An Airborne Precipitation Cloud Particle Charge Measurement Device and Analysis System

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ABSTRACT

A system is described for measurement and analysis of precipitation particle charge from an aircraft in the highly variable and harsh environment of a convective cloud. A compromise, practical instrument design enables particle charge and sign to be measured with concentrations up to 5 L^{-1}. The system employs two induction rings in series; it is de-iced both on the electrostatic shield and internally. New techniques are described which enable rapid analysis of sequential charge data over a penetration period of 55 s, with rejection of spurious data pulses resulting from particle impaction.

1. Introduction

During the last few years, there has been growing interest in linking the electrical development of thunderstorms with cloud growth and development, using cloud physical measurements performed aboard instrumented aircraft. In particular, a need has arisen to measure the electric charge carried on precipitation particles in order to determine which types of particle carry charge and to determine the sign and magnitude of these charges from the viewpoint of inferring possible charge generation mechanisms.

Ideally, we need to measure particle charge, type and dimension simultaneously and obtain statistically meaningful data over regions of cloud where other environmental parameters—liquid water and vertical velocity—are changing significantly. In a typical cumulonimbus, this measurement presents a major challenge since such variations are often important on a scale of less than 100 m. The purpose of the present paper is to seek the best compromise for available technology.

2. General charge sensor design principles

Pioneering measurements of the electric charge on precipitation particles were made by Gunn (1947, 1948, 1950), who measured the charge induced on a metal tube due to a charged particle passing through the tube. Similar methods have been used by MacCready and Proudfit (1965), Latham and Stow (1969), Gaskell et al. (1978), and Christian et al. (1980). The same technique was used in the present study. One of the major difficulties is to ensure that the charge pulses produced by particle collision and separation with the leading edge or wall of the induction tube are not accepted for analysis. By the very nature of the experiment, the front edge of the tube has to be exposed, and cannot be completely shielded from the environmental electric field. Thus, a particle that splashes on the leading edge may become charged, possibly enhanced in the presence of the ambient field, and then carry its charge through the tube. In order to shield the primary region of the tube from the environmental electric field, a guard ring, with a diameter greater than that of the sensing tube, is mounted upstream. This must be positioned such that particles cannot bounce into the tube from the guard ring.

3. Mechanical and electrical design

The geometrical design of the tube was controlled by the requirement that only one charged particle should be in the tube at any one time in order to avoid pulse overlap. Consideration was given also to the fact that a wide tube would require a correspondingly wide shield from the ambient electric field and that a short, wide tube would not trap as many electric field flux lines from a charged particle as a long thin tube. The sample volume chosen was 166 liters per second for a typical airplane speed of 100 m s^{-1}, which gave the possibility of pulse overlap in regions of particle concentration in excess of 5 L^{-1}.

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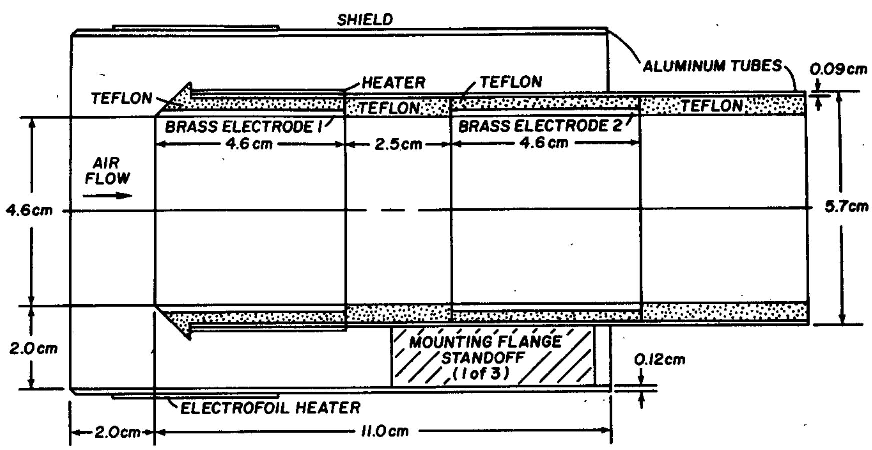

FIG. 1. Cross-sectional view of the particle charge measurement induction tube.

The charge tube is shown in Fig. 1. An innovation of this design is the flush mounting of the inner charge-sensing electrode within the outer electrostatic shield, the two being separated by an insulating layer outside of which is mounted a thin foil heater (370 W) to de-ice the device in regions of high liquid water content. A similar heater keeps the shield ice free.

The charge tube was mounted on the nose of an Aerocommander airplane so that the tube was horizontal in level flight. Calculations showed that particles larger than several hundred micrometers in size, which were expected to be the charge carriers, would not have time to follow the airstream up over the nose of the airplane and would pass through the tube nearly horizontally, albeit with an angle to the horizontal set by their fall velocity and the aircraft velocity. A certain fraction of the particles encountered were expected to collide with the tube due to their fall within the tube and to the finite response time of the aircraft to changes in vertical velocity as it encountered regions of the cloud with different updrafts and downdrafts. Examination of data from in-cloud penetrations shows that about 10% of all particle passages impact on the induction tube, which agrees with a calculation of the number falling to the floor of the tube during transit.

Figure 2 shows the circuit design. The time constant of the circuit was designed to be shorter than the particle passage time so that a characteristic pulse shape was produced by a clear passage and was uninfluenced by small variations of aircraft speed. A second advantage of the short time constant was that the DC output baseline level was rapidly restored after excursions due to splash events.

The induction tube was connected to a pre-amplifier that was mounted as closely as possible to the tube to reduce microphonic noise. Its low impedance output was further amplified with variable gain inside the aircraft. The on-board scientist was able to select the appropriate gain by watching the induced voltage pulses on an oscilloscope; he was also required to note the tape recorder frame counter number and the time before and after each cloud penetration. The pulses were frequency modulated, permitting them to be stored on

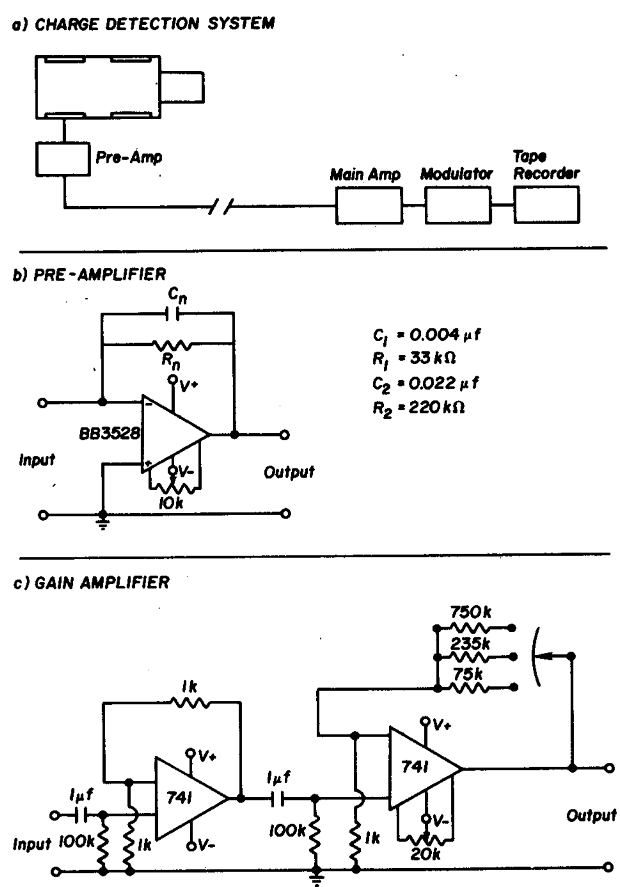

FIG. 2. (a) Schematic diagram of charge detection system. (b) Pre-amplifier circuit diagram. (c) Gain-amplifier circuit diagram. For (b), $C_1R_1 = 0.13$ ms, $C_2R_2 = 5$ ms, time constants of the first and second induction tubes respectively.

a simple analog cassette tape system with a minimum of distortion. On playback for analysis, the original pulses were restored by a frequency to voltage converter. On-board amplification of the pulses was adjusted so the recorded voltages were in the range from −4 to +4 volts, which were converted to frequencies in the range 9000 ± 3000 Hz.

Because of the use of a short time constant, before the charge sensor could be used in the field, it was necessary to calibrate it to relate the particle charge values to the recorded voltages. The system was calibrated in the laboratory by projecting, with a CO_2 gun, charged pellets through the tube at aircraft velocity, a technique used by Gunn (1947). The pellet charge was determined by catching the pellets in a Faraday-can connected to a calibrated electrometer. As a further test, water drops carrying known charges were dropped through the tube. In this case, the time constant of the pre-amplifier was adjusted to have the same fraction of the passage time as for the airborne measurements. At an airplane speed of 100 m s^{-1}, the nominal passage time of a particle through the tube is 0.46 ms, compared to the time constant of 0.13 ms. Thus, a clear passage by a charged particle produces an easily recognizable induced waveform with excursions to either side of the preceding DC level, as shown in Fig. 3. A particle splashing or shattering on the tube results in a unidirectional pulse and recovery which clearly identifies the event.

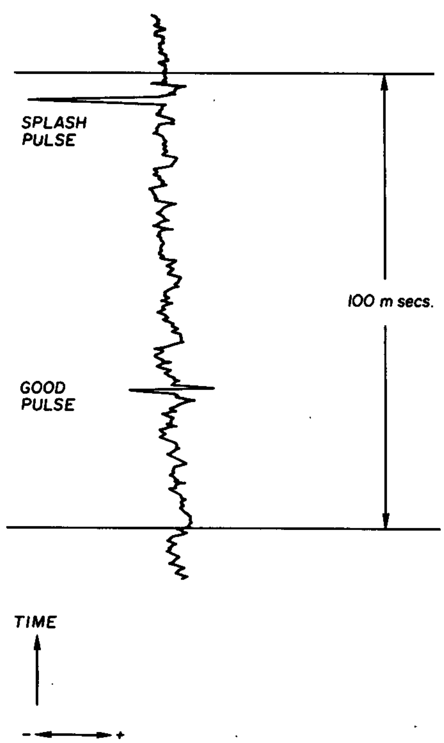

FIG. 3. Voltage output from the charge detection system showing the pulse from a clean passage and that produced by a splash.

A second induction tube was mounted behind the first for the purpose of providing further confirmation of a clear passage. This tube was connected to a preamplifier having a time constant ten times longer than the passage time so that a clear passage induced a voltage of one sign only with a pulse time of the same order as the passage time; a splash, however, produced a pulse with a long recovery time. For this tube, the relationship $C = kQ/V$ holds, where C is the input capacitance, Q the charge as the particle, V the induced voltage and k a factor which accounts for the tube geometry which may be found by theory or experiment. For a particle in the center of a tube having equal values of length and diameter, k is approximately 0.71; however, at the edge of the tube, $k = 1$ which leads to an uncertainty in the charge value of about 20%. Analysis of the data confirmed that the first tube alone proved sufficient to discriminate between a clear passage and a splash. A problem with the second tube was that it provided an increased probability for splashing to occur, and thus a smaller percentage of data from the second tube was useful. However, the second tube was invaluable in confirmation of the validity of the data from the first tube.

Three amplifier gains were provided so that the onboard scientist could ensure that the charge pulses would be recorded at a level that avoided both saturation and signals too small to resolve. For these three gains, a voltage output of 1 volt peak to peak corresponded to charges of 5.3, 16.9 and 53.5 pC. Charges of these magnitudes would produce a peak pulse of ⅙ V in the second tube. The minimum detectable signal was controlled by the effective noise level, which was principally due to particles splashing on the tube. These splash events may be due to small particles, whose trajectories were altered by the airflow up over the nose of the airplane. This supposition is supported by the low noise level noted while flying out of cloud. The minimum detectable signal was 2 pC, while the maximum, which was never observed, was 200 pC.

4. Data analysis

For the instrument to provide a comprehensive body of precipitation particle charge data, it is important to examine complete cloud transits. This allows the detection of charged regions and determination of their spatial extent, and allows acquisition of a sufficient number of data points to express meaningful results. Our initial attempts to use a visicorder (ultraviolet pen recorder) required a chart paper speed of 1.3 m s^{-1} to resolve pulses, and thus it was quite impractical to acquire data for complete cloud passages. A more satisfactory data analysis system was developed using an Apple microcomputer to store data and display selected portions on a CRT monitor.

The Apple II Plus microcomputer was configured with 64K bytes RAM memory, an R.C. Electronics

TABLE 1. The total number of positive charges (N+) and negative charges (N−); the means ($\bar{Q}$+, $\bar{Q}$−) and standard deviations (σ+, σ−) of the positive and negative charges; the total positive (+ΣQ) and total negative (−ΣQ) charge; and the net charge for given sample volumes each extending over ~300 m in a single cloud pass.

Start time	Sample volume (L)	N+	N−	$\bar{Q}$+ (pC)	σ+ (pC)	$\bar{Q}$− (pC)	σ− (pC)	+ΣQ (pC)	−ΣQ (pC)	Net charge (C km^{-3})
1429:24.60	335.3	10	35	24.61	9.52	31.05	11.01	246.1	1086.7	−2.51
27.36	362.9	9	35	12.05	6.02	20.11	7.73	108.43	703.7	−1.64
30.12	385.3	8	13	11.66	4.10	22.02	10.44	93.28	286.25	−0.5
32.88	335.3	2	17	8.34	1.07	14.3	6.75	16.68	243.05	−0.68
35.97	301.3	10	48	14.03	11.44	24.27	12.38	140.27	1165.14	−3.4
38.40	379.6	2	64	12.52	10.19	22.22	10.74	25.03	1422.17	−3.68
41.16	385.6	2	47	11.76	5.37	23.23	11.96	23.51	1091.97	−2.77
44.09	277.7	3	3	3.66	1.16	13.9	13.12	10.99	41.71	−0.11
46.71	48.47	0	3	0	0	3.79	0.66	0	11.37	−0.23

two-channel, eight-bit storage oscilloscope (APL D-2), and an Axlon Ramdisk, which provided 320K bytes of data storage.

The APL D-2 consists of two circuit cards that plug into two of the computer peripheral slots. This hardware and the Scopedriver 3.0 software, provided by the manufacturer, convert the computer into a dual channel storage oscilloscope, with screen display and keystroke control of the oscilloscope operation. The input signal voltage range is ±9.08 V, with individual data points quantitized at 71 mV intervals.

The Ramdisk contains 320K bytes of storage, accessible as 256 byte pages. It is used to store twenty 16K blocks of data. Since Scopedriver software does not allow use of disk storage during its data input phase, a new Scopedriver command was implemented to copy data to Ramdisk during input.

The Scopedriver software allows the operator to position two vertical cursors on the screen, and displays the times and voltage levels of the signal at the cursors, along with delta time and delta voltage. Another Scopedriver command was developed to print this information in response to a keystroke.

The Scopedriver patches[1] were implemented in 6502 assembler language, modifying the keystroke reading code to recognize the new commands and to branch to appropriate new subroutines. Also, a patch to the data collection code checks each time a 16K block of data has been collected whether the flag to save to Ramdisk has been set by previous command. If so, the data is copied to Ramdisk and a new 16K block of data collection is initiated.

When the Ramdisk is filled, data acquisition terminates. A 7 kHz sample rate is sufficient to resolve waveform characteristics and charge magnitudes. Thus, the 20 Ramdisk buffers hold 46.8 seconds of data, which requires 55 seconds of real-time data input.

Each Ramdisk buffer is then in turn copied back into the Scopedriver data buffer for data screening. The data are scanned and, when a good pulse is detected, the cursors are set and the data is printed. In this manner, several days may be taken to evaluate the data from a single cloud pass without losing one's place in the cloud.

Measurements of particle charge in Montana thunderstorms have been made using this charge detection system. Some of the data obtained have been analyzed and reported by Gardiner et al. (1985) and Dye et al. (1986). Table 1 gives an indication of the information available with the system from a single pass through a cloud. In a given sample volume, for each sign of charge, the numbers, mean charge, standard deviations of the charge values and total charges can be determined.

5. Conclusion

An airborne system has been developed to record and analyze the charges carried on precipitation particles inside a supercooled cloud. The data acquisition system permitted the continuous collection of charge data during a cloud pass. The analog recording technique proved satisfactory but led to tedious data reduction. A high capacity storage unit was used to gather 20 successive 2.76 second intervals (2.33 seconds data, 0.43 seconds dead time) through the cloud. This technique permitted detailed analysis of charge events during a pass and also preserved the relative positioning of all detected events.

The information on individual charge values has been used to determine total electric charge densities in clouds whose sign, magnitude and position can be included with the other cloud microphysical information gathered simultaneously, to provide a comprehensive dataset which will lead to a better understanding of electrification processes in convective clouds.

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[1] Specific code changes are available from the authors on request. Address inquiries to R. Pitter.

REFERENCES

Christian, H., C. R. Holmes, J. Bullock, W. Gaskell, A. J. Illingworth and J. Latham, 1980: Airborne and ground-based studies of thunderstorms in the vicinity of Langmuir Laboratory. *Quart. J. Roy. Meteor. Soc.*, **106,** 159–174.

Dye, J. E., J. J. Jones, W. P. Winn, T. A. Cerni, B. Gardiner, D. Lamb, R. L. Pitter, J. Hallett and C. P. R. Saunders, 1986: Early electrification and precipitation development in a small isolated Montana cumulonimbus. *J. Geophys. Res.,* **91,** 1231–1247.

Gardiner, B., D. Lamb, R. L. Pitter, J. Hallett and C. P. R. Saunders, 1985: Measurements of initial potential gradient and particle charges in a Montana summer thunderstorm. *J. Geophys. Res.,* **90,** 6079–6086.

Gaskell, W., A. J. Illingworth, J. Latham and C. B. Moore, 1978: Airborne studies of electric fields and the charge and size of precipitation elements in thunderstorms. *Quart. J. Roy. Meteor. Soc.,* **104,** 447–460.

Gunn, R., 1947: The electrical charge on precipitation at various altitudes and its relation to thunderstorms. *Phys. Rev.,* **71,** 181–186.

——, 1948: Electric field intensity inside of natural clouds. *J. Appl. Phys.,* **19,** 481–484.

——, 1950: The free electrical charge on precipitation inside an active thunderstorm. *J. Geophys. Res.,* **55,** 171–178.

Latham, J., and C. D. Stow, 1969: Airborne studies of the electrical properties of large convective clouds. *Quart. J. Roy. Meteor. Soc.,* **95,** 486–500.

MacCready, P. B., and A. Proudfit, 1965: Observations of hydrometer charge evolution in thunderstorms. *Quart. J. Roy. Meteor. Soc.,* **91,** 44–53.