NOTES AND CORRESPONDENCE

Perturbations Produced by Jet Aircraft in the Earth's Electric Field[1]

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1. Introduction

It is well known that measurements of the vertical electric field (potential gradient) at the surface of the earth are influenced by space charges produced by human activities. Mühleisen (1956), among others, has identified the perturbing effects of the charge in the smoke clouds from railway locomotives, and of the space charge in motor car exhausts. Jet aircraft can also generate exhaust charges, while in addition the aircraft itself, when in flight, carries an appreciable electrical charge. This note examines the influence of these charges upon field measurements at the ground.

When the engines of a jet aircraft are running, the exhaust carries away a positive charge, while the corresponding negative charge passes to the aircraft. For water-injected engines, the current may approach 500 microamperes (μa), and even with "dry" operation 100 μa is attained.[2] Under fair weather flying conditions, the negative charge upon the aircraft builds up until a potential is reached at which corona currents from the aircraft approximately balance the engine charging current (Pierce, 1958). This equilibrium potential is of the order of 10^5 volt negative; since a typical aircraft capacitance is 10^{-9} farad, the equilibrium negative charge is some 10^{-4} coulomb[2].

Natural agencies modify the simple balance between engine and corona current. The triboelectric currents generated during the passage of an aircraft through clouds and precipitation can be several milliamperes. However, in fair weather circumstances—which will be assumed for the remainder of this note—the currents of meteorological origin are apparently small as compared with the engine current. Two such meteorological currents may be identified. The space charge current caused by the collection by the aircraft of the natural atmospheric space charge is $VA\rho$, where V is the aircraft speed, A its cross-sectional area and ρ the space charge density. Direct measurements, such as those by Clark (1958) and by Moore *et al.* (1962), indicate that it is unlikely for ρ to exceed 20 electronic charges per cm^3 or 3.2×10^{-12} coulomb m^{-3} in clear daytime air. The speed V may be taken as perhaps 250 m sec,$^{-1}$ while 150 m^2 is a very generous estimate for A. Thus the space charge current is only of the order of 0.1 μa. A more significant current also of meteorological origin is the ionic conduction current. If Q denotes the negative charge upon a conductor in the atmosphere and λ_1 is the conductivity for positive ions then the ionic conduction current dQ/dt attempting to neutralize the charge Q is given by $dQ/dt=\lambda_1 Q/\epsilon_0$ where ϵ_0, the permittivity of free space, is $10^{-9}\times1/36\pi$ farad m^{-1}. At the surface of the earth λ_1 is of the order of 10^{-14} ohm^{-1} m^{-1} (Chalmers, 1957), while it is unlikely to exceed 10^{-12} ohm^{-1} m^{-1} (Clark, 1958) below the ceiling of operation for conventional commercial jet aircraft. Thus with a charge of 10^{-4} coulomb the ionic conduction current ranges from about 0.1 μa at ground level to some 10 μa at maximum aircraft altitude. Hence, both the space charge and the ionic conduction currents are usually small in comparison with the engine charging current.

2. Experimental observations

Measurements of the vertical electric field at the surface of the earth were made under clear daytime conditions at San Francisco International Airport on 28 October 1963. Conventional field-mills (Chalmers, 1957) were employed.

Considerable changes from the ambient field level (+300 v m^{-1}) were detected. Observations at the edge (30 m from the center) of a take-off runway showed that a transient positive field-change of some +200 v m^{-1} was associated with the taxiing past of turboprop and turbojet aircraft. If the craft were airborne (even just following take-off) the change in field was initially negative (*ca.* −100 v m^{-1}) with a quick return to the ambient level; this was often succeeded by a considerable positive overshoot. Some examples of these variations are given in Fig. 1. Measurements at a distance of 100 m from the runway showed only positive deflections

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[2] R. L. Tanner, and J. E. Nanevicz, 1961: Precipitation charging and corona-generated interference in aircraft. Technical Report 73, SRI Project 2494, Air Force Contract AF 19(604)-3458, Stanford Research Institute, Menlo Park, Calif.

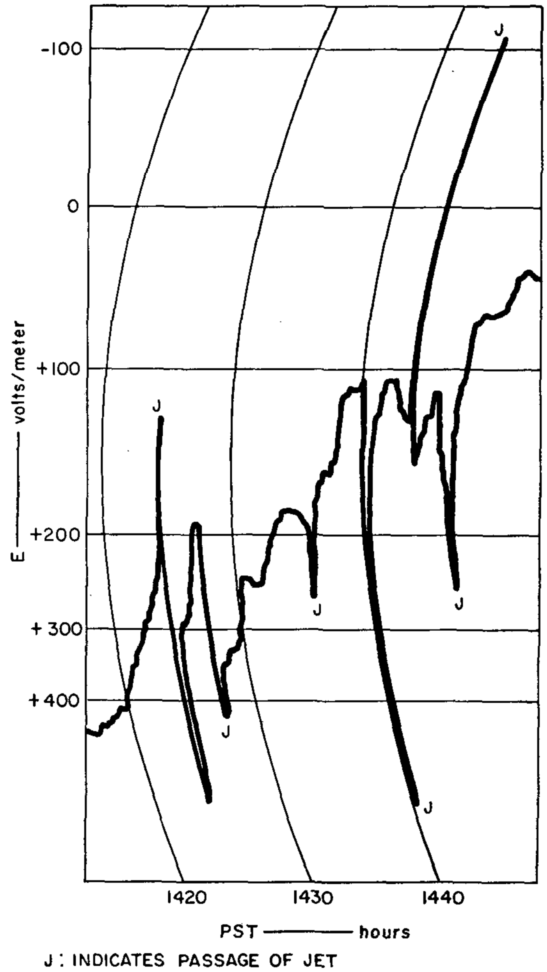

FIG. 1. Portion of typical field-mill record illustrating effects associated with jet aircraft.

(*ca.* +100 v m^{-1}) irrespective of whether the aircraft taking off was airborne or not. The onset of these field changes was delayed and their form less abrupt, when compared with the measurements at the edge of the runway.

Some very interesting observations were made at the approach end of a landing runway. Aircraft coming in to land passed over a field-mill at a height of some 40 m and typically produced a negative field charge of about -300 v m^{-1}. The change in field from the ambient was always unilateral without any indication of a positive excursion. If the change in field is assumed to be due to a negative charge on the aircraft then electrostatic theory—taking into account the disturbance of the natural electric field by the conducting aircraft—enables the charge on the aircraft to be estimated. The results for a varied selection of turbojet aircraft were remarkably consistent. Thirteen aircraft gave charges ranging from -2 to -37 microcoulomb and in ten of these instances the deduced charge lay between -28 and -37 microcoulomb.

3. Discussion

The interpretation of the results is straightforward. When taxiing under power the engine current is large so that the positive space charge of the exhaust can produce considerable unilateral positive changes in field. Diffusion of the exhaust charge—as with other meteorological impurities—enables its influence to extend to points remote from that of generation.

As soon as an aircraft becomes airborne the negative current, corresponding to that of the positive exhaust, ceases to flow to earth and acts to charge the aircraft. With an engine current of 100 μa, only a second is needed to build up a charge of 10^{-4} coulomb. Thus the observation, soon after take-off, of a negative field change followed by a more protracted positive excursion, represents passage of a negatively charged aircraft trailed by a positive exhaust cloud.

It is interesting to note that there is no indication of any trailing positive cloud when the aircraft is approaching to land. This probably implies that engine power has then been considerably reduced or completely shut down, so that the engine current is almost eliminated. Under these circumstances the equilibrium negative charge, established before engine shut down, is being dissipated by the space charge and ionic conduction currents. The relaxation time (ϵ_0/λ_1) for the latter is perhaps 15 minutes near ground level, while,—as already indicated—unless the space charge is abnormally large, it will again occupy some 15 minutes for the space charge current to neutralize a charge of 10^{-4} coulomb. Thus the presence of many microcoulombs of negative charge upon jet aircraft approaching to land is understandable, although the consistency of the observed charge magnitudes is somewhat surprising.

Finally, it is perfectly feasible by combining electrostatic theory and the observations from a network of field mills to locate quite accurately the height and location of a landing aircraft as a function of time. Thus the perturbation of a standard meteorological measurement has an immediate application of possible practical importance.

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