Available online at www.sciencedirect.com
ScienceDirect
Journal of Electrostatics 65 (2007) 655–659
Journal of ELECTROSTATICS
www.elsevier.com/locate/elstat

A DC corona discharge on a flat plate to induce air movement

Pierre Magnier[a,*], Dunpin Hong[b], Annie Leroy-Chesneau[a], Jean-Michel Pouvesle[b], Jacques Hureau[a]

[a]*Laboratoire de Mécanique et d'Energétique, 8, Rue Leonard de Vinci, 45072 Orléans Cedex 2, France*
[b]*GREMI, UMR 6606 CNRS/Université d'Orléans, 14, Rue d'Issoudun, 45072 Orléans Cedex 2, France*

Received 3 January 2007; received in revised form 2 March 2007; accepted 16 April 2007
Available online 11 May 2007

Abstract

This paper describes a DC surface corona discharge designed to modify the airflow around a flat plate. The electrode configuration consisted of two thin copper layers placed on each side of the plate's attack edge. Discharge optical measurements with a photomultiplier tube indicated that the light emitted by the plasma is pulsating at a frequency that increases with applied voltage. Moreover, with voltage higher than a threshold value, the electric discharge changes regime with brighter pulses. This discharge also induced an "ionic wind" whose velocity was measured with a pressure sensing probe (up to 1 m/s). Experiments with the particle image velocimetry system in a subsonic wind tunnel showed that this discharge can reduce the separated airflow on the flat plate for a flow of 14 m/s (Reynolds number of 187,000).

Keywords: Corona discharge; Electroaerodynamics; Ionic wind; Plasma actuator

1. Introduction

The use of so-called ionic wind induced by a high voltage discharge [1] has been studied in electrostatic precipitators [2,3] and, more recently, in aerodynamics [4]. In this latter case, the ionic wind is used to modify the airflow around an obstacle in order to control the airflow in the boundary layer and reduce drag. For this purpose, different electric discharges have recently been developed, such as the "One Atmosphere Uniform Glow Discharge Plasma" [5,6] and DC surface corona discharges [7–9]. Labergue et al. [7] used the latter discharge on an inclined wall to detach the flow; Léger et al. [8] and Artana et al. [9] re-attached the flow on a flat plate. Published results indicate that the discharge can be used for active control of low-velocity airflow, but the mechanism of interaction between discharge and flow has not yet been clarified.

In this paper, we present an investigation of a DC corona discharge and measurements of the induced flow. The electrode configuration consisted of two metallic tapes placed on each side of a circular leading edge (see Fig. 1). This configuration slightly differs from that in reported works [8,9], where both wire electrodes were placed on the same side of the attack edge.

2. Experimental setup

2.1. Plasma actuator and power supply

The plasma actuator consisted of a DC surface corona discharge established between two electrodes (copper, 170 mm long, 25 mm wide and 35 μm thickness) mounted on both sides of the circular leading edge of a flat plate (polyvinyl chloride (PVC), 213 mm × 200 mm × 15 mm), as shown in Fig. 1. The anode was placed 7.5 mm downstream of the leading edge and connected to a positive high-voltage source (SPELLMAN SL300, 0–60 kV, 5 mA); the cathode, placed 37 mm from the edge, was connected to ground. A 15-MΩ series resistor prevented the transition to an arc regime.

2.2. Optical setup

As the light emitted by the discharge was very weak, a highly sensitive photomultiplier tube (Hamamatsu R928 having a spectral domain from 185 to 900 nm) was used to

*Corresponding author.
E-mail address: pierre.magnier@univ-orleans.fr (P. Magnier).

0304-3886/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.elstat.2007.04.002

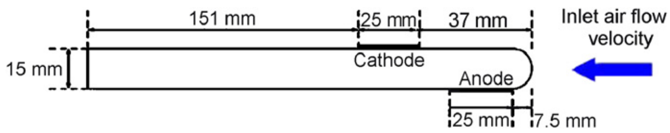

Fig. 1. DC surface corona discharge actuator on a flat plate.

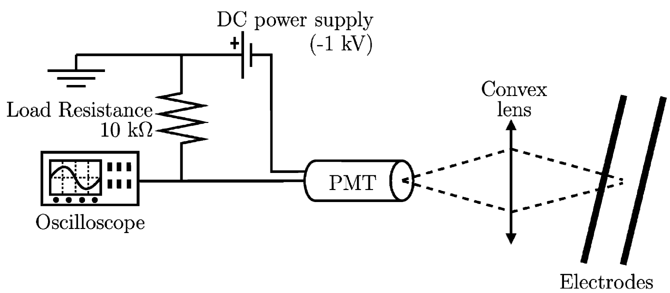

Fig. 2. Optical setup for measurements using photomultiplier tube.

detect the plasma fluorescence. A load resistance of 10 kΩ was placed between the anode of the PMT and ground to measure the photocurrent. The rise time of the detection system was about 200 ns. The PMT signal was measured with an oscilloscope. The setup shown in Fig. 2 used a quartz lens to capture the ultraviolet (UV) light from the discharge.

2.3. Wind tunnel

Experiments with external airflow were performed in a subsonic wind tunnel (Fig. 3) of 50 cm × 50 cm cross-section in a 2-m long test section (mean turbulence ratio of 0.5%), where a flow with maximum velocity of 50 m/s was generated by a 30-kW electric fan. The test flat plate was placed between two transparent rotating disks, shown in the test section in Fig. 3, which allow for obtaining the desired attack angle.

2.4. Particle image velocimetry system

Measurements of the flow velocity fields were performed using the particle image velocimetry (PIV) system shown in Fig. 4. A laser beam of wavelength 532 nm (Nd:Yag laser, Spectra Physics 400) was transformed into a laser light sheet using mirrors and lenses. The laser sheet illuminated smoke particles (generated by incense sticks) that seeded the flow. Images of illuminated smoke particles were captured using a charge coupled device (CCD) camera called PIVCAM. The vector displacement of each particle could be determined using two images recorded for two successive laser pulses having a time delay of 10 μs. The velocity fields presented in this paper are the mean vector fields of 500 pairs of such images recorded over a duration of 50 s at repetition rate of 10 Hz.

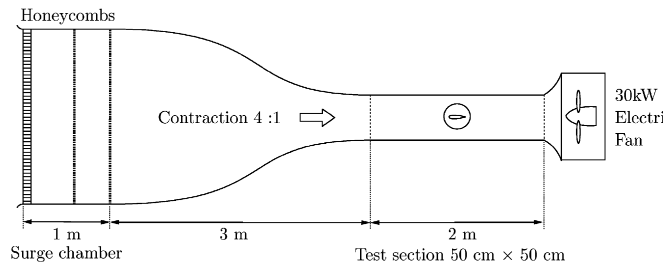

Fig. 3. Schematic side view of the wind tunnel.

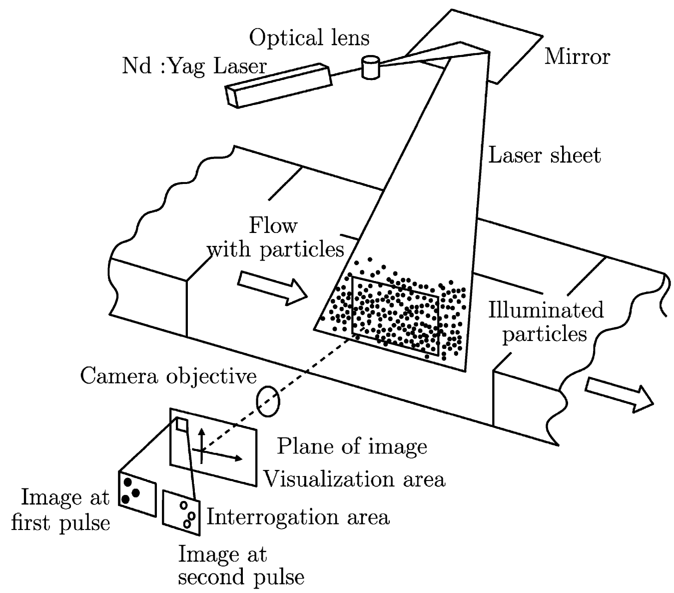

Fig. 4. Experimental setup of the particle image velocimetry system.

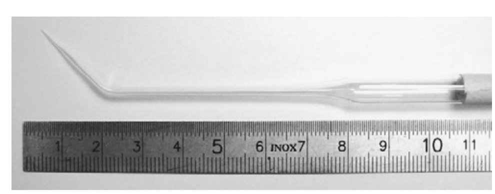

Fig. 5. Pressure sensing probe made of glass.

2.5. Pressure sensing probe

Velocity measurements were made with a pressure sensing probe consisting of a tube made of glass, shown in Fig. 5, thus avoiding conductive materials near the discharge that could cause unwanted arcs. The tube was connected to a differential low-pressure transducer Druck^{TM} LPM 9481 (0–20 Pa, output voltage 0–5 V) and measurements were acquired on a PC using a 16-bit acquisition card, over a 2-s interval at a 2-kHz sampling rate. The flow velocity V was determined from the differential pressure values ΔP using the Bernoulli relation $\Delta P = 1/2\rho V^2$, where ρ is the air density. This sensor was calibrated with a classical Pitot tube in a