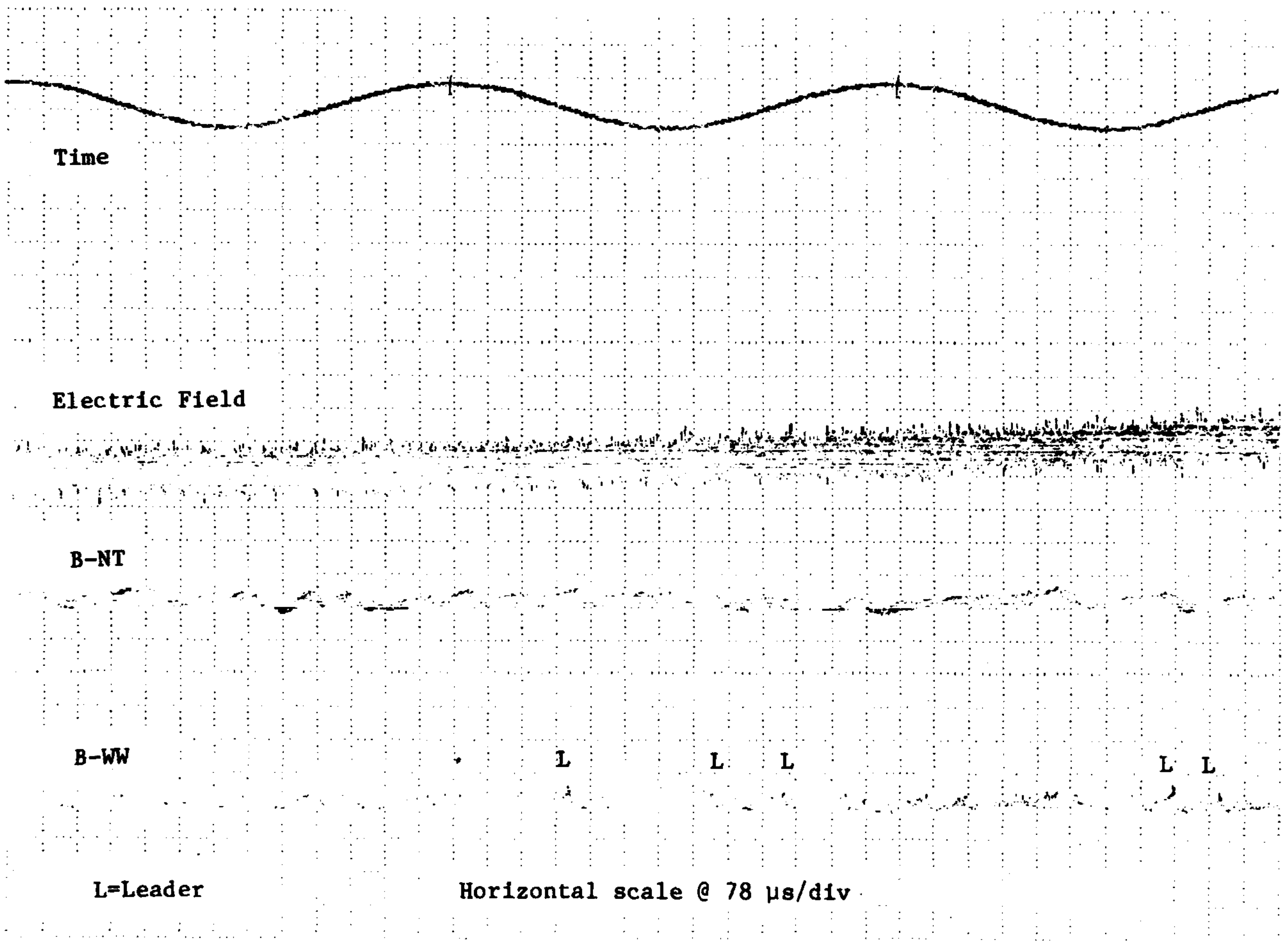
Figure 16. Electric and Magnetic Field Records for Nearby Strike at 14:20:34.75 on 25 August 1981

lightning channel typically do not contain the initial (leader related) slower rate of rise.

Because of the apparent proximity to the aircraft and the resulting signal amplitudes, the electric and magnetic field data appear to contain activity that occurs immediately before the return stroke and which is attributed to the descending step leader. This activity consists of a series of short duration fast pulses (spikes) that occur at much shorter intervals than the strokes of a lightning flash. These pulses can be seen in the expanded time scales of Figures 17 and 18. It is surmised that most of the dots appearing during the same field on the Stormscope are related to this activity and that only the dot displayed closest to the aircraft corresponds to the first return stroke. This is because part of the criteria used by Stormscope to determine range is signal amplitude. As was the case with the electric field, the amplitude of the B-WW sensor exceeded the data channel's dynamic range. Therefore, an azimuth could not be computed for the first stroke. The polarity of the deflections indicate, however, the source was in the correct quadrant. In Figure 16 there appears to be a small pulse that occurs about 60 ms after the first pulse and another one that occurs about 33 ms later. These pulses appear to correspond to the two dots that appeared individually on the Stormscope display.

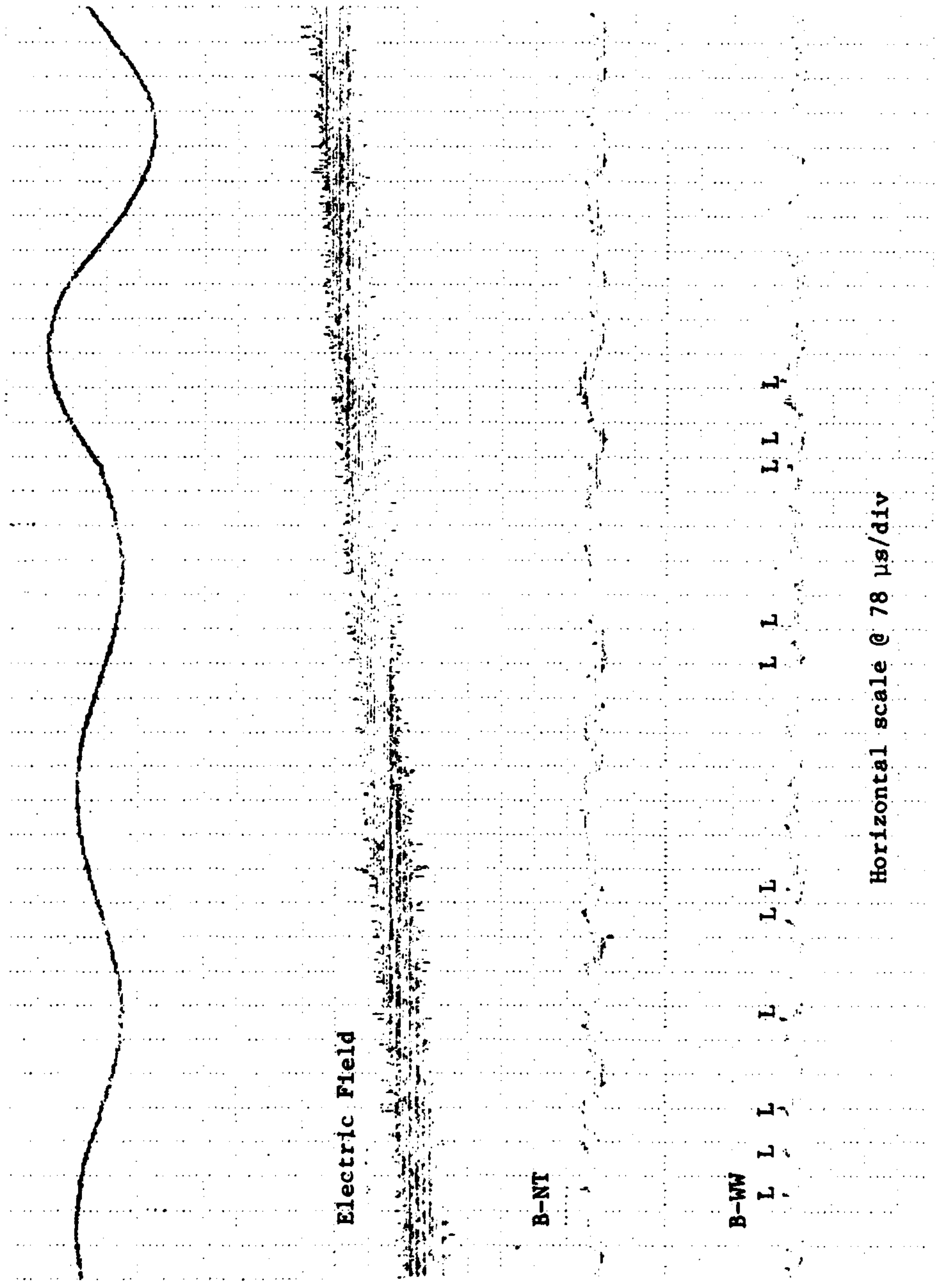
f. Summary of Stormscope and Lightning Characterization Data Correlation

The preceding examples are typical and demonstrate that Stormscope consistently detects cloud-to-ground lightning activity. There are indications that Stormscope can also detect cloud-to-cloud (intracloud) activity. However, only a small sample of this type of data was available for comparison purposes. For lightning activity occurring at short distances (>5 km) from the Stormscope, it appears that Stormscope is sensitive to intra-



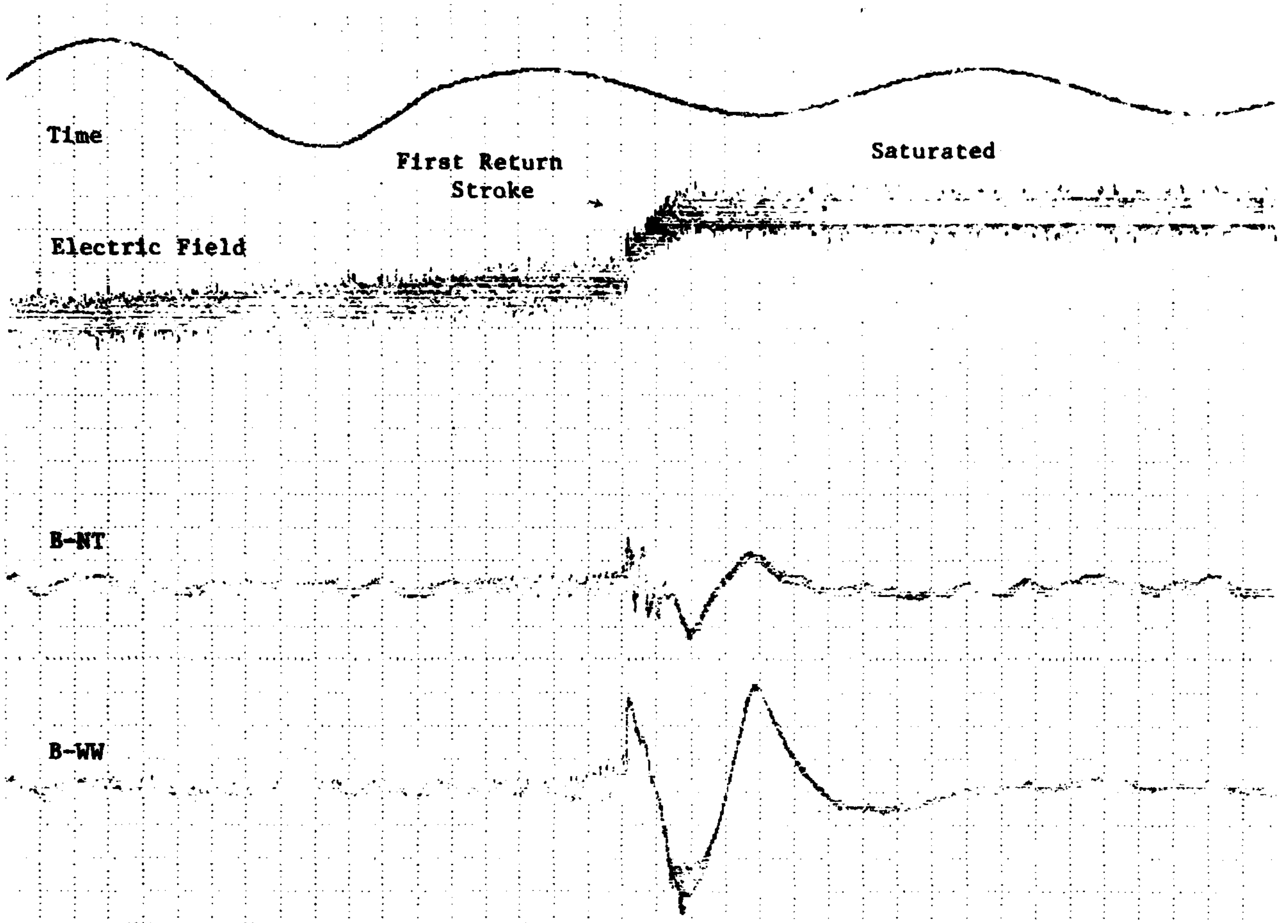
a. Part I

Figure 17. Expanded Electric and Magnetic Field Traces During the Leader Process and First Return Stroke of the Flash at 14:20:34.75 on 25 August 1981



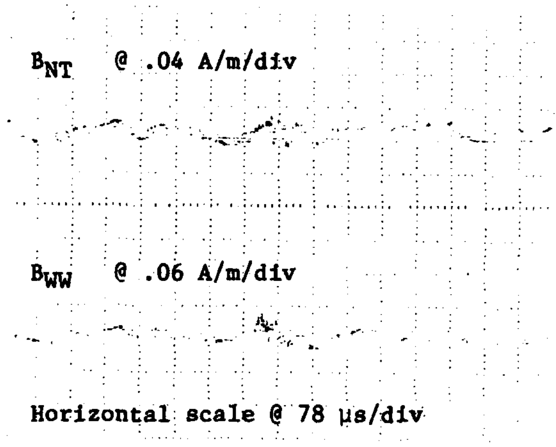
b. Part II

Figure 17. Expanded Electric and Magnetic Field Traces During the Leader Process and First Return Stroke of the Flash at 14:20:34.75 on 25 August 1981

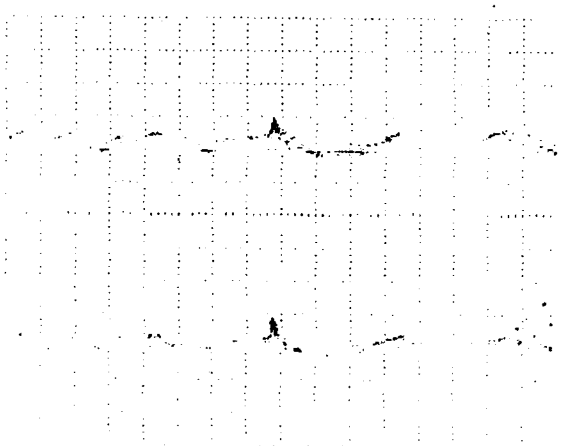


c. Part III

Figure 17. Expanded Electric and Magnetic Field Traces During the Leader Process and First Return Stroke of the Flash at 14:20:34.75 on 25 August 1981



a. First Pulse



b. Second Pulse

Figure 18. Expanded Magnetic Field Traces for the Small Pulses Associated with the Nearby Strike at 14:20:34.75 on 25 August 1981

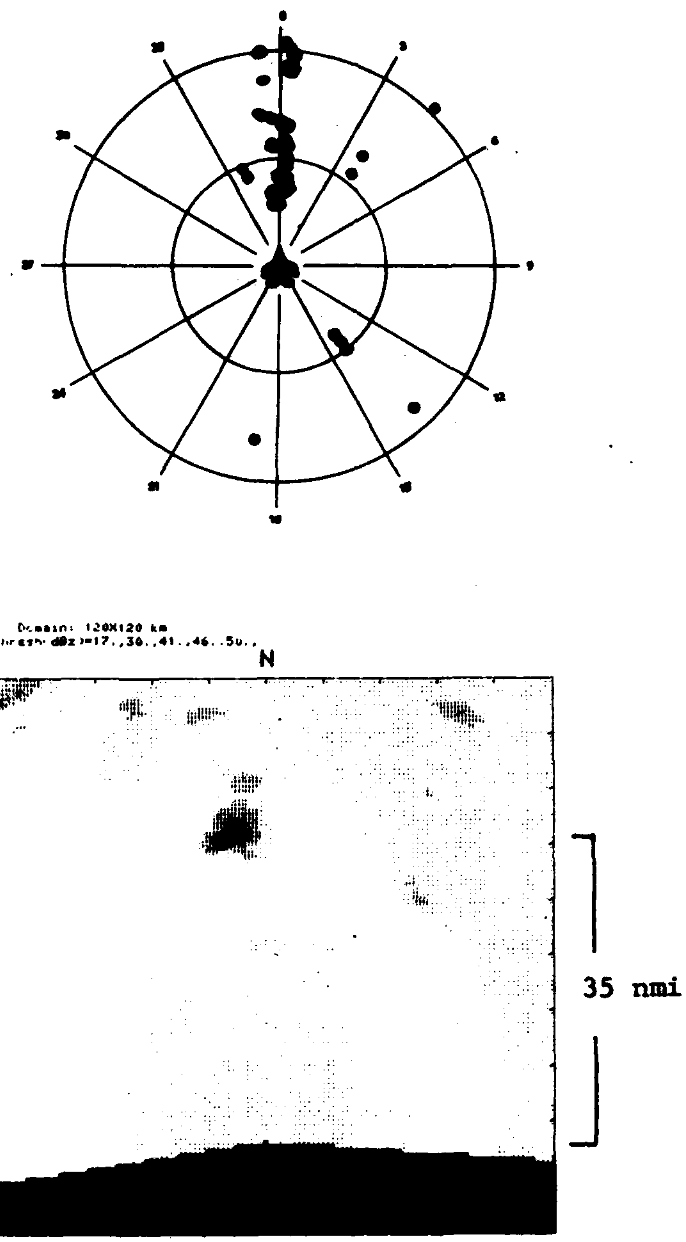
cloud and step leader processes, but only a limited amount of comparison data were available.

2. TRACKING TO STORMS

The Stormscope was used on all the flights to detect distant thunderstorms on the 100-200 mile ranges and track to them. On five of the flights, information was available before takeoff from ground weather radar observations at Homestead AFB, Florida on the probable azimuth and range of thunderstorms from the aircraft's Miami base. In all five cases, the Stormscope began showing clusters of dots in the correct location during taxi and the aircraft was able to fly to the thunderstorm area.

The C-130 aircraft was equipped with a weather radar which could provide digital readouts for comparison with Stormscope indications. Up to five levels of precipitation intensity, corresponding to levels of 17, 30, 41, 46, and 50 dBz, are indicated on the printouts by increasing the density of the dots in a given area. A level of about 40 dBz generally indicates an area of heavy precipitation with a probability of moderate turbulence.

A typical sequence of Stormscope indications and the corresponding airborne weather radar data are shown in Figures 19, 20, and 21 as the aircraft flies toward a storm. In Figure 19, the Stormscope is still on the 100 nmi range. Clusters of dots appear on the 360° radial from 28-70 miles out, with scattered dots in other locations. Radar is showing an area with dBz levels up to 51.25 (a third level contour usually indicates about 40 dBz) 37 miles ahead of the aircraft, which is located at the small X near the bottom of the figure. Figure 20 shows the Stormscope pattern shortly after changing to the 50 nmi range. The radar picture is almost the same as before. The Stormscope has only had time to pick up a few events but is still



Aircraft at x, heading 355

Figure 19. Stormscope and Weather Radar Indications as Aircraft Approaches Storm at 15:44:31 EDT on 7 August 1981, with Stormscope on 100 nmi Range

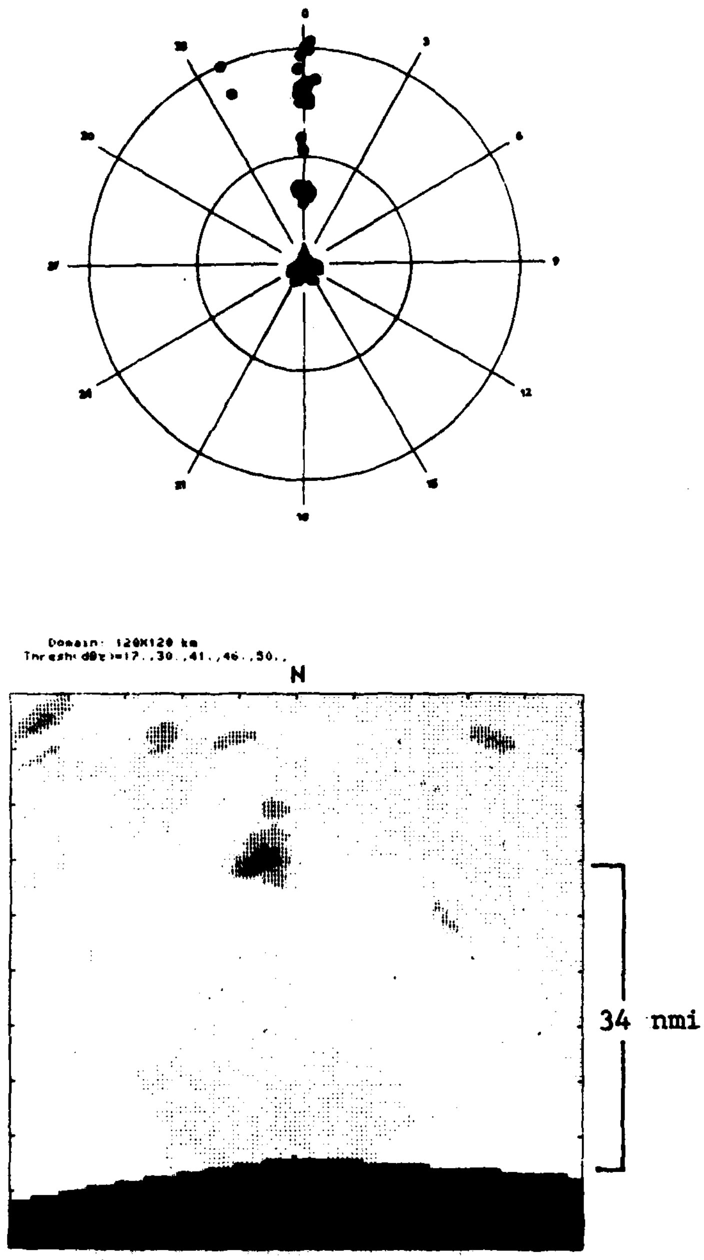


Figure 20. Stormscope and Weather Radar Indications as Aircraft Approaches Storm at 15:44:31 EDT on 7 August 1981, with Stormscope on 50 nmi Range

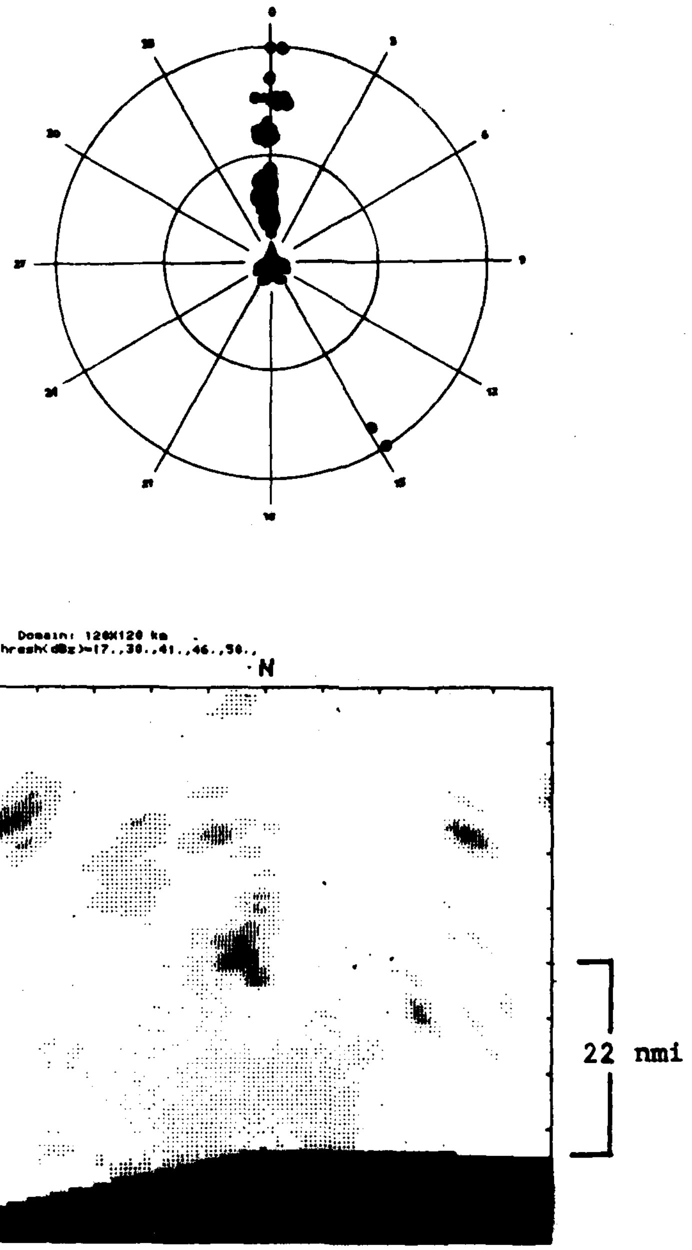


Figure 21. Stormscope and Weather Radar Indications as Aircraft Approaches Storm at 15:50:29 EDT on 7 August 1981, with Stormscope on 50 nmi Range

showing activity from 28-50 miles out on the 360° radial. Figure 21 shows the patterns five minutes later. Radar indicates the storm is 22 nmi away, extending for about 8 miles. Stormscope shows a cluster from 7-23 miles out and light activity from 28-50 miles out. The center of the cluster is at about 15 nmi.

Generally an active storm would show as a cluster of dots on the same radial as a second or third level contour on the radar screen. The range covered by the dots on the Stormscope, however, would often be much larger than the area covered by the radar contour.

On one occasion, ground weather radar information relayed to the aircraft during take off indicated that an active thunderstorm was located southwest of Lake Okeechobee. The Stormscope display also indicated activity in the same area. The mission was flown in that direction but the Stormscope activity was decreasing en route and zero when over the area. The ground radar observer verified that ground weather radar also indicated that the storm cell had dissipated.

In a few instances, fairly active but widespread patterns of dots appeared on the 100-200 mile ranges but no active storms were found as the aircraft moved in closer. This type of activity occurred on days when clouds were able to build only to a lower height than is usually required for strong lightning activity, due to the presence of a high pressure ridge over the area. It may be that electrical activity due to this convection is high enough to appear on the more sensitive, longer ranges but not on the less sensitive 25-50 mile ranges. It is also possible that the activity was due to storms which dissipated before the aircraft arrived, although the dots did not cluster as would be expected in this case.

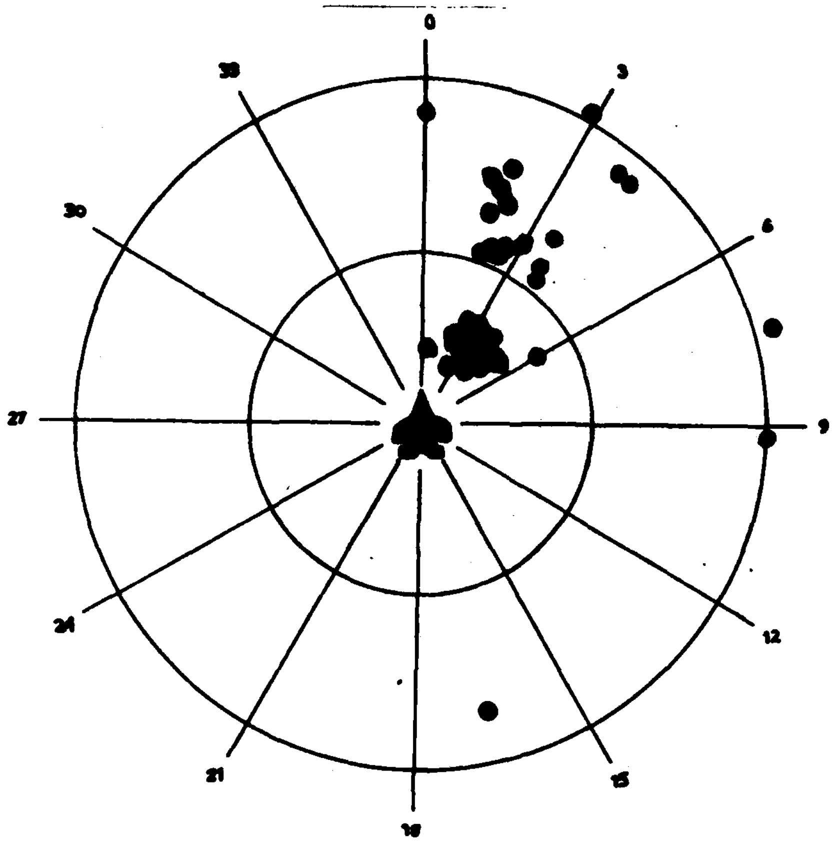
3. COMPARISON OF STORMSCOPE AND WEATHER RADAR INDICATIONS

Stormscope and weather radar indications were recorded simultaneously during several of the flights. On four of these flights, the digitized radar data were also recorded by NOAA so that a complete presentation showing all contour levels could be obtained later. Nine of these comparisons from two flights are presented here.

Figures 22 through 26 are from the flight on 7 August 1981. The radar and Stormscope pictures have been reduced so that both are now on the same approximate scale. In the radar picture, the aircraft is located at the tail of the arrow and is heading in the direction of the arrow. The small airplane in the center of the Stormscope presentation must be mentally turned to this same orientation to compare the pictures. In Figures 22, 23, 25, and 26, the Stormscope is on the 50 nmi range. In Figure 24, it is on the 25 nmi range. The contour levels on the radar in this set of pictures ranged from 20 dBz for the lightest areas to 45 dBz for the darkest areas.

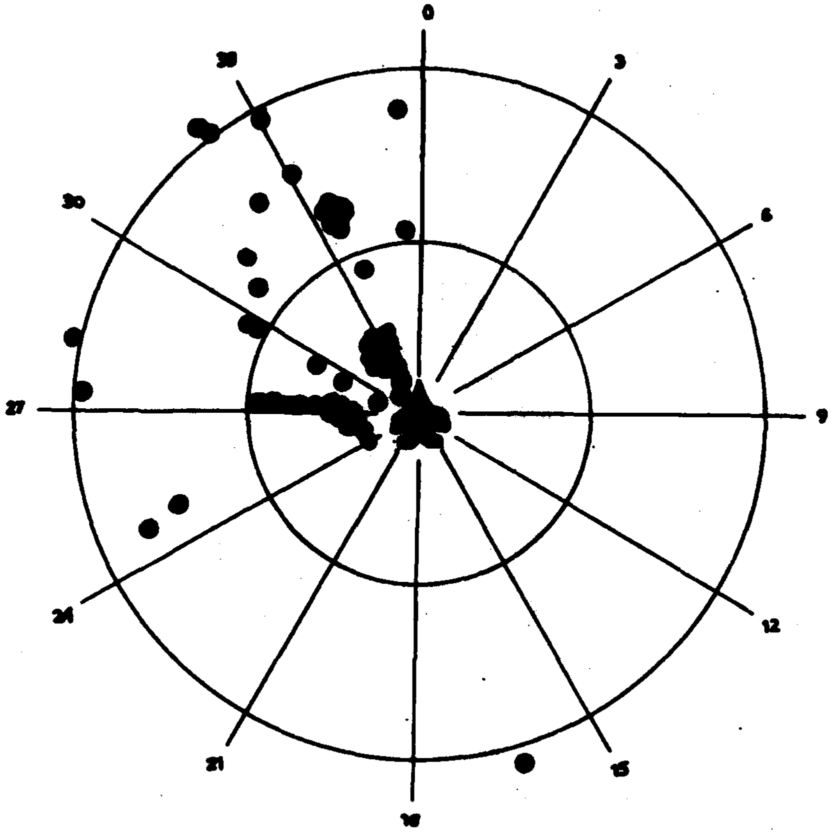
Figures 27, 28, 29, and 30 were obtained during the flight on 25 August 1981. In Figures 27 and 30, the Stormscope is on the 50 nmi range. In Figures 28 and 29, it is on the 25 nmi range. Figure 28 is of particular interest in that the Stormscope seems to be showing a non-existent cell at approximately 12 miles out, whereas the cell shown by the radar is at about 25 nmi. In Figure 27, however, a small cell has appeared directly in front of the original storm and it is possible that the earlier Stormscope indications came from this area.

In general, the agreement between Stormscope and the radar data is satisfactory. The Stormscope dots are scattered over a wider range than the radar contours but the azimuths of the activity areas agree almost exactly.



Radar Presentation on same scale as Stormscope Presentation

Figure 22. Stormscope and Weather Radar Indications as Aircraft Approaches Storm at 16:48:41 EDT on 7 August 1981, with Stormscope on 50 nmi Range



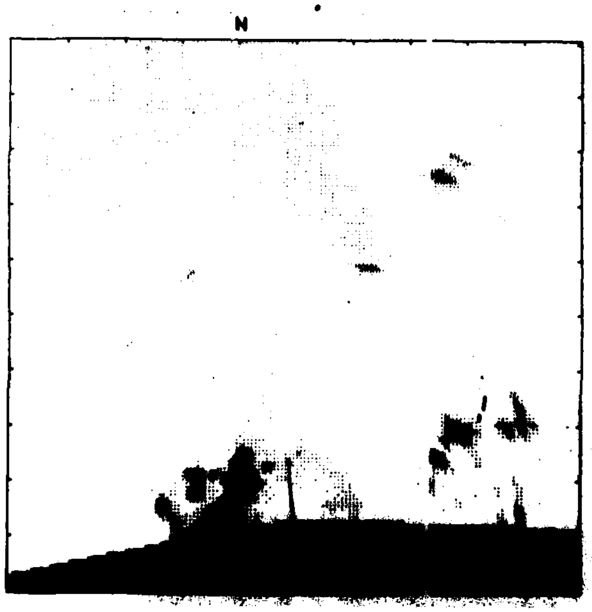


Figure 23. **Stormscope and Weather Radar Indications as Aircraft Approaches Storm at 16:54:49 EDT on 7 August 1981, with Stormscope on 50 nmi Range.**

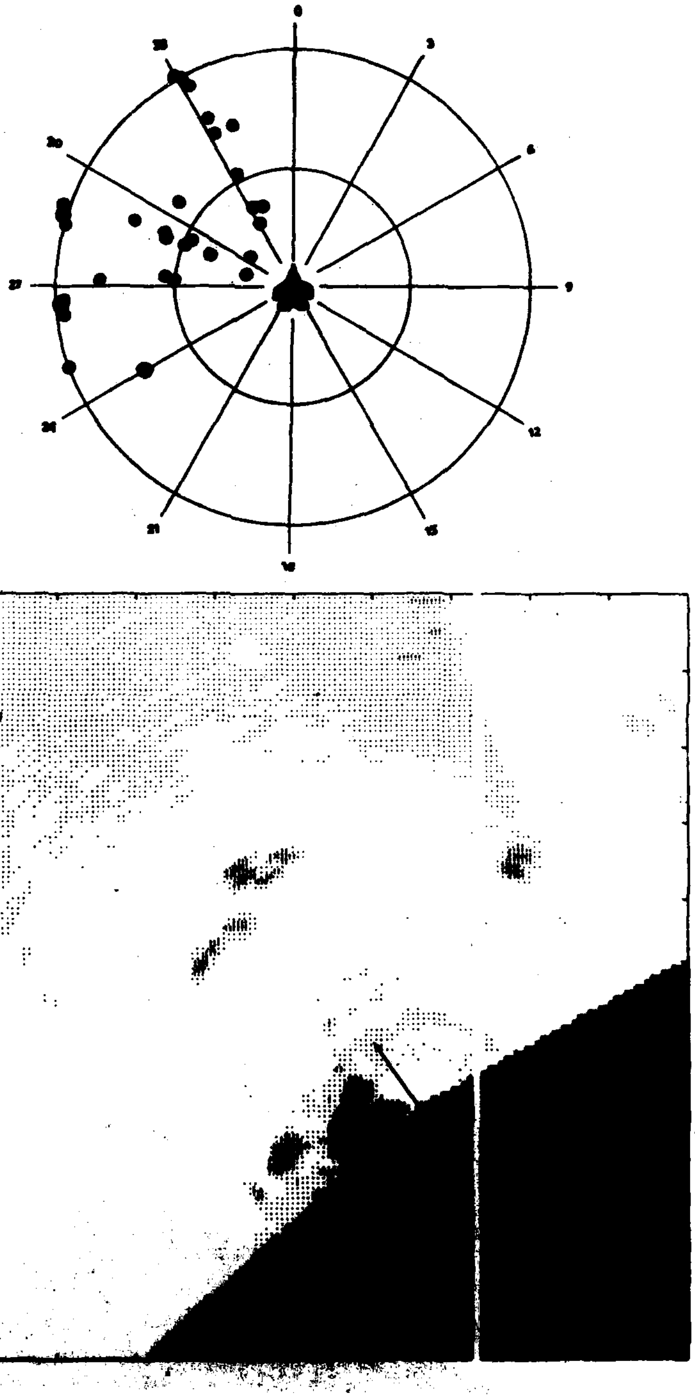


Figure 24. Stormscope and Weather Radar Indications as Aircraft Approaches Storm at 17:08:22 EDT on 7 August 1981, with Stormscope on 25 nmi Range

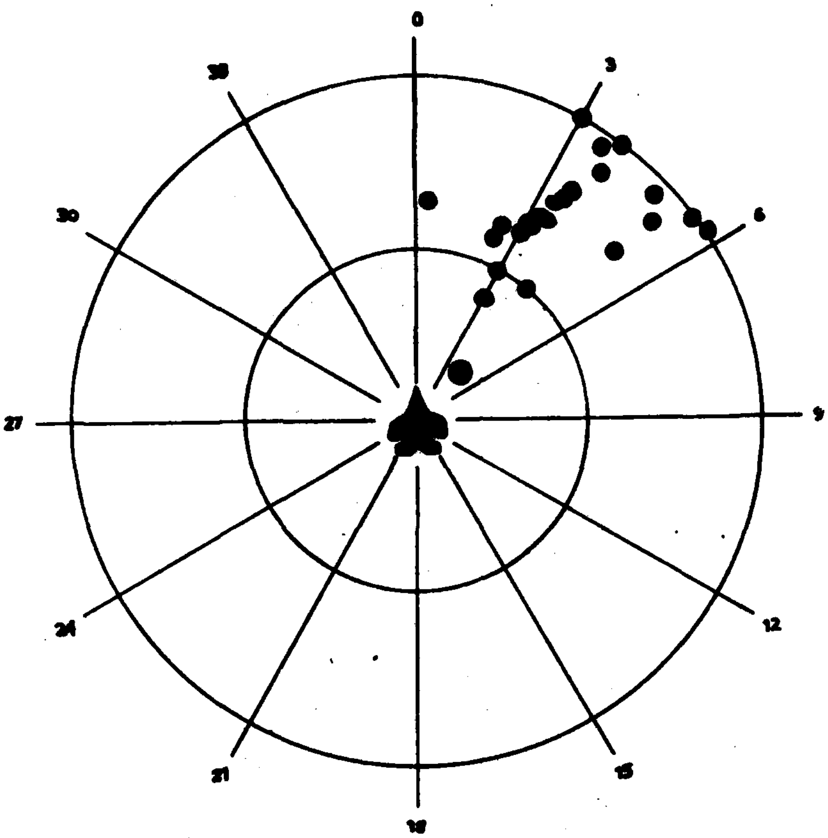
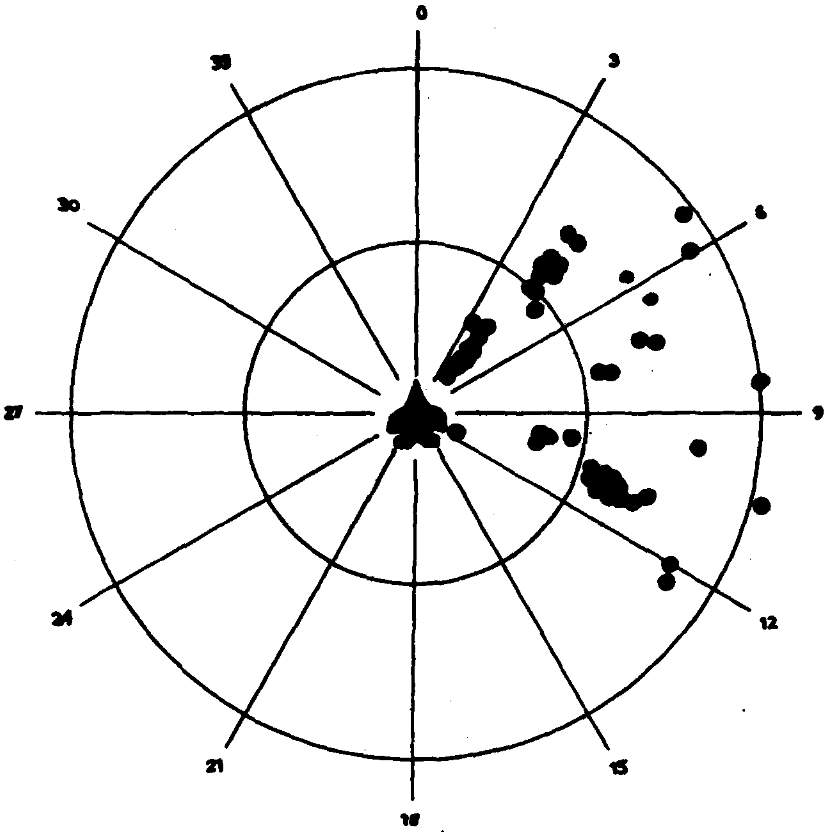


Figure 25. Stormscope and Weather Radar Indications as Aircraft Approaches Storm at 17:13:00 EDT on 7 August 1981, with Stormscope on 50 nmi Range.



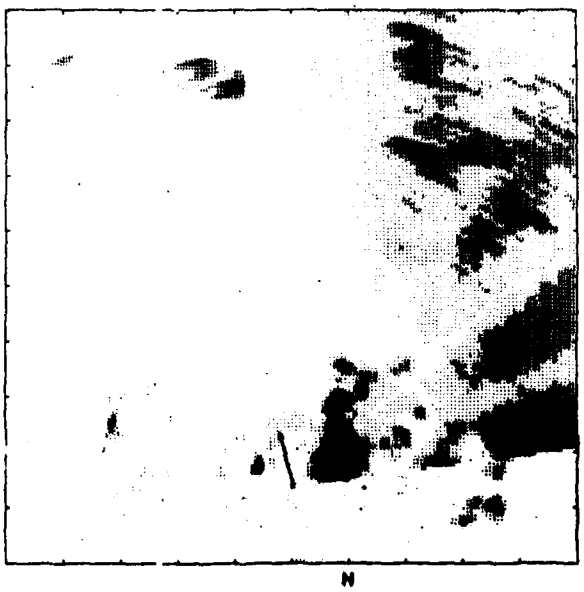


Figure 26. Stormscope and Weather Radar Indications as Aircraft Approaches Storm at 17:14:47 EDT on 7 August 1981, with Stormscope on 50 nmi Range

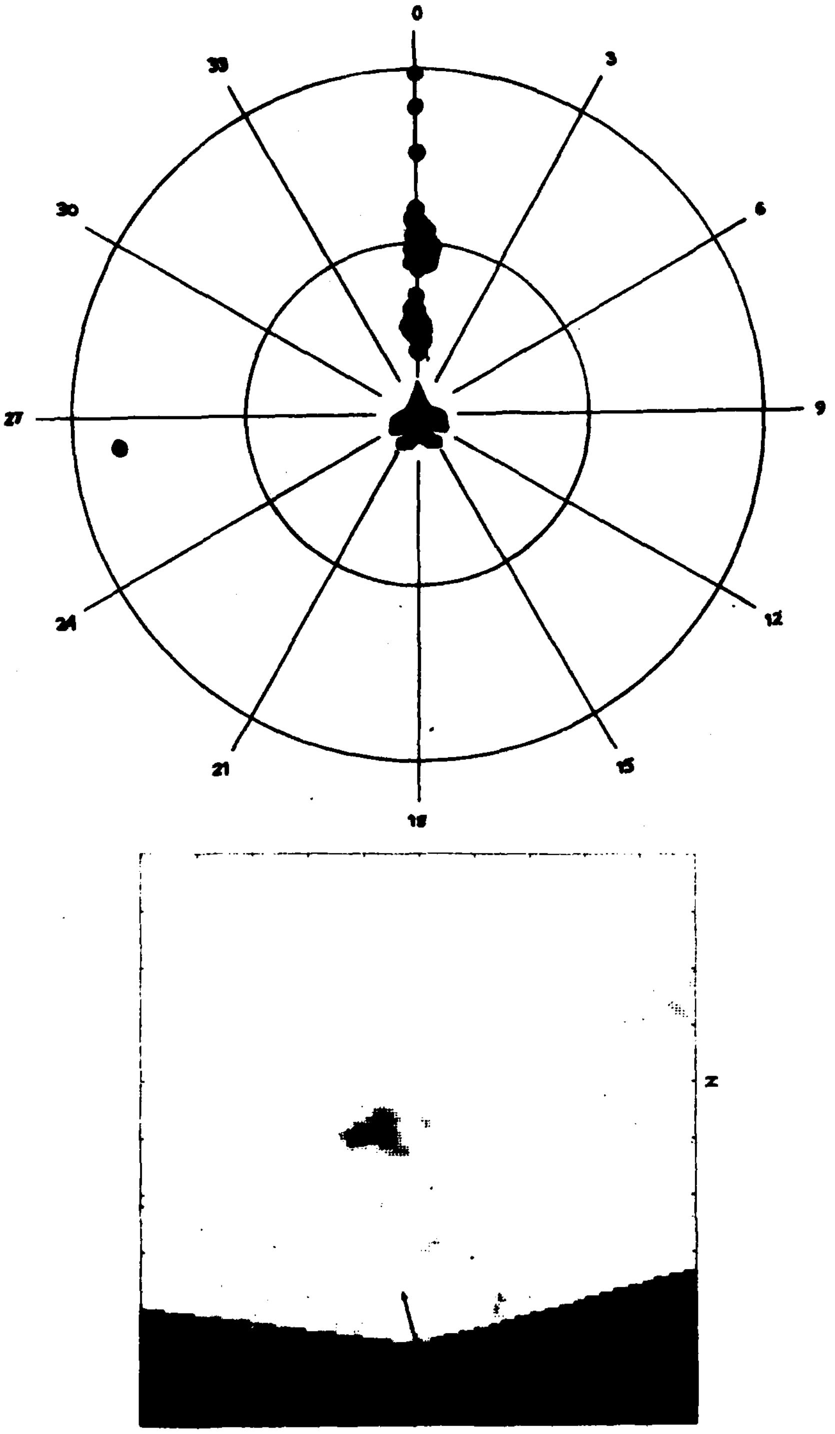


Figure 27. Stormscope and Weather Radar Indications as Aircraft Approaches Storm at 14:14:00 EDT on 25 August 1981, with Stormscope on 50 nmi Range.

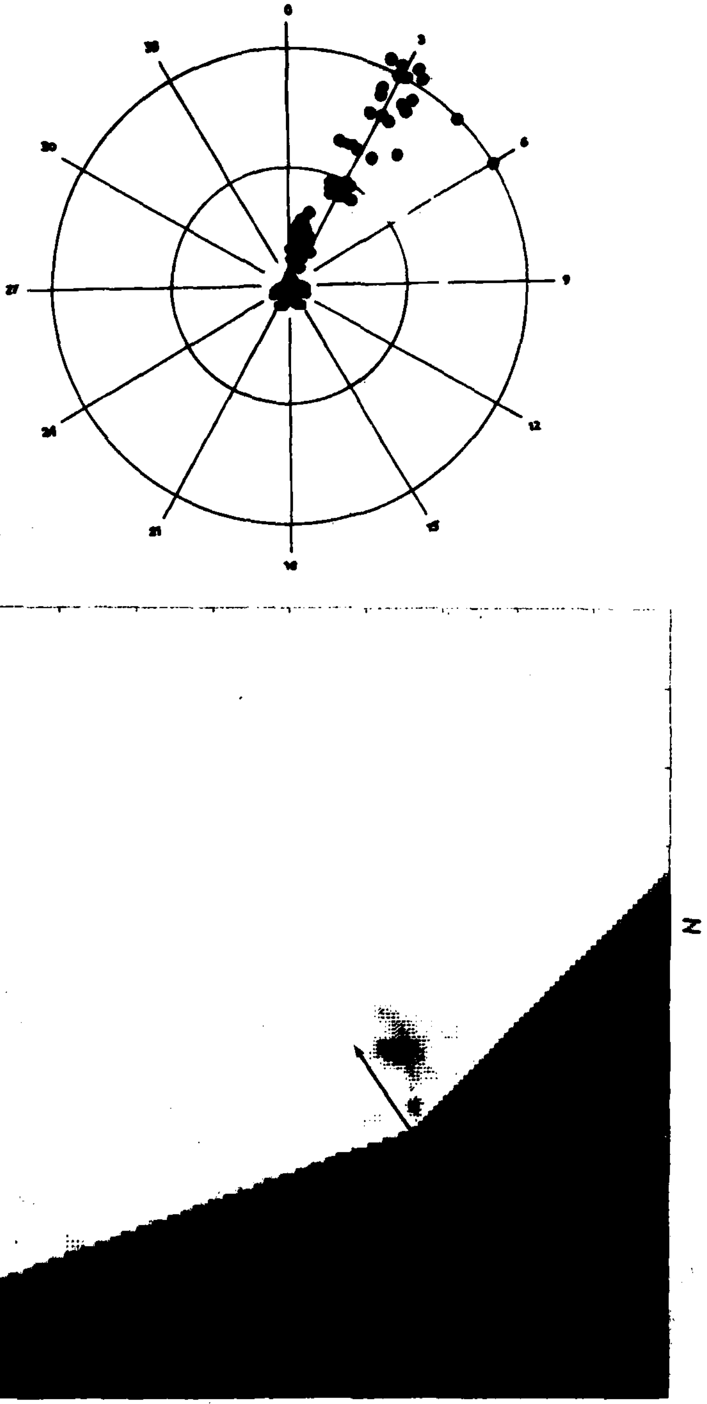


Figure 28. Stormscope and Weather Radar Indications as Aircraft Approaches Storm at 14:19:56 EDT on 25 August 1981, with Stormscope on 25 nmi Range

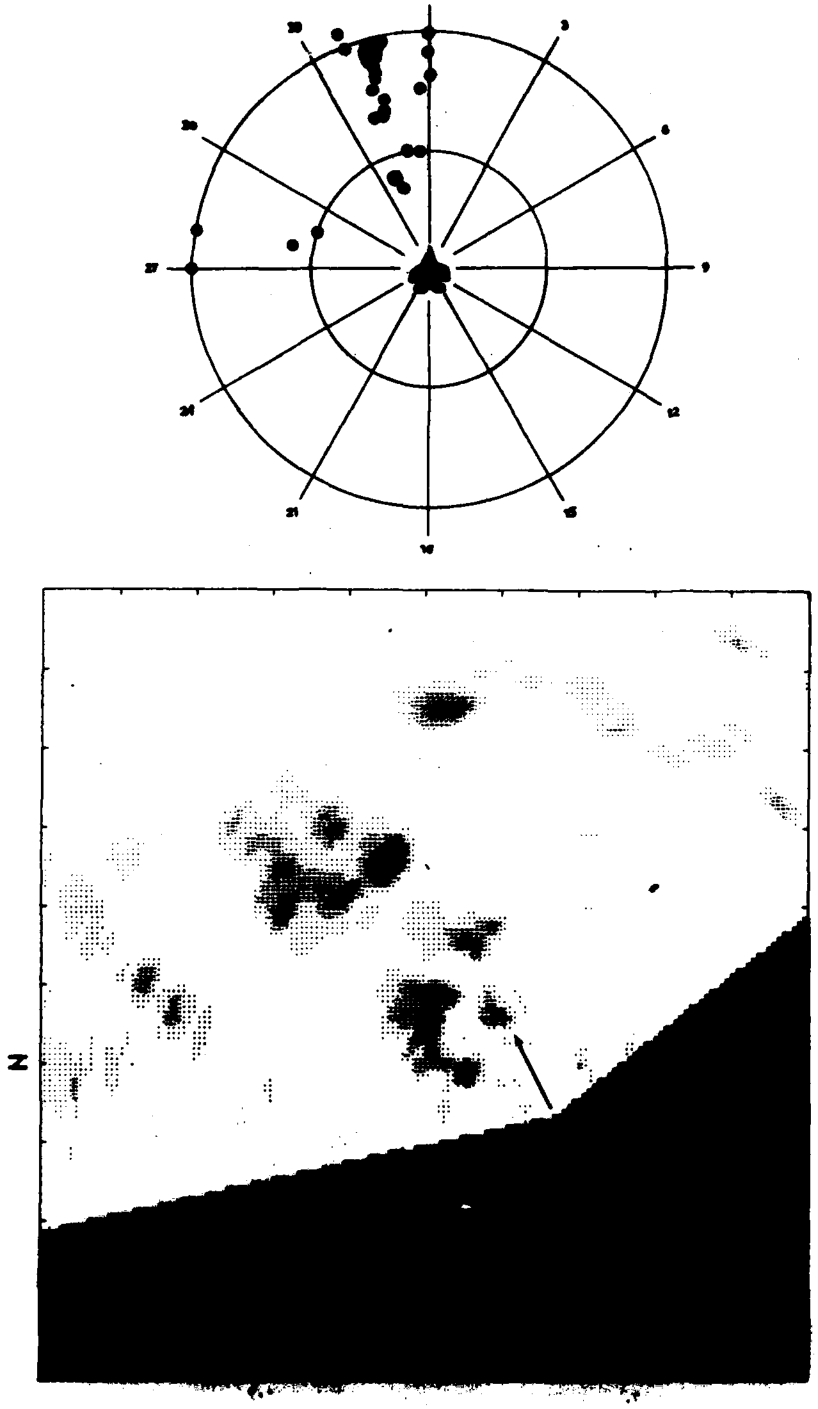


Figure 29. Stormscope and Weather Radar Indications as Aircraft Approaches Storm at 15:24:17 EDT on 25 August 1981, with Stormscope on 25 nmi Range

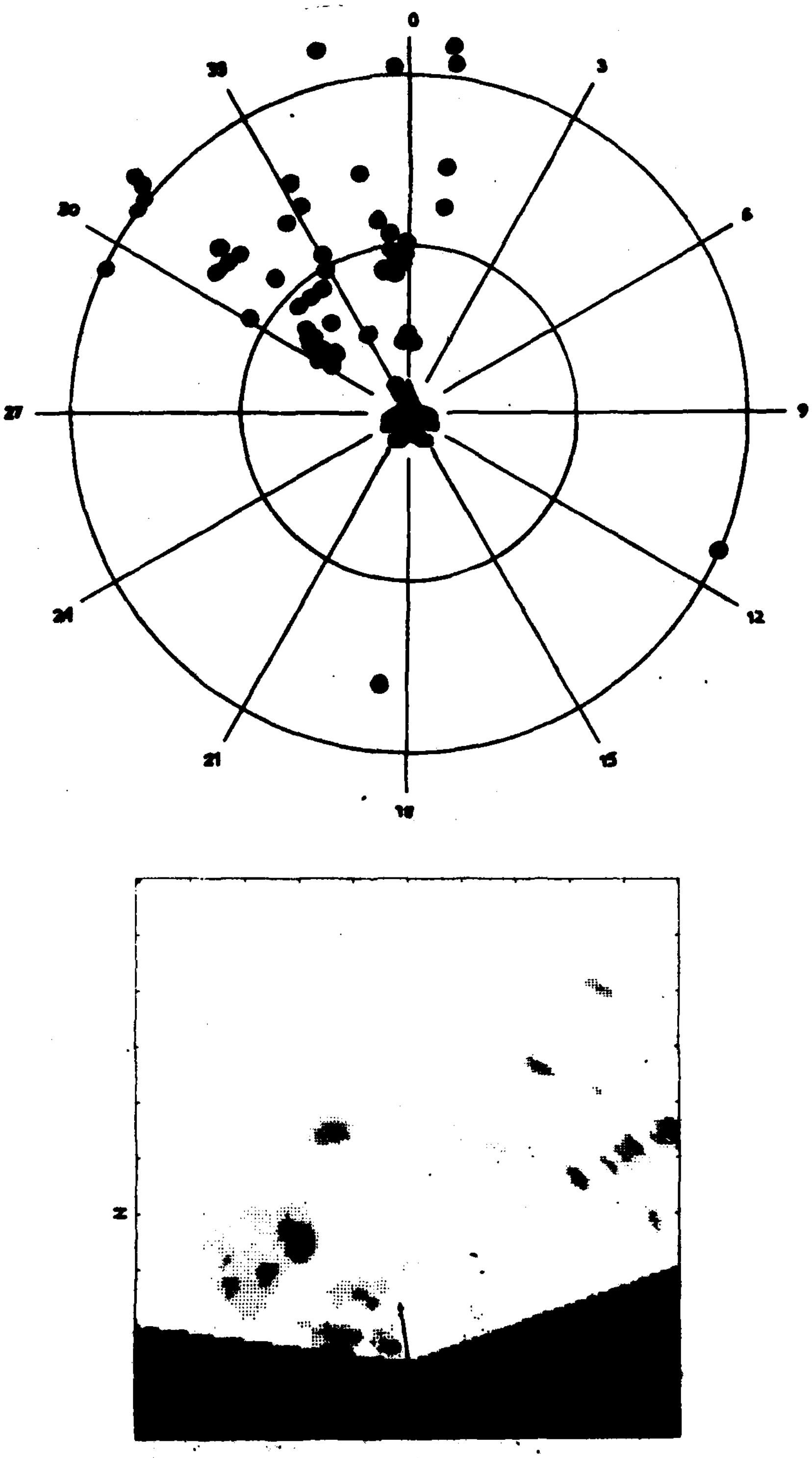


Figure 30. Stormscope and Weather Radar Indications as Aircraft Approaches Storm at 15:26:30EDT on 25 August 1981, with Stormscope on 50 nmi Range

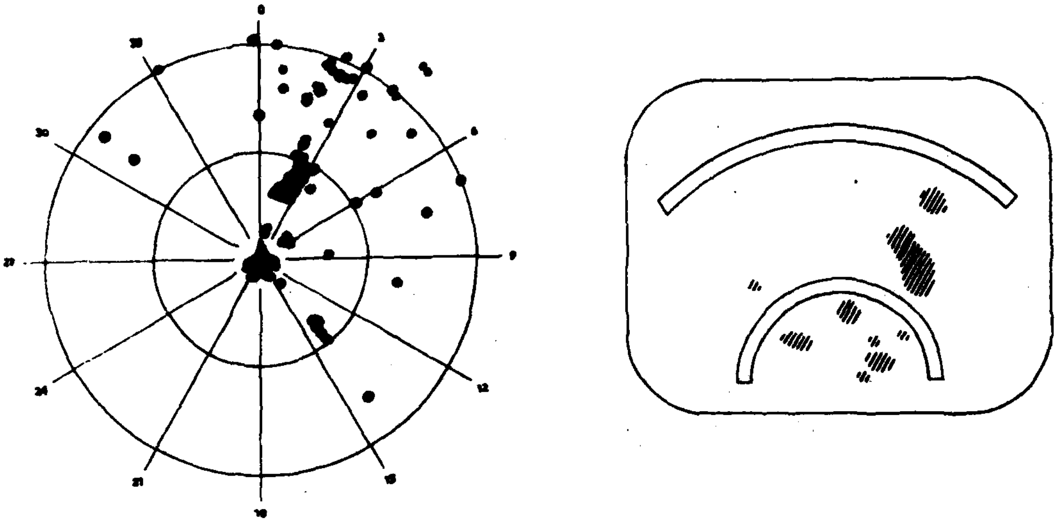
Figure 23 illustrates a case in which radar shows activity to the right of the aircraft at about 30 nmi and Stormscope shows a completely clear area. Without penetration of this area it was not possible to tell whether turbulence existed that was not causing electrical activity on the Stormscope or if there was only heavy precipitation. Although the primary purpose of this effort was to study the Stormscope as a lightning detector, two penetrations of this type were made during one flight in which isolated, very small third level contours appeared in areas with no Stormscope indications. In the first penetration, the ride, which lasted approximately 30 seconds, was generally smooth, with only very light turbulence. In the second penetration, however, the 30 second ride included initial light turbulence, then a severe jolt of approximately 20 meters/second up, followed by more light turbulence. No further penetrations were attempted. There were differences of opinion among the flight crew as to the severity, duration, etc. of the turbulence during the second penetration. Similar penetrations, and penetrations in cases where Stormscope shows activity and radar does not, would be needed in a better protected aircraft with turbulence monitoring devices before conclusions could be drawn as to the relative ability of Stormscope vs radar to indicate areas where severe turbulence exists.

4. RECORDING OF A DIRECT STRIKE

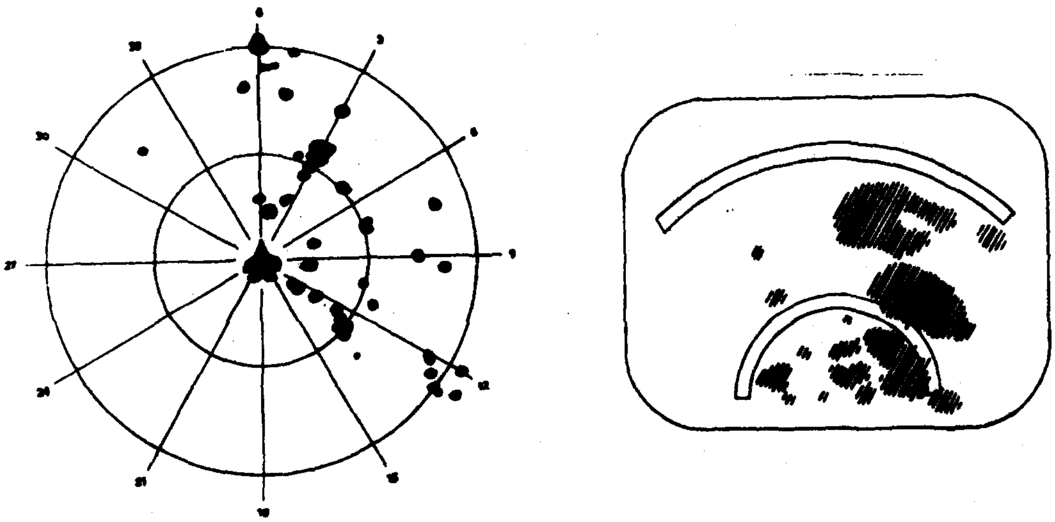
During the flight on 17 July 1981, the aircraft was hit by a lightning strike. At the time of the strike (17:21:43.9), the C-130 aircraft was at 17000 ft., in clouds and precipitation, moving at a true air speed of 220 knots. The outside air temperature was -0.7°C and there was light turbulence but no icing. The pilot and copilot estimated the nearest thunderstorm convective cloud to be 2-3 miles away with tops to 22000 ft. and in the developing phase. The lightning flash first attached to the right side of the nose above the cockpit, swept back over the right side of the fuselage, leaving several pit marks, then attached to and burned through a high frequency antenna wire which ran from slightly aft of the flight deck to the top of the vertical tail.

Radar and Stormscope indications were recorded prior to, during, and after the strike. Due to equipment problems, no digital radar recordings were available. Therefore, illustrations have been prepared from the video tapes of the display. Figure 31a shows the Stormscope and radar indications at 17:17:12. The radar at this point was set to show only 40 dBz level or higher areas and the range marks were at 25 and 50 nmi. Stormscope was on the 50 nmi range. Figure 31b shows the Stormscope and radar at 17:20:29, with the radar set to show all dBz levels above 20 dBz. The video tape shows evidence of light turbulence beginning at 17:21:10; then the aircraft began a slight turn to the left so the Stormscope was cleared. At 17:21:37 the turn was completed. Three events were recorded between 17:21:37 and 17:21:43 as shown in Figure 32 with the simultaneous radar returns of 20 dBz and above. Figure 32a shows the Stormscope display immediately prior to the strike. Figure 32b shows the direct strike at 17:21:43.9. All memory locations were filled immediately, as indicated by the disappearance of the previous patterns shown in Figure 32a. The middle of the display glowed as it became saturated with dots; scattered dots filled the 25 nmi range in a circular pattern all around the display aircraft. Figure 32c was taken at 17:24:40, with the activity now behind the aircraft.

Another direct strike occurred on a later flight. Unfortunately, this one was not recorded on video tape. The event was observed as a spoke from the lower left corner to the upper right corner of the Stormscope display. No attachment or exit points were found on the aircraft. Neither direct strike interfered with subsequent operation of the Stormscope.

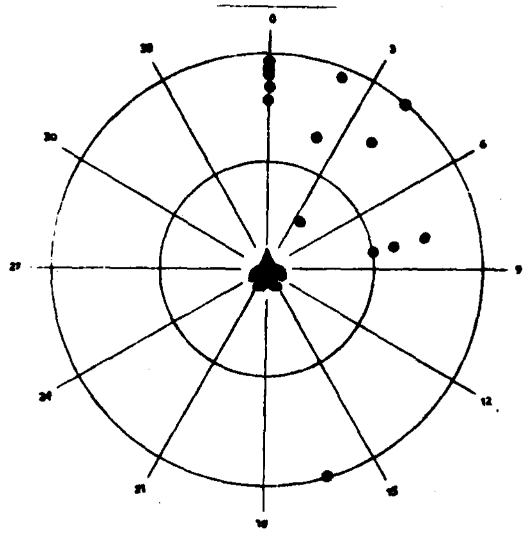


a. 17:17:12 EDT

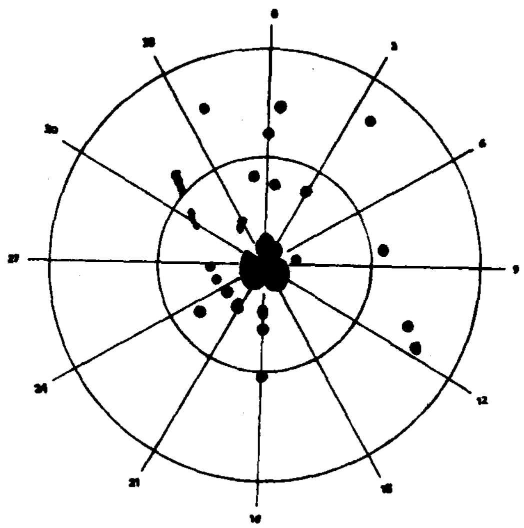


b. 17:20:29 EDT

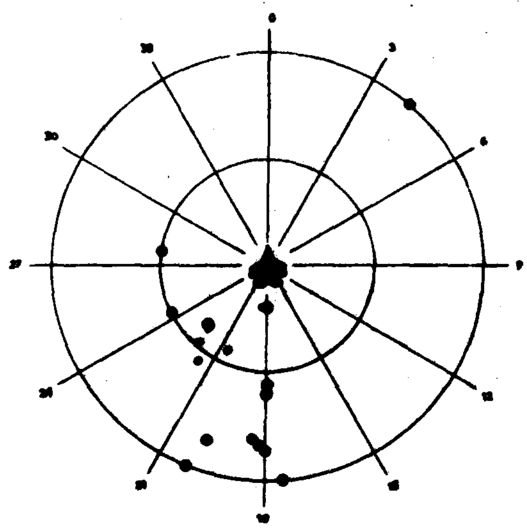
Figure 31. Stormscope and Weather Radar Indications Before the Direct Strike on 17 July 1981



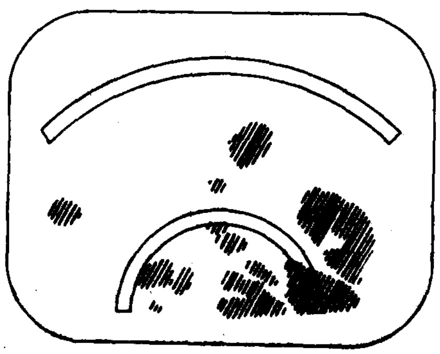
a. Immediately Prior to Strike (17:21:37)



b. At Strike (17:21:43.9)



c. After Strike (17:24:40)



d. Weather Radar (17:21:37)

Figure 32. Stormscope and Weather Radar Indications Associated with The Direct Strike on 17 July 1981

SECTION V

CONCLUSIONS

1. The Stormscope usually detected electrical activity at the same time as the lightning characterization instrumentation system and when a luminous flash was seen by the flight crew.

2. Individual Stormscope events (isolated sets of dot patterns) correlated well with the times of occurrence of cloud-to-ground return strokes in separate lightning flashes recorded in electric field records by the lightning characterization instrumentation system. Azimuths of these return strokes determined from the magnetic field sensors correlated to within 5% of the azimuths of the respective dots during the Stormscope events. Range variations, however, were large with a dot pattern sometimes indicating a strike over a radial distance of 25 nmi. Only a few intracloud flashes were recorded at times when the low frequency electric field record was available to allow differentiation between intracloud and cloud-to-ground activity. The Stormscope detected these few events but not enough data were available to report that it detected intracloud activity consistently.

3. The Stormscope was able to locate thunderstorm activity 100-200 nmi away and guide the aircraft to its vicinity.

4. The Stormscope showed reasonable agreement in azimuth with areas of heavy precipitation on radar presentations. The Stormscope's range variations, however, appeared fairly large, depicting some storms as more spread out radially from the aircraft than they actually were.

5. The Stormscope warned of the presence of lightning within 5 nmi of the aircraft prior to the two strikes to the aircraft, recorded them and continued functioning thereafter.

6. There was no evidence of interference from the aircraft systems affecting the operation of the Stormscope during the test program.

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