THE EFFECT OF AEROSOLS ON THE ELECTRICAL CONDUCTIVITY IN THE ATMOSPHERE (*)

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Summary — The value of the electrical conductivity of the free atmosphere is inversely related to the concentration of nuclei. Measurements made with an airborne conductivity meter illustrates this effect. It was found that for these particular meteorological conditions a change of 47 nuclei/cm^3 could be detected. It was also found that in one case nuclei from a smoke source were carried down wind for a distance of 400 miles. The concentration of nuclei varied from 14.6×10^3 nuclei/cm^3 near the source to $1{\cdot}3 \times 10^3$ at the distant location.

In 1948 a research program was initiated by USAF Cambridge Research Center to study the electrical conductivity of the atmosphere at altitudes ranging from sea level to approximately 40,000 feet. The development of an airborne conductivity meter (1) required hundreds of hours of flight testing under different meteorological conditions. It had been noted during this period of testing that the values of conductivity depends on the turbulence of, on the relative and absolute humidity of, and on the concentration of the contaminants within the sampled air. Some of these effects have been reported in the literature (2,3,4).

The object of this paper is to present two striking examples showing the effect of aerosols on the electrical conductivity of the atmosphere. They suggest possible applications of the airborne conductivity meter as an instrument not only to detect pollutants in the atmosphere but also to study their time-behavior.

The record shown in Figure 1 was taken on July 11, 1950 with an instrument installed in a B-17 aircraft. Its altitude was 2500 feet and its ground speed was 180 miles per hour. Figure 1 is a reproduction of the actual graph recorded on a « Brown Electronic Recorder ». It is a typical record taken under a particular meteorological condition, namely on a clear summer day, around noon. The air at 250 feet was slightly turbulent as evidenced by the bumpiness of the aircraft.

The graph shows that as the B-17 proceeds from right to left the value of conductivity increases until it reaches *C* where a slight but abrupt decrease in value

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occurs. At D an abrupt large decrease in value takes place. The decrease in value is attributed to the presence of smoke particles within the sampled air. At C the smoke was not visible; whereas, at D, approximately 1 mile distant from C a white cloud of smoke was present. The source of the smoke was a chimney below.

The electrical conductivity λ is defined as

$$\lambda = nek \tag{1}$$

where

n = the polar concentration of ions per cm^3,

e = the electrical charge in ESU,

k = mobility of ions in ESU.

The interval of measurement for events C and D are of the order of 5 seconds. During this short time interval the concentration of large ions N (nuclei) will not change perceptibly. Hence, equilibrium conditions can be assumed. Under these conditions, the concentration of small ions, n, is given by

$$q = \alpha n^2 + \beta N n \tag{2}$$

where

q = the rate of production of ions,

α = the recombination coefficient between small ions,

β = is a function of combination coefficients for collisions between small ions and nuclei and of the ratio of uncharged to charged nuclei (see Ref. [3])].

From equations (1) and (2) we get

$$\lambda = ek \frac{\beta N \pm (\beta^2 N^2 + 4\alpha q)^{\frac{1}{2}}}{2}. \tag{3}$$

Equation (3) shows that as the value of N increases, the value of conductivity decreases.

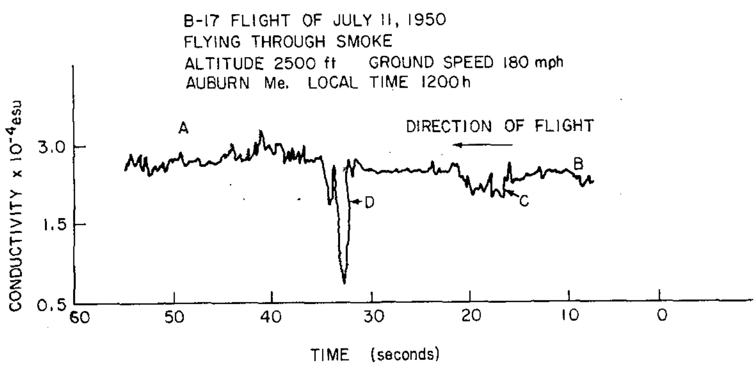

Fig. 1 - *Effect of Smoke on Conductivity.*

The computed value of N is shown in Table 1 for various sections of the curve of Figure 1 using equations (1) and (2). The value of q was taken from Figure 6, p. 195 of FLEMING [5].

Table 1 shows that the source of smoke nuclei was at D. The change in value of nuclei from A to D was from 390 to 1210, an increase of 820. This change corresponds to a change in conductivity value of 1.7×10^{-4} ESU. The instrument can measure 0.1×10^{-4} ESU very accurately. Under these conditions the instrument is capable of detecting a change of 47 nuclei/cm³.

TABLE I - *Computed Values of N for Figure* 1.
$\alpha = 1.6 \times 10^{-6}$; $\beta = 2\alpha$; $q = 7.6$; $k = 1.5$ cm²/sec V

Part of curve	λ ESN	n ions/cm³	N nuclei/cm³
A	2.6×10^{-4}	13.8×10^2	390
B	2.25×10^{-4}	12.0×10^2	580
C	2.1×10^{-4}	11.1×10^2	710
D	0.9×10^{-4}	4.8×10^2	1210

C represents another pocket of smoke nuclei. These were not visible from the aircraft. The peak value of nuclei/cm³ at C is 710, a decrease of 500 from the peak value of D. In the interval of time required by the smoke to travel from D to C, a distance of 0.75 miles, the nuclei have suffered considerable dispersion or settling. In high concentrations, smoke and other aerosols tend to coagulate to form large particles which settle according to gravity and STOKES' Law. This rapid decrease indicates that the lapse rate was high which is to be expected for this particular meteorological condition around noontime, when the measurements were made. Generally, when the lapse rate is high, particles of smoke or aerosols will be diluted rapidly because the air is in a state of instability.

The other example illustrates night-time conditions. During the night the con-

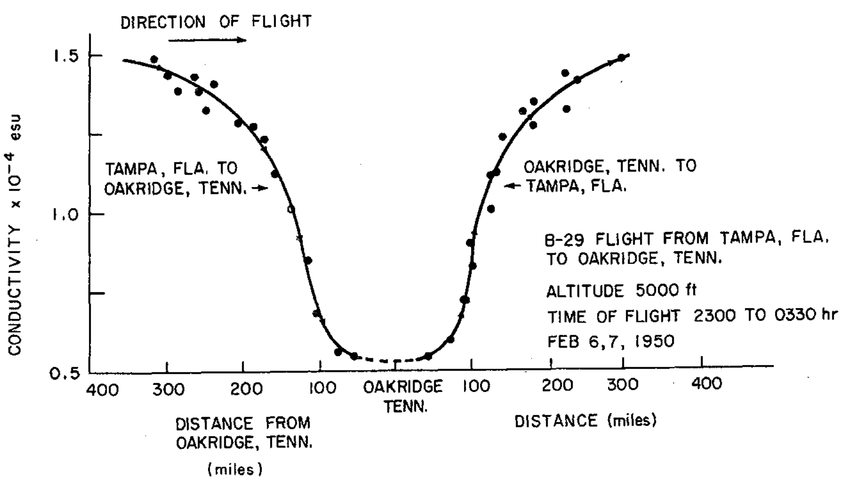

Fig. 2 - *Effect of Aerosols on Electrical Conductivity of the Atmosphere.*

taminants over large cities are trapped beneath and within the inversion layer ([6]). Furthermore, large scale atmospheric motion transport nuclei at an average speed of wind. The smaller the wind speed the more concentrated are the pollutants, provided the pollutant source is a continuous one ([7]). In other words, the concentration of pollutants away from the source decreases slowly with time. An excellent example of these principles is shown by the curve in Figure 1. This curve was plotted from a conductivity record obtained with the same airborne conductivity meter installed in a B-29 aircraft. The flight originated at McDill Air Force Base, Florida at approximately 2300 on February 6, 1950 and proceeded at a constant altitude of 5000 feet toward Oak Ridge, Tenn. at an average speed of 195 miles per hour. Soon after takeoff the conductivity value began to decrease slowly with time and became more rapid as we approached the source where the minimum value was obtained. At this point, the aircraft changed the direction of its course by 180° and headed back for McDill Air Force Base, Florida. During this segment of the flight the conductivity value increased with increasing distance from Oak Ridge. The duration of the flight was 5 hours and 30 minutes.

The remarkable feature of the data is that during a period of up to 4 1/2-hours the concentration of nuclei for any particular volume along the flight path remained constant. In other words, the divergence of the nuclei concentration was zero, indicating an extremely stable atmosphere. Furthermore, it indicates although no radiosonde data have been analyzed that the aircraft was immersed throughout its flight path in or below the inversion layer where the nuclei were trapped.

The computed values of nuclei concentration for distance from the source are shown in Table II.

The value of $q = 5$ ions/sec; $k = 1.5$ cm^2/sec-volt, $\alpha = 2.1 \times 10^{-6}$ cm^3 sec^{-1}; $\beta = 2\alpha$.

TABLE II - *Computed Values of Nuclei/cm³ versus Distance From Source* (Oak Ridge).

Distance From Source Miles	Nuclei/cm^3 $\times 10^3$
50	14.6
100	4.8
150	1.9
200	1.6
300	1.4
400	1.3

Near the source the nuclei concentration is very high. Its value decreases by a factor of 3 for the next two successive 50 miles after which the decrease is gradual.

It has been shown that since there exists an inverse relationship between electrical conductivity and nuclei concentration [see equation ([3])] the airborne conductivity meter can be employed as a method for measuring the degree of air pollution and for estimating the effectiveness of atmospheric diffusion in dispersing particulate contaminants. It can also be used to measure turbulence.

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