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RF RADIATION FROM LIGHTNING CORRELATED WITH AIRCRAFT MEASUREMENTS DURING STORM HAZARDS-82

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ABSTRACT

During the Storm Hazards Experiment 1982, the Goddard Space Flight Center monitored radiation from lightning from a site at the Wallops Flight Facility, Wallops Island, VA. Measurements were made while the NASA F106 penetrated thunderstorms to obtain data on lightning strikes to the aircraft. The objective of the ground-based measurements was to help determine if the events recorded by the F106 were part of lightning discharges. During the experiment, 53 cases were obtained in which events were recorded aboard the aircraft while reliable quality RF radiation was recorded on the ground. These cases came from 12 different storms occurring from June through August 1982. The data confirms that the aircraft was measuring events which were part of lightning and indicates that the events recorded on the aircraft tend to occur early in the flash.

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RF RADIATION FROM LIGHTNING CORRELATED WITH AIRCRAFT MEASUREMENTS DURING STORM HAZARDS-82

INTRODUCTION

During the summer of 1982, the Goddard Space Flight Center measured radiation from lightning as part of the Storm Hazards experiment. These measurements were made on the ground while the NASA F106 aircraft was being flown through thunderstorms to obtain data on lightning strikes to airplanes (Pitts et. al., 1979). The objective of the ground-based measurements was to provide information to aid in the interpretation of data collected by the aircraft. In particular, it was desired to determine if events on the aircraft were in fact part of real lightning discharges or perhaps some other form of discharge resulting from charge on the aircraft.

The ground-based experiments were performed at the Spandar Radar Facility at NASA's Wallops Flight Facility (WFF) from June through August 1982. The measurements consisted of fast and slow electric field changes and recordings of RF radiation at selected frequencies between 3 and 300 MHz. The slow electric field change system provides information on flash type (cloud-to-ground or intra-cloud) and together with the fast field changes can be used to identify specific events within the discharge, such as return strokes and certain types of intra-cloud processes (Uman, 1969). The RF radiation in this frequency range helps identify the event as lightning and provides information about its duration and some indication of flash type (Le Vine, 1978).

In several respects, the 1982 experiments were quite successful. During the experiment period (June to August) data was obtained from 12 different storms, and 53 events were recorded on the aircraft while data was being recorded on the ground. However, except in a very few cases, only data on RF radiation was available. This was because the distance of the storms from WFF was too great to obtain slow field changes (the slow electric field change system has an effective range of less than 30 km) and because the fast field change system was not fully operational until late in the season. However, the RF data alone provides sufficient information to identify lightning flashes.

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and by comparing the records of RF radiation with the times of events observed on the aircraft, it is possible to determine whether or not the aircraft events occurred during lightning and if so to determine where within the flash the events occurred. The purpose of this report is to present the results of this comparison.

INSTRUMENTATION

The RF radiation from lightning was recorded at several frequencies in the range from 3 MHz to 300 MHz. Measurements were made near 3 MHz and 30 MHz using fixed tuned receivers developed at the Georgia Institute of Technology (Le vine, et. al., 1976). These receivers were driven by linear vertical antennas (i.e. whips) located on the flat grassy lawn outside of the Spandar Radar Facility (Figures 1 and 2). Measurements in the 50 MHz to 300 MHz range were made using commercially available radio receivers (Watkins Johnson receivers, models WJ 977 and WJ 8730) which were modified to provide DC coupled video output. These receivers were connected to disk-cone antennas also mounted on the ground next to the Spandar radar facility (Figure 2). Signals from these receivers were recorded directly on a strip chart (using an 8 channel Brush recorder, model Mark 200-1707) which provided a real-time indication of lightning activity, and also were recorded on an analogue instrumentation tape recorder (Ampex model PR-2200). The tape recorder provided a permanent record for later analysis. Data was recorded in both FM and direct format at a tape speed of 15 ips or greater. At 15 ips the effective bandwidth of the recorded data was 10 KHz on the FM channels and about 75 KHz on the direct channels. By playing the FM data back at reduced tape speed, strip chart records of the lightning signals could be obtained with millisecond time resolution.

RF radiation from lightning consists of a sequence of many irregular impulses which correspond to radiation from the individual events (e.g. return strokes, leader steps, etc.) in the flash. A cloud-to-ground flash typically begins abruptly with a period of intense closely spaced pulses followed by several larger pulses. Smaller pulses fill the gaps between the large pulses making an early active

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phase of high pulse density. The flash tends to end in a period of gradual decrease in both pulse amplitude and density. Figure 3 is an example of a relatively nearby cloud-to-ground lightning flash showing radiation at 3 MHz and also the associated slow electric field change for reference. The slow electric field change (Slow E) indicates changes in the quasi-static electric fields at the ground due to changes in the charge distribution in the cloud (Uman, 1969). Cloud-to-ground flashes have a characteristic staircase pattern, as evident in Figure 3, the steps indicating neutralization of (negative) charge in the cloud due to a return stroke. In contrast, intra-cloud flashes, which neutralize both negative and positive charge within the cloud tend to be associated with field changes of the opposite sign and without the abrupt steps characteristic of return strokes. Figure 4 shows the slow electric field change and RF radiation at 3 MHz typical of intra-cloud flashes. Notice that in contrast to cloud-to-ground flashes, the RF radiation in this case tends to begin slowly and build to an intense stage of closely spaced pulses and then to decay, much as it began, in a stage of gradually decreasing pulse amplitude and density. (For additional discussion and examples at several frequencies, see Le Vine, 1978). While these patterns in the RF radiation are typical, exceptions are frequent and it is not uncommon to see cloud-to-ground flashes which begin with an intra-cloud phase (Le Vine, 1978). Also, these are patterns which have been observed for relatively close lightning. As the thunderstorm gets further away, one expects to lose detail (i.e. some of the weaker events) and therefore, probably some of the characteristics that distinguish flash type.

Keeping these limitations in mind, one frequently can get information as to flash type from the RF radiation. This point is illustrated in Figure 5 which shows RF radiation at 3 MHz together with the slow electric field changes, for a period of about 10 minutes during a storm near WFF on June 20, 1981. A dichotomy in the pattern of RF radiation is clearly evident, flashes A, B, and G being in one class, and flashes C, D, E, and F in the other. The slow electric field changes indicate that flashes A, B, and G are intra-cloud flashes (B might be two flashes) and flashes D and E are cloud-to-ground flashes. The slow field change records aren't sufficiently clear to draw conclusions about flashes C and F, but the RF patterns are strongly suggestive of cloud-to-ground flashes.

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In the data to be presented here, no attempt has been made to identify flash type; rather the RF radiation has been used only to identify events which appear to be lightning. Then by comparing the RF radiation with the time of the events recorded aboard the aircraft, information about the coincidence of these events with lightning can be obtained.

The aircraft was instrumented with several different sensors including electric and magnetic field sensors as well as a current probe on the nose boom (Pitts, et. al., 1979). The recording systems on the aircraft consisted of a digital waveform recorder (a modified Biomation model 8100 waveform recorder) which recorded a millisecond of data in 10 nanosecond samples and an analogue tape recorder. The digital waveform recorder could record data from two sensors and was connected to various pairs of these sensors during the course of the summer. The correlation to be done here is with the events recorded with this device without regard to sensor type.

TIMING

In order to establish that events measured on the ground and aboard the aircraft could be correlated in time, a test of time synchronization between the two systems was conducted.

Time on the ground was derived from the WFF time standard (which is periodically synchronized with Loran-C and kept with a cesium standard to better than ±5 μs) and was recorded in a IRIG-B format (1 KHz carrier) on the analogue tape recorder with the lightning data. The maximum synchronization error between time source and the tape recorder due to cable and equipment delays is about 1 ms. Time on the aircraft was also kept in an IRIG-B format using an onboard time code generator which was synchronized prior to each flight with WWV. To determine how well these two time sources were synchronized, a test was performed on June 29, 1982. For this test, the data system aboard the aircraft transmitted its time code to WFF where it was recorded on the analogue tape recorder along with the locally generated time code. Figure 6 is an example of data played back from the tape recorder on to a strip chart. The upper trace is the time

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code received from the aircraft and the lower trace is the local (WFF) time code. Both time codes are in an IRIG-B format. In this format time updated every second, and the 1 second intervals are indicated by the double wide lines. The time between the single wide pulses is 0.1 seconds and the time between the narrow pulses is 0.01 seconds. This test indicated that the two time codes were synchronized to within about 12 ms, with the aircraft time being 12 ms early ($T_{ground} = T_{air} + 12$ ms). This accuracy is certainly adequate to determine if events measured on the airplane and ground correspond to the same lightning flash (typical flash durations is 0.75 sec) and also to give a clear idea of where within the flash the aircraft event occurs. On the other hand, better time synchronization would be required to compare specific events recorded on the aircraft with fast field changes due to events such as return strokes or leader steps (the fast field change from a first return stroke, for example, typically lasts about 100 μs).

DATA

The summer of 1982 was a successful season with a large number of strikes to the aircraft. On 12 flights, the storm was close enough to receive good quality data on at least one RF channel of the ground-based system. Data on 53 events was collected during these 12 storms. The approximate storm locations are indicated on Figure 7 where they are identified by the corresponding flight number. Table I lists the flight number, approximate location of the storm and approximate time data was collected. Most of this data consisted of records of RF radiation at 3 MHz from storms within 200 km of WFF.

A comparison has been made of the time of events recorded by the Biomation waveform recorder aboard the aircraft with the ground-based records of 3 MHz radiation. The radiation measured on the ground is a history of the entire lightning flash whereas the Biomation times indicate relatively brief events which involved the aircraft. The objectives of this comparison were to see if the Biomation triggers occurred during lightning flashes, and if so, to establish where within the flash these triggers occurred. To do this, data was played back from the tape recorder with high time resolution

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Figure 11 is an example of a case where the high time resolution records indicated an aircraft event not occurring in the flash. This particular example occurred on August 9, 1982 during Flight #39 near West Point, Virginia. In this case, the two channels of the waveform recorder aboard the aircraft triggered at different times at (19 hours 48 minutes 38.92 seconds and 39.28 seconds). As can be seen from the figure, these times are between two flashes and definitely are not part of either. This isn't proof that the aircraft was not involved with a lightning discharge, but only that if there was one it was not strong enough to be detected by the ground system. However, it is strongly suggestive that this is not lightning since radiation from other lightning flashes in this storm were being detected on the ground. Of the 53 cases examined, in only four cases were the events not close (several seconds away) from lightning, and in four other cases the events on the aircraft occurred a few tenths of seconds before (two cases) or after (two cases) discernable RF radiation from lightning.

The distribution of the Biomation trigger times within the flashes is indicated by the histogram in Figure 12. This histogram was obtained by plotting the number of events against the time interval from the beginning of the flash to the event. Since the flashes are not all of the same duration, this time has been recorded as a percent of the duration of the flash. Thus, an event occurring .3 seconds after the beginning of a flash which lasted .75 seconds would be plotted at 40% in Figure 12. As can be seen from the figure, it was most likely to find the aircraft event occurring within the first 20% of the flash. The mean occurrence was at about 29%. Although it was very likely to find events within the first 10% of the flash relatively few events occurred right at the beginning of the flash. In almost all cases the flash had clearly begun before the aircraft instrumentation was triggered.

The durations of the 49 flashes close to events recorded on the aircraft are plotted in Figure 13. The duration varied from several tenths of a second to over two seconds in some extreme cases. The mean duration was 1.03 seconds but there is some indication of a bunching into flashes whose duration was less than one second and those whose duration was greater than one second. The mean duration of the shorter flashes is about .65 sec.

CONCLUSION

A comparison of radiation at 3 MHz from lightning with the time of events recorded by the Biomation waveform recorder aboard the F106 indicates that a significant majority of the aircraft events were coincident with the RF radiation, strongly supporting the hypothesis that these events are in fact part of a lightning discharge. If the aircraft events had occurred independently of lightning, one would have expected less than a 40% coincidence with the RF radiation. This is a number obtained by assuming, as a worst case, a high flashing rate and that the aircraft events were uniformly distributed in time. Furthermore, if uncorrelated with lightning one would have expected the aircraft events to be uniformly distributed in the flash (i.e. equally likely to be found at the beginning or end of the flash). In fact, better than 80% (45 out of 53) correlation of the aircraft events with lightning was found, and the events were very pronouncedly bunched toward the beginning of the flash.

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TABLE I

Date	Flt. #	Location	Distance from WFF	Time (hrs/min.)
June 17	20	Moyock, NC	170 km	19/30
July 19	26	Richmond, VA	150 km	21/20
July 30	34	Easton, MD	110 km	19/45
July 31	35	Oceana, VA	140 km	19/50
August 6	37	Smith Pt., MD	65 km	20/00
August 8	38	Currituck Sound, NC	180 km	20/20
August 9	39	West Pt. VA	130 km	20/00
August 9	40	Line of storms	140 km	22/40
August 11	41	Hopewell, VA	190 km	16/30
August 11	42	Scotland Neck, NC	265 km	22/10
August 17	43	Waverly, VA	170 km	20/25
August 25	44	Virginia Beach, VA	130 km	20/40

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References:

Le Vine, D. M., et. al (1976), "The Structure of Lightning Flashes HF-UHF: September 12, 1975, Atlanta, GA," NASA X-953-76-176, August.

Le Vine, D. M. (1978), "The Temporal Structure of RF Radiation from Lightning," NASA TM-78113, April (available NTIS #N78-22300).

Pitts, F. L. et. al. (1979), "Inflight Lightning Characteristic Measurement System," Proceedings, Federal Aviation Administration/Florida Institute of Technology Workshop on Grounding and Lightning Technology, Rep. #FAA-RD-79, pp. 105-111.

Uman, M. A. (1969), *Lightning*, McGraw-Hill.

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Figure 1. The Spandar Radar Facility showing the front of the building and the radar antenna. The lightning monitoring equipment was housed in this building and the antennas were in a grassy field to the left of the building (Figure 2).

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Figure 2. The antennas used to monitor RF radiation. The Spandar Radar Facility is immediately to the right of this photograph.

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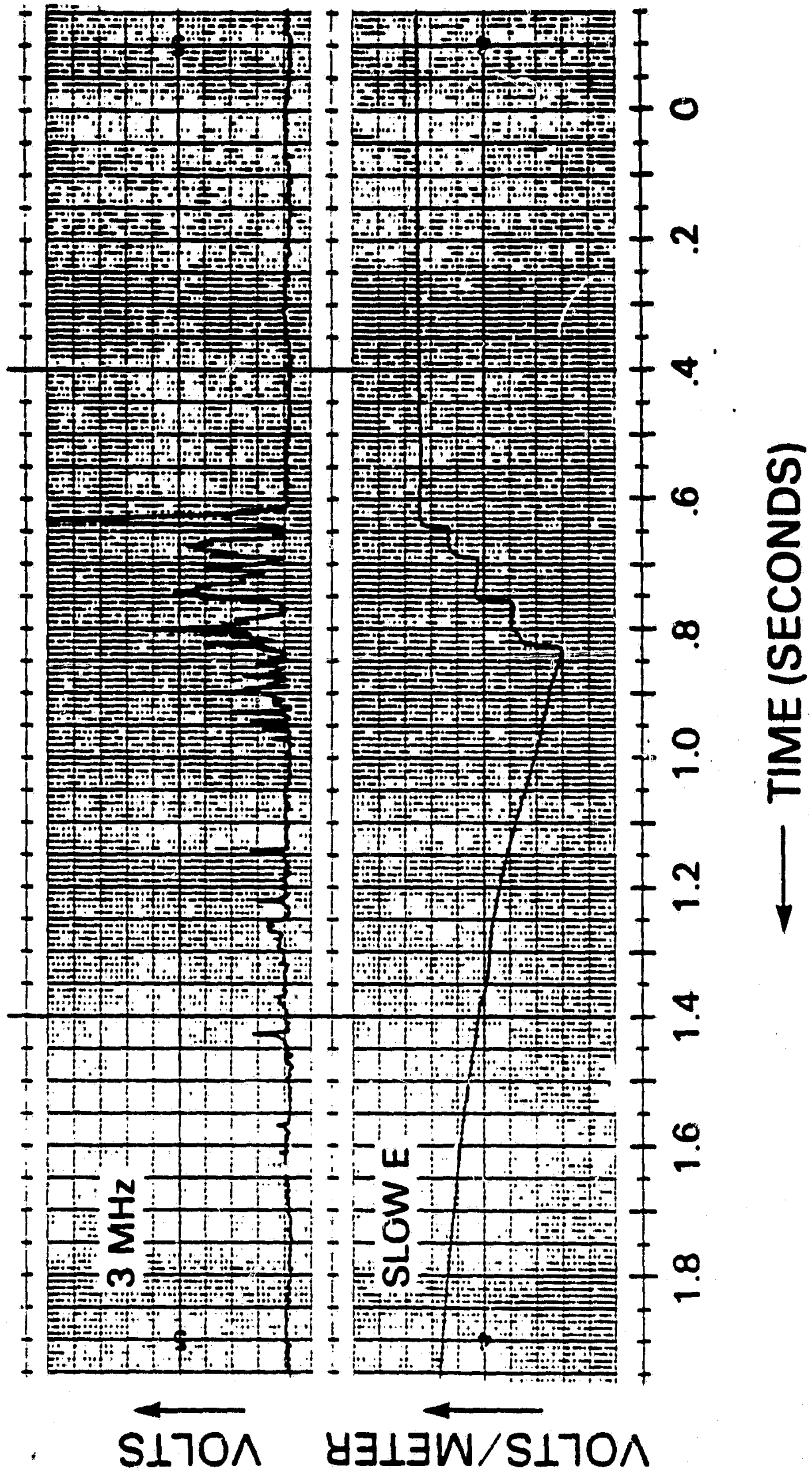

Figure 3. Radiation at 3 MHz and slow electric field changes for a cloud-to-ground lightning flash.

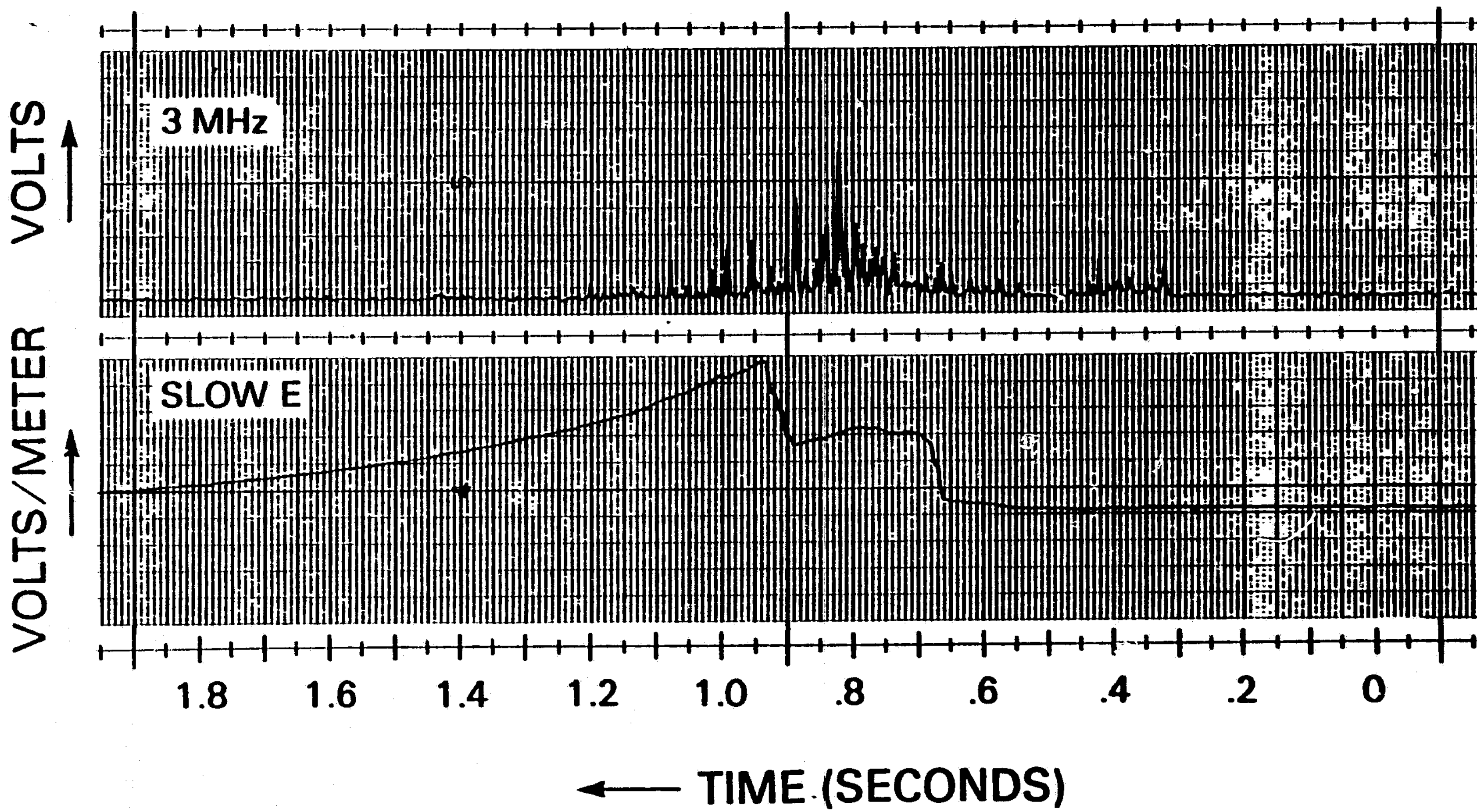

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Figure 4. Radiation at 3 MHz and slow electric field changes for an intra-cloud lightning discharge.

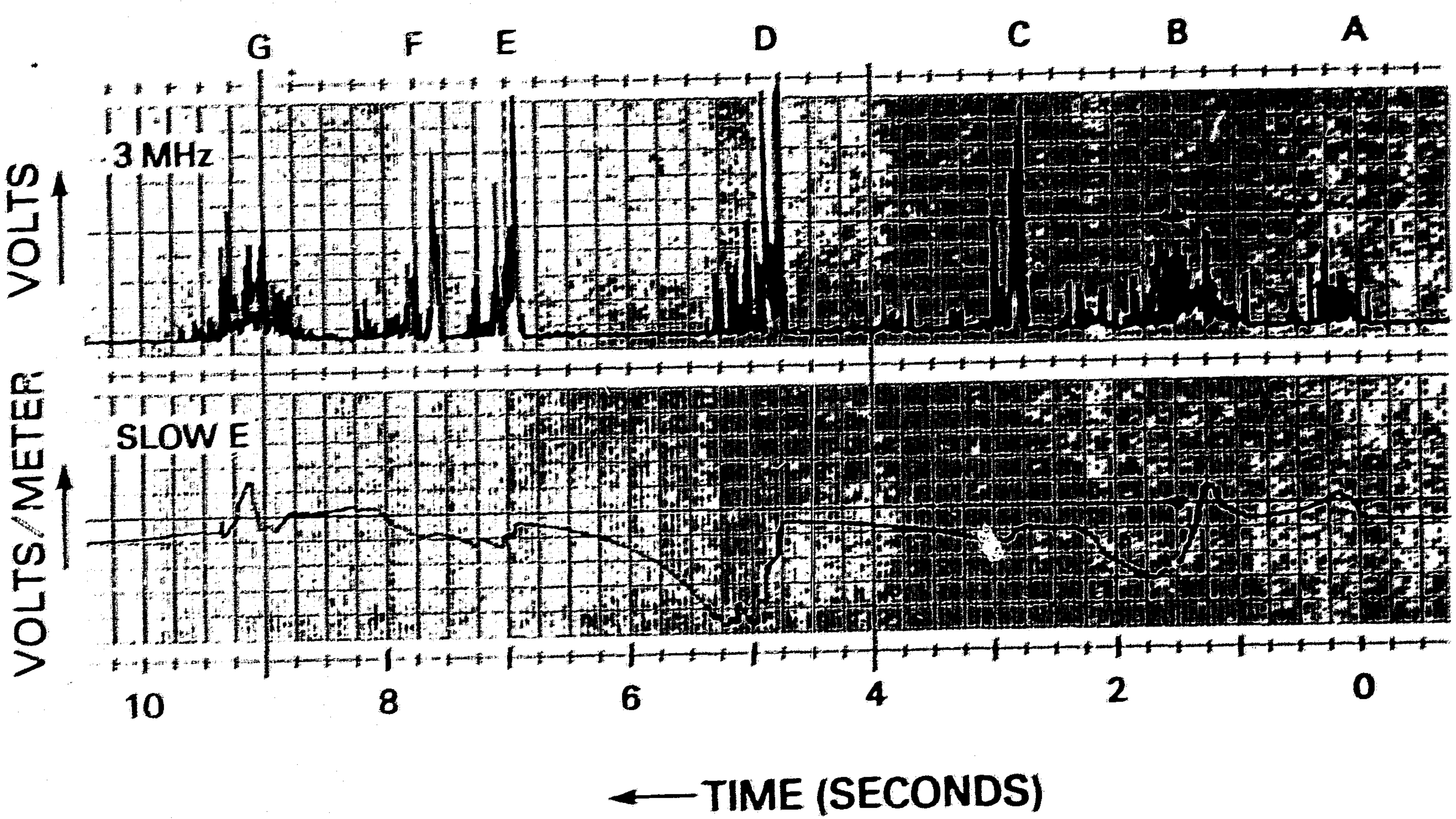

Figure 5. Radiation at 3 MHz and slow electric field changes recorded at the WFF on June 20, 1981.

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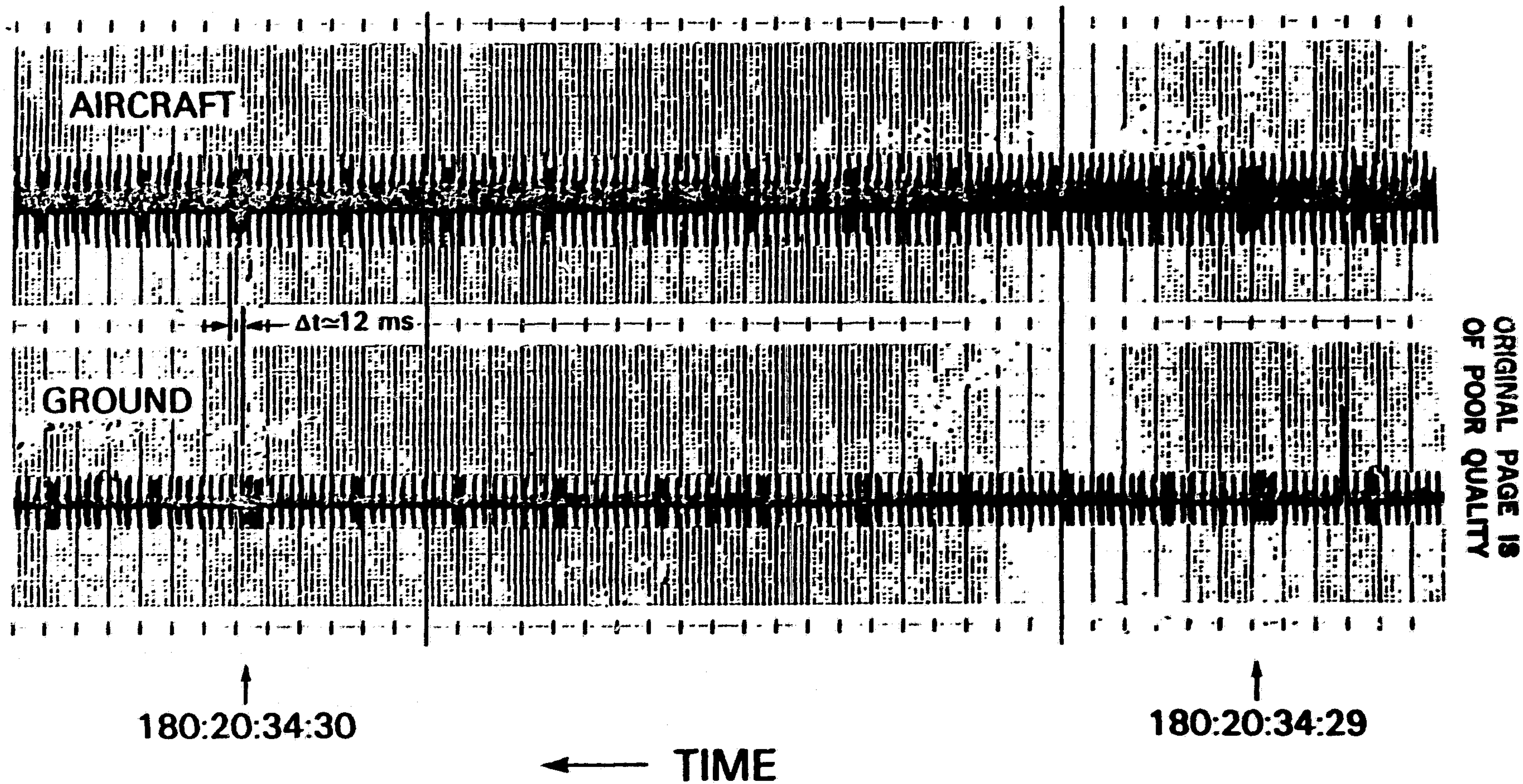

Figure 6. Time code recorded during a time synchronization test on June 29, 1982. The time code is in an IRIG-B format in which time is up-dated once every second. The one second intervals are identified by the double wide lines. The single wide lines are 0.1 seconds apart and the narrow lines are 0.01 seconds apart.

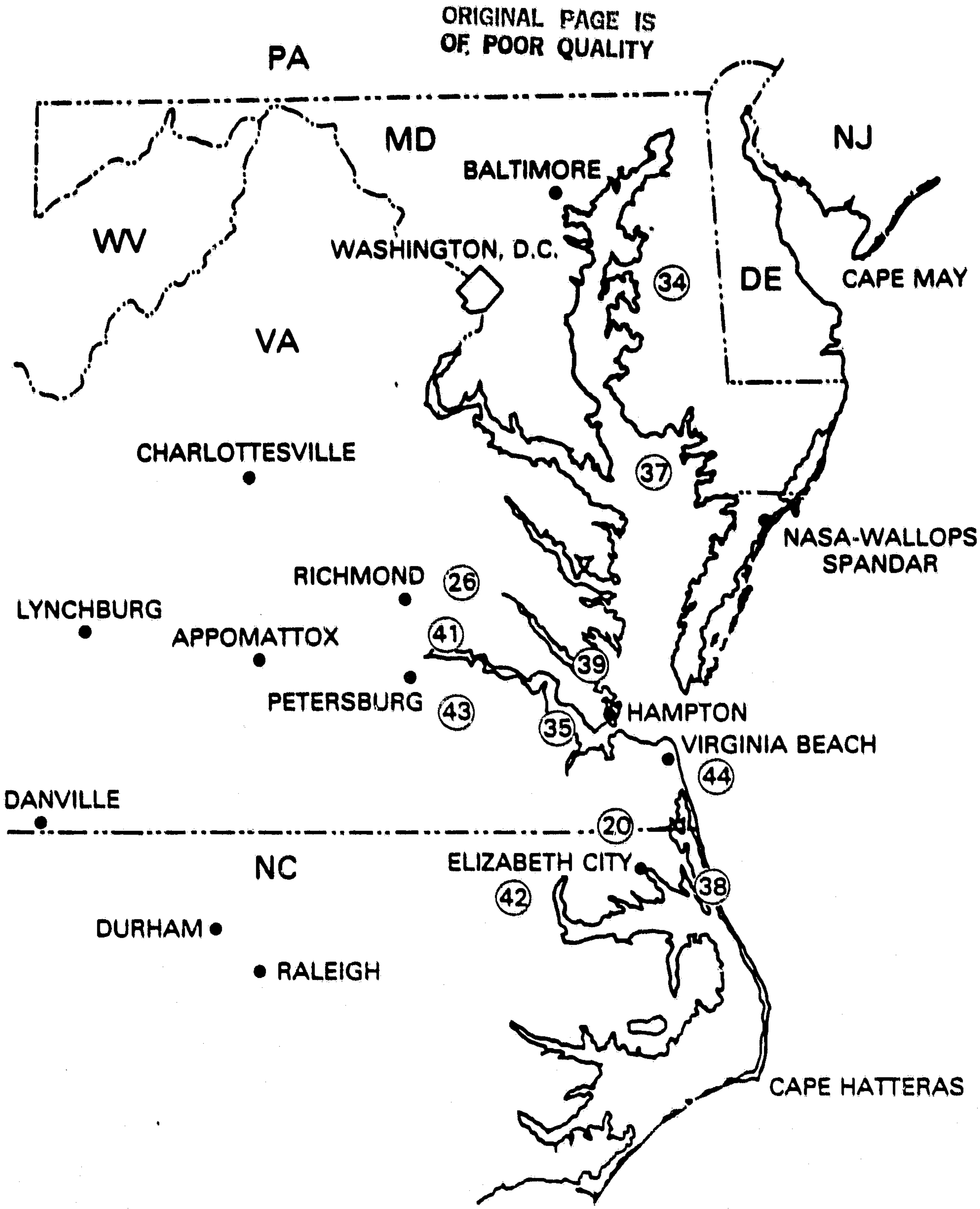

Figure 7. The approximate location of storms during which correlated ground and aircraft measurements were made. Storm locations are identified by circles and the flight number is in the circles. Additional information is given in Table I.

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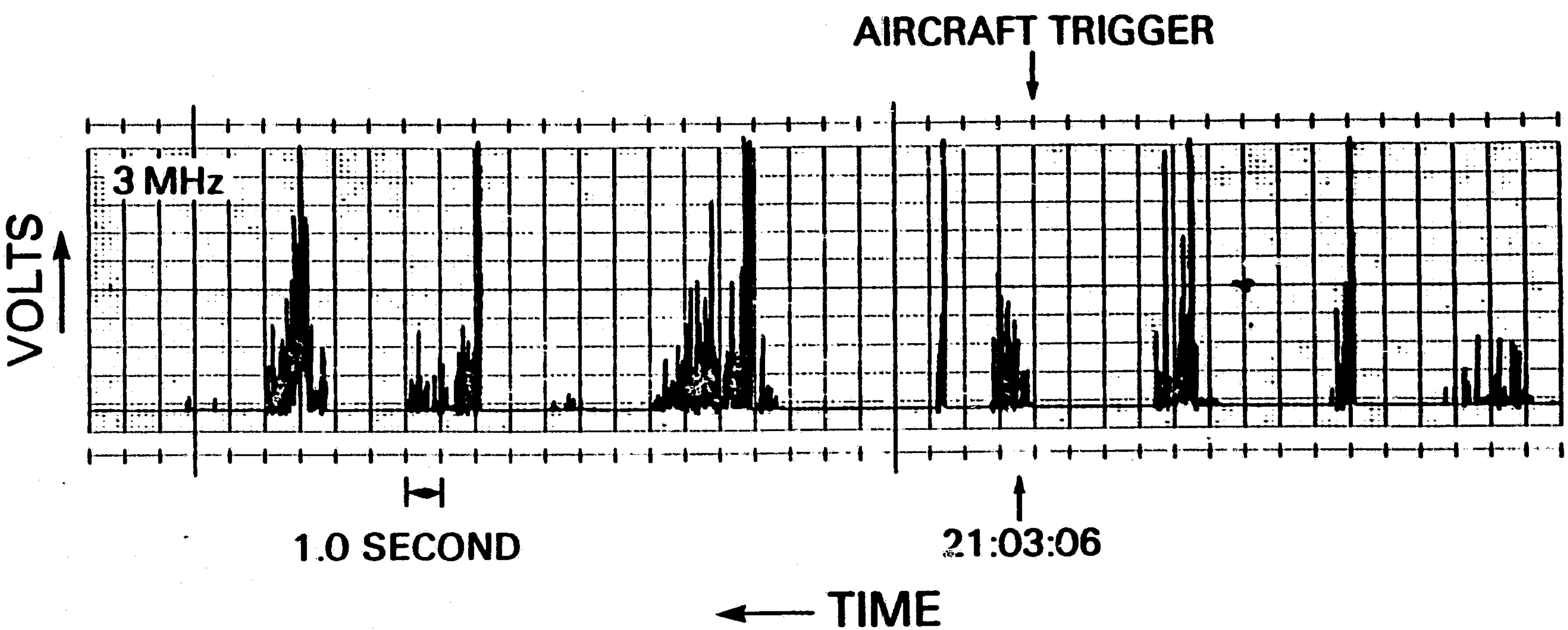

Figure 8. Strip chart record of data collected on August 25, 1982 during Flight #44. The aircraft reported a lightning strike at about (21 hrs 03 min 067 sec) as indicated by the arrow.

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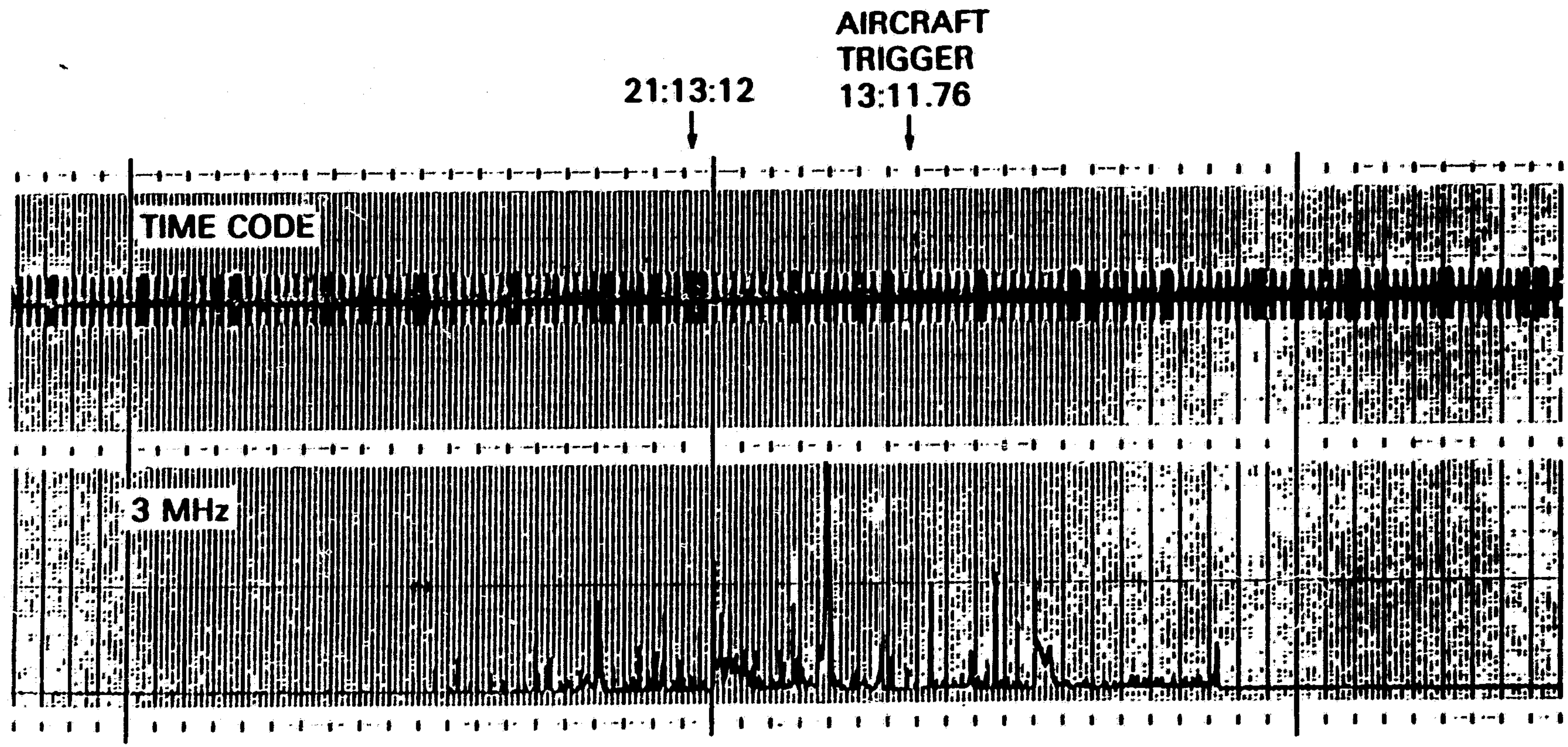

Figure 9. 3 MHz radiation from a lightning flash on July 10, 1982 at about (21 hrs 13 min 12 sec). The aircraft recorded an event during this flash at (21 hrs 13 min 11.76 sec) as indicated by the arrow.

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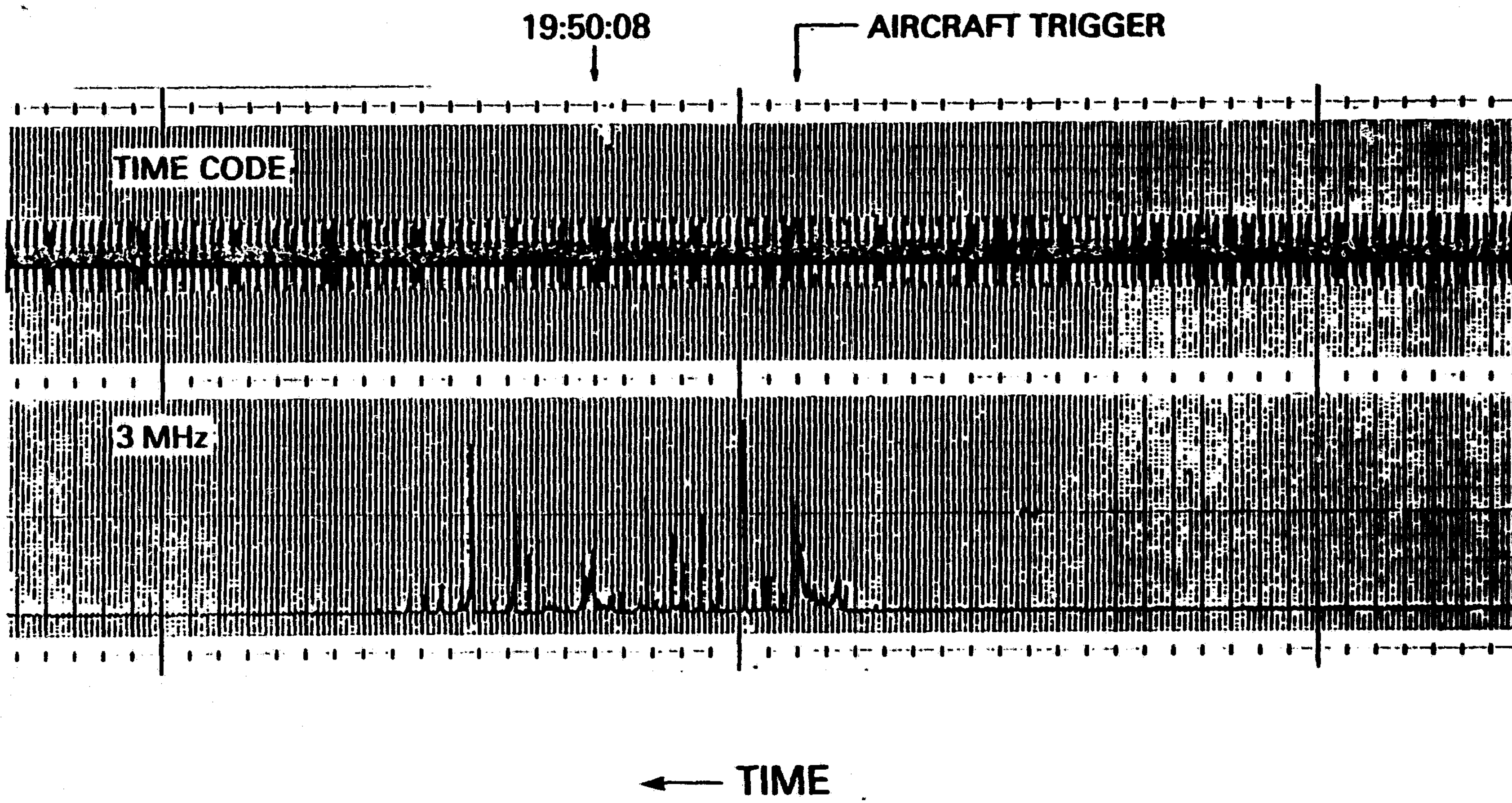

Figure 10. 3 MHz radiation from a flash on August 6, 1982 during flight #37. The aircraft reported an event at (19 hrs 50 min 07.8 sec) as indicated by the arrow.

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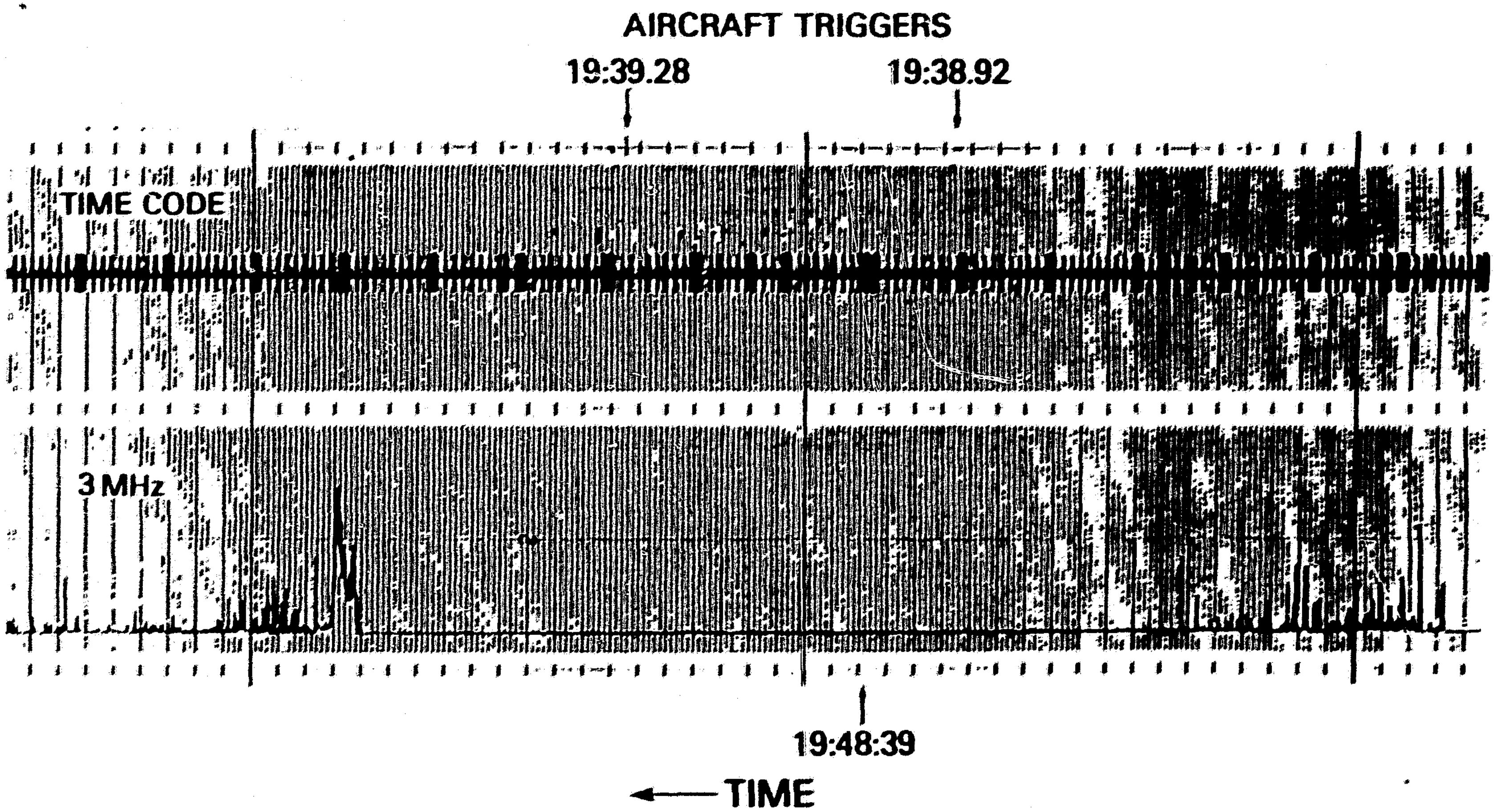

Figure 11. 3 MHz radiation from two flashes on August 9, 1982 during flight #39. The aircraft reported events at (19 hrs 48 min 39.28 sec) and (19 hrs 48 min 38.92 sec). These times lie between the two flashes.

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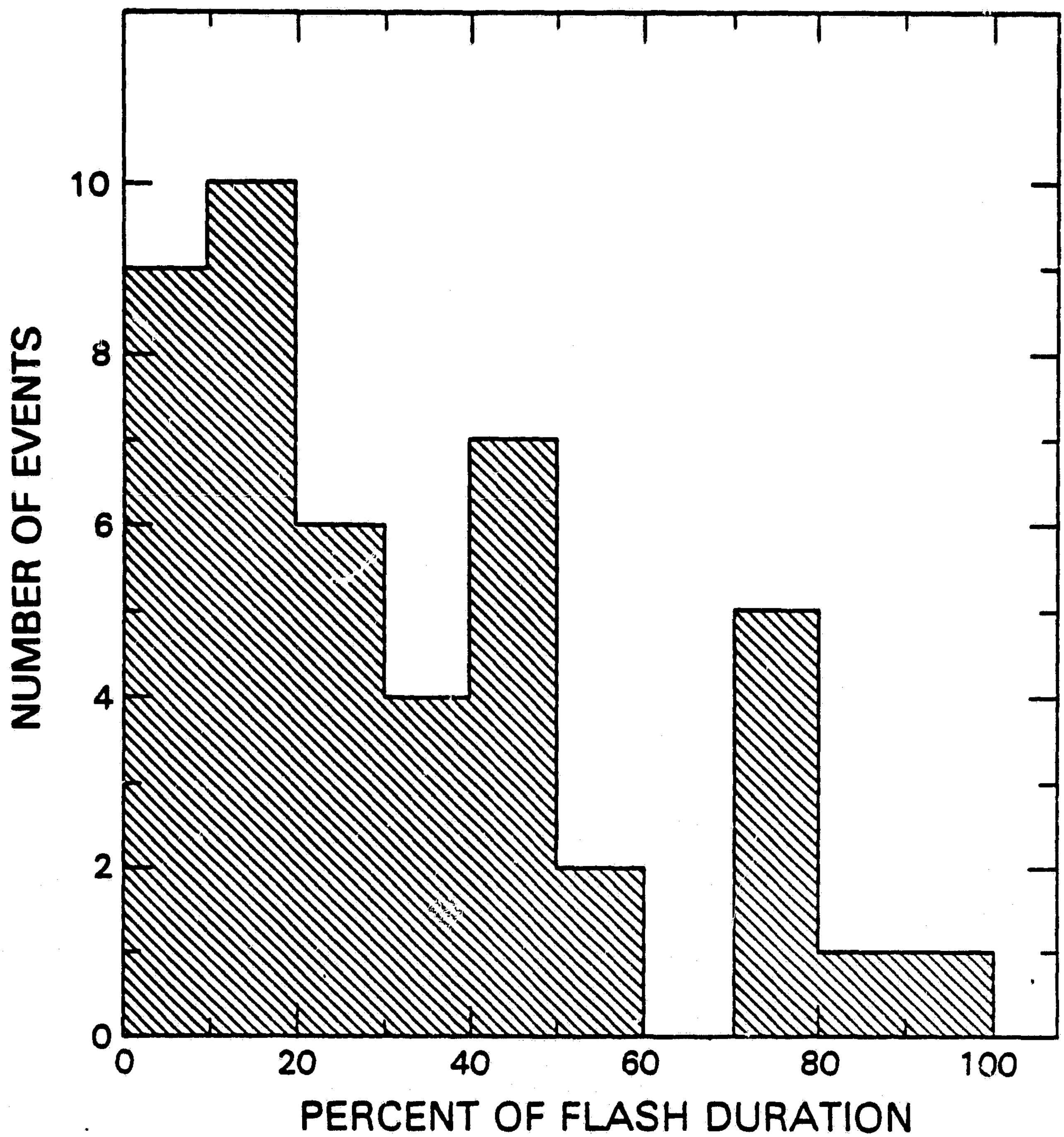

Figure 12. The occurrence of events reported by the aircraft measured from the beginning of the flash as a percentage of the flash duration.

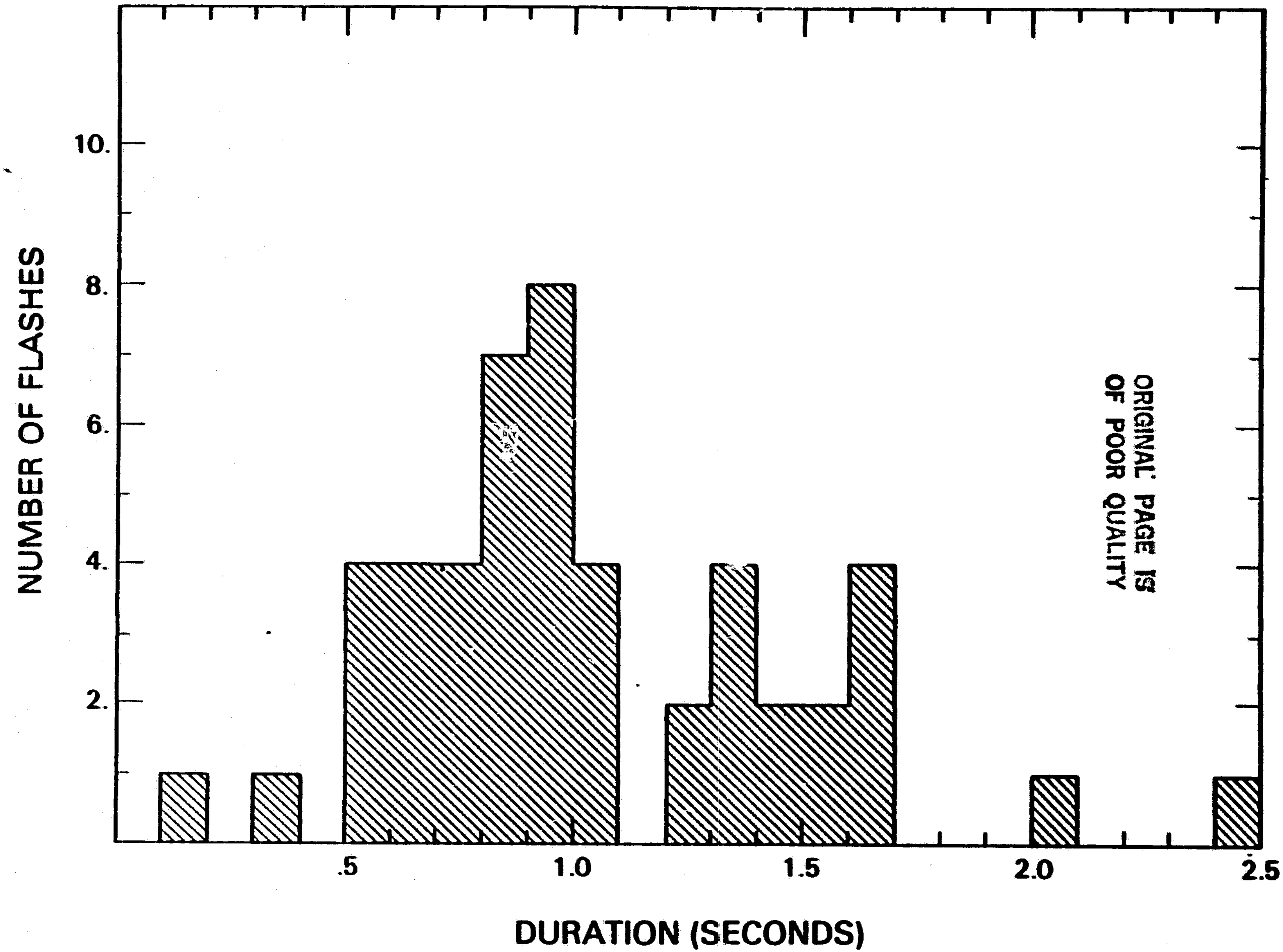

Figure 13. Distribution of flash durations for those flashes for which events were recorded by the aircraft and RF radiation was received on the ground. The durations were measured from the records of 3 MHz radiation.