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Electric discharges produced by clouds of charged water droplets in the presence of moving conducting object

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ABSTRACT

The possibility of initiation of electric discharges by a crossbow bolt (projectile) moving in the electric field of a cloud of negatively charged water droplets has been demonstrated for the first time. Over one hundred of discharges have been produced. For each event, a high-speed video camera recorded the images of upward positive leaders developing from both the nearby grounded sphere and the projectile, followed by the return-stroke-like process. Corresponding currents were measured and integrated photos of the events were obtained. The results can help to improve our understanding of lightning initiation by airborne vehicles and by a vertical conductor rapidly extended below the thundercloud in order to trigger lightning with the rocket-and-wire technique.

1. Introduction

Lightning discharges initiated by airborne vehicles in the electric field of a thundercloud may pose a serious risk to their navigation and other equipment (Fisher et al., 1999; Uman and Rakov, 2003). Similar discharges can be initiated from natural thunderclouds using the so-called altitude version of the rocket-and-wire lightning triggering technique (e.g., (Lalande et al., 1998)). In both cases, a floating conducting object serves to enhance the electric field at its extremities, which can lead to initiation of a bidirectional leader from that object. A study of this phenomenon in nature is difficult because of the small number of events that can be recorded during the thunderstorm season and the high cost of the experiments. On the other hand, the laboratory methods can be used, with much greater efficiency, to simulate discharges initiated by isolated objects in the atmosphere.

In this study, we managed to initiate electric discharges by rapidly introducing a conducting crossbow bolt into the electric field of a cloud of charged water droplets. We have measured the key parameters of the initiated discharges. The results may have implications for improving our understanding of both lightning discharges initiated by aircraft and altitude-triggered lightning.

2. Experimental setup

More than one meter long sparks initiated from a grounded object in the field of artificially created cloud of charged water droplets were reported, for example, in Vereshchagin et al. (1988) and Anshilov et al. (1990). In this work, we used an experimental facility for generating charged clouds (see Fig. 1), which was similar to that employed in Vereshchagin et al. (1988) and Anshilov et al. (1990). Clouds of either polarity were created, but the results presented here correspond only to negative polarity. The charged cloud **1** was formed by the steam generator **2** and the high-voltage source **3** coupled with the corona-producing sharp point **4**. The latter was located in the nozzle **5** through which the high-pressure steam-air jet was passing. The jet had a temperature of about 100–

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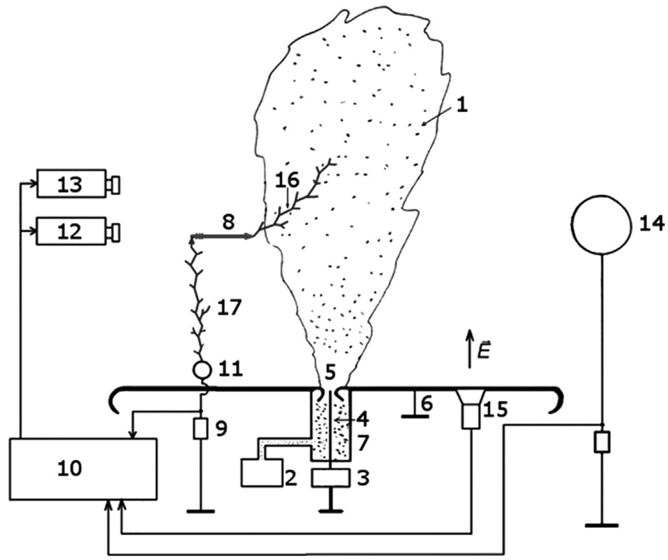

Fig. 1. Experimental setup: 1 – charged-aerosol cloud; 2 – steam generator; 3 – high-voltage source; 4 – corona producing sharp point; 5 – nozzle; 6 – grounded metal screen; 7 – steam conduit; 8 – conducting projectile; 9 – current-measuring shunt; 10 – oscilloscope; 11 – metal sphere, grounded via 1-Ω resistor 9; 12 – high-speed video camera; 13 – still camera; 14 – copper sphere for monitoring the cloud charge variation; 15 – fluxmeter; 16 – positive leader initiated from the projectile; 17 – upward positive leader initiated from the grounded sphere.

120 °C and a pressure of 0.2–0.6 MPa. It moved out at a speed of about 400–450 m/s with an aperture angle of 28°. The nozzle was located at the center of a flat metal screen **6** of 2 m in diameter with rounded edges. As a result of rapid cooling, the steam condensed into water droplets of about 0.5-μm radius. The ions charging the water droplets were formed in the corona discharge between the sharp point **4** and the nozzle **5**. A DC voltage of 10–20 kV of negative polarity was applied to the point. The current of charge carried by the jet was in the range of 60–150 μA. As the total charge accumulated in the cloud approached 50 μC or so, spark discharges spontaneously occurred between the cloud and grounded objects nearby.

Conducting projectiles **8** (aluminum or carbon crossbow bolts; no differences in results were found) 0.58 m in length and 8.8 mm in diameter were launched horizontally using a hand-held crossbow, at a velocity of 75 m/s, toward the cloud from a distance of 10–12 m from the jet axis, at an altitude of 0.5–1.2 m above the grounded metal screen (presented in this paper are only the results for relatively low altitudes, 0.50–0.6 m). To measure the discharge current passing through the flying projectile, we used a shunt **9** with 1 Ω resistance, the signal from which was fed to a Tektronix digitalizing oscilloscope **10**. The shunt was connected to a metal sphere **11** of 5-cm diameter, the uppermost point of which was 10 cm above the screen. The sphere was 0.8 m away from the screen center and was the object from which the spark usually initiated. As the current exceeded a given value, the oscilloscope was triggered, which, in turn, generated a pulse to trigger a high-speed video camera (FASTCAM SA4) **12**, operating in the visible range. FASTCAM SA4 was operated in the loop mode at a rate of 225,000 frames per second (fps) and was stopped at the frame at which a synchronization pulse from the oscilloscope was received. Frame duration was 4.44 μs, equal to the frame exposure time (no dead time), and the resolutions was 128×64 pixels (128 vertical and 64 horizontal). In order to monitor the variation of the charge of the aerosol cloud, we used a copper sphere **14** of 50-cm diameter, which was essentially isolated (grounded through a 100 MΩ resistor) and the signal from which was recorded by the oscilloscope **10**. Overall picture of the discharge was recorded using a Canon still camera **13**. The speed of projectile was measured using the high-speed video camera. Electric field at the grounded plane was measured with fluxmeter **15**.

3. Results

In these experiments, the cloud was charged to 50–80 μC, so that spark discharges spontaneously occurred, mostly connected to ground via the sphere **11**. As measured by fluxmeter **15**, the electric field generated by the cloud on the surface of the grounded screen at about 0.8 m from the jet axis was 400–500 kV/m (4–5 kV/cm) and slightly increased toward the cloud. It was estimated that the electric field of the cloud nowhere exceeded 1.0–1.1 MV/m (10–11 kV/cm). This was also confirmed by the absence of the

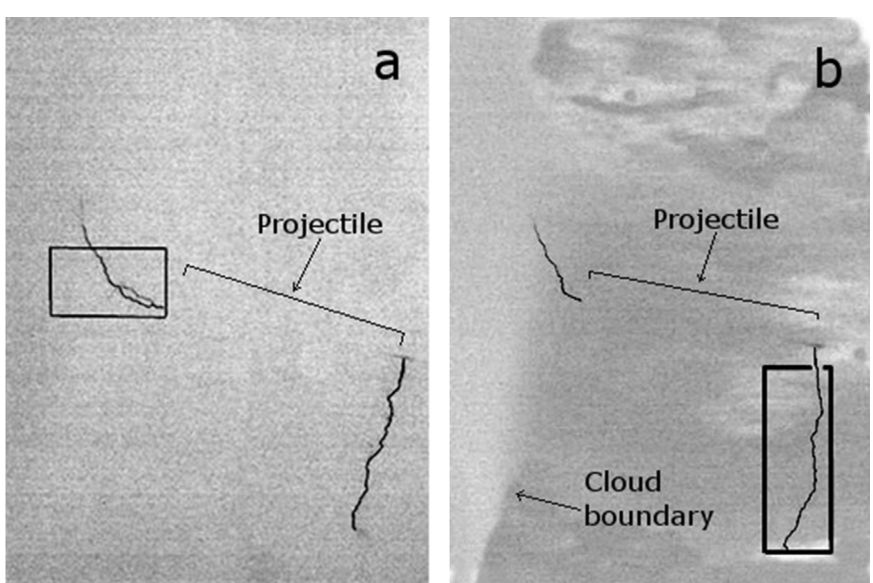

Fig. 2. Examples of integrated photos (inverted) of projectile-initiated discharges. Two separate discharges are shown in (a) and (b) with the rectangular areas showing the fields of view of the high-speed video camera imaging (pointing toward) the leaders from the projectile and from the grounded sphere, respectively. The 0.58-m long projectile is not seen on the photos, but its position is marked. The boundary of the charged cloud is visible and marked in (b).