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# Unmanned Air Vehicle Wing-Tip Corona Nonlinear Effect on Atmospheric Electric Field Measurements

Xingya Da,* Huairong Shen,† Lei Hong,‡ and Rui Zhang§
*Academy of Equipment Command & Technology, 101416 Beijing, People's Republic of China*

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**The use of aircraft to measure the electric field in clouds has been ongoing for several decades to study electrification mechanisms of clouds. However, the measurements have been problematic partially due to corona emissions at sharp metallic points. The demand for reliable, robust, and precise measurements requires the study of the corona effect in theory rather than based on uncertain measurements. By using numeric studies of the TF-1 unmanned air vehicle employing four electric field mills, problems caused by wing-tip corona emissions are presented in this paper. The wing-tip corona current model, of net charge $Q$, field component $E_y$, and wind speed $w$, is established based on a space-charge-limited method. Numerical results indicate wing-tip corona effects are nonlinear and are proportional to $E_zQ$ and $E_zE_y$. Field component $E_x$ is more problematic to retrieve than other field components whether or not the field mills are located downstream of the plume when corona ions are present. To improve measurement precision, it is necessary to consider the nonlinear corona effect and detect definitely when and where corona ions are emitted, especially for manned aircraft.**

## I. Introduction

MEASUREMENTS of atmospheric electric fields in clouds and storms greatly contribute to the differentiation between those electrification mechanisms advocated in the last few decades or more. However, the mechanisms whereby clouds become electrified and lightning is produced are not satisfactorily understood. To solve this problem, aircraft have been widely applied in measuring fields in clouds and storms, such as the T-28 of the South Dakota School of Mines and Technology [1]; the Special Purpose Test Vehicle for Atmospheric Research of the New Mexico Institute of Mining and Technology [2,3]; and the Altus [4], Lear 28/29 [5–7], and others of NASA in the past few decades. Using aircraft to measure electric fields is theoretically simple; however, obtaining reliable and robust electric field measurements is rather complex due to the difficulty in designing and calibrating field mills, as well as the difficulty in determining the effects caused by corona emissions and so on. The latest field mill designed by the NASA Marshall Space Flight Center and the University of Alabama in Huntsville currently has excellent performance exhibiting high sensitivity, wide dynamic and measurement ranges, and very low noise [8]. Field mill calibration, the core of aircraft electric field measurements, is an intricate process; it is difficult to acquire robust and convergent input–output relations, namely, the relations between the ambient field, net charge, and the mills' outputs. In the 1990s, many effective methods were proposed [5,9]. Koshak's latest calibration method [6] can retrieve storm fields within an error of 12% in simulations [7] and takes into consideration the errors in the field measurement and the mean fair-weather field function. Another method proposed by Mach and Koshak [10] can converge after a few iterations. These improvements make the measurements more reliable and robust.

In contrast, problems caused by corona emissions are difficult to determine by directly analyzing aircraft field measurements [1–3]. Information about the place and time that corona ions were emitted, as well as the magnitude of the corona current, is essential to determine the corona effects. Unfortunately, using aircraft field measurements in these corona-predicting and corona-calculating processes is not an easy (and is perhaps an impossible) task. How corona emissions affect field measurements is still a question to be answered.

Currently, attempts are underway to apply the TF-1 unmanned air vehicle (UAV) to the measurement of atmospheric electric fields. The TF-1 is China's first-generation aeroexploration UAV, designed to measure meteorological data such as wind speed, temperature, pressure, and humidity. Additional information on the evolving charge structure of electrified clouds can be obtained if the TF-1 is used to measure the field. Yet, before taking a flight test, it is necessary to understand the corona effects. Rather than a measurement-based study, we have chosen to conduct a theoretical study, motivated by the physics that corona discharge is determined by the electric field distribution around the corona point. In this paper, we will present our theoretical study on the corona effects at the wing tip, where corona emission is most likely to take place. The road map for this paper can be found in Fig. 1, which itemizes the general ideas of the theoretical study. Because the field distribution around the wing tip is essential to calculating the wing-tip corona current, the first key task is the computation of the electric field for the aircraft, as seen in box A. Furthermore, the tasks in boxes A and B have been completed in previous works [11–13]. Therefore, we will not pursue the details of those two boxes in this paper, but only briefly introduce the methods that were used. Details of boxes C, D, and E will be presented.

## II. Field Computational Method for Aircraft

Because the corona discharge is determined by the field distribution around a corona point, the first task is to compute the electric field distribution around the wing tip, namely, the process in box A of Fig. 1. The field computational method for aircraft used in this paper establishes the computational model of the electric field, which can be expressed as

$$\boldsymbol{E} = \boldsymbol{C}[E_x \quad E_y \quad E_z \quad Q]^T \tag{1}$$

where $\boldsymbol{C}$ is a $3 \times 4$ matrix called the electric field enhancement factor; $E_x$, $E_y$, and $E_z$ are the field components in the aircraft body frame (see Fig. 3); and $Q$ is the net charge on the surface. The numerical computational method for $\boldsymbol{C}$ is based on the method of moments. At the core of the computational method for $\boldsymbol{C}$ is the use of symmetrical surface meshing and the solution of the systems of electric potential equations based on eigenvalue decomposition. These

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*Postgraduate, Postgraduate College; Dxingya@gmail.com.

†Professor, Department of Aeronautics; Shenhuair@tom.com.

‡Postgraduate, Postgraduate College; Redleilei@163.com.

§Teaching Assistant, Key Laboratory; Mary1984@126.com.