Air flow control with electrohydrodynamic actuators

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Abstract *– This article deals with experiments we have undertaken to get a better knowledge of the ion wind effect on an air flow contouring a flat plate. Electrodes flush mounted on the surface connected to high voltage sources of opposite polarities enable the establishment of a discharge of the "glow type". Our results show dramatic modifications of the flow field and significant drag reduction on an important range of velocities.*

1 Introduction

The knowledge of the physics of corona discharge occurring in air close to an insulating surface is of interest in different engineering applications but it has not been as widely studied as has occurred with coronas without any extraneous bodies.

For instance, in the mechanical engineering domain, it is of interest to analyse the effects of the corona discharge on the fluid mechanics close to a limiting solid surface process which may be used for flow and instabilities control. The ions injected on a fluid flow and subjected to coulombian forces will exchange momentum with the fluid particles in their trajectory from one electrode to the other, modifying the fluid velocity field in the vicinity of the surface. As a result ion injection could be used as an actuator in wall bounded or free flows that could control the transition of boundary layers from laminar to turbulent, change the position of the separation line, or modify the stability of coherent structures. In this article we will call electrohydrodynamic actuators to this kind of device.

Prior research has focused in different possible applications of these electrohydrodynamic actuators in air. Either on the possibility of reduction of sonic boom [1,2], or of heat transfer augmentation [3,7] , or of drag reduction [8-14]. Also prior research work has analysed the effects of the forced electroconvection on the main flow in some industrial process like that in an electrostatic precipitator [15-17].

Wit a few exceptions [10,12] most of these researches have been undertaken with electrodes placed at some distance form the walls and the increase of momentum because of the electroconvection action was mainly in the direction of the normal to the surface. Though these research works show that injected ions can modify the characteristics and stability of the main flow, these devices (like most of the actuators actually considered in active fluid mechanic's research) should be largely optimised to obtain an important energy benefit.

It seems that in view of achieving better devices to control some characteristics of the flows (like skin friction forces, heat transfer, ...), the results could attain more dramatic effects if the electrodes were placed flush mounted on the wall surface and momentum added to the fluid tangentially to the wall. To achieve this goal it is necessary to get a better knowledge of the characteristic of the discharge under these conditions to operate it with a higher control degree. Recent results [18,19] indicate that when considering cylindrical geometry for the insulating surfaces some aspects of the discharge are modified and under some circumstances a special regime can be observed similar to a glow discharge where the drift region of the "normal" coronas almost fully disappears.

We propose with this work to analyse the discharge characteristics produced by electrodes flush mounted on a surface of a flat plate and how the electroconvection modifies the fluid mechanics occurring around the flat plate when traversed by an air flow.

2 Experimental study

In our study the injection of ions is obtained by a d.c. corona discharge between a wire type electrode (0.90 mm diameter) and a plane electrode of aluminium foil (of the same length than the wire)

The electrodes are located flush mounted on the surface of a flat plate of PMMA (5mm thick) as can be seen in the figure 1. Two different H.V. sources of opposite polarity (+30kV, -20kV, 500μA) enable to impose voltage differences between both electrodes. Wire type electrode is connected to the positive polarity source and by increasing the voltage difference between both electrodes different discharge regimes can be detected. The characteristics of the different discharge regimes as described in [18] for a cylindrical geometry with electrodes flush mounted are quite similar with the case under study here.

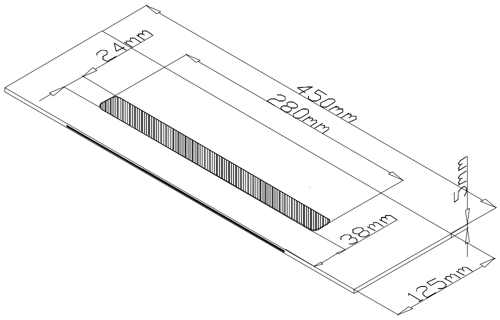

Figure 1 Electrode arrangement

Spot type regime: The discharge is concentrated in some visible spots of the wire and by increasing the voltage difference they can increase in number. Some of them may ionize in a plume like type or may lead to a narrow channel quite attached to the cylinder surface.

Generalized glow regime: At higher voltage differences, it can be observed a regime characterized by a luminescence, occupying almost the whole interelectrode space . The discharge makes the plate surface appear to look like supporting a thin film of ionised air. This discharge is quite homogeneous noisy and the current quite stable with time.

Streamer type regime: In this regime some points of the wire have a concentrated discharge in an arborescent shape or in filament type. By further increasing the voltage some localized sparks appear following a non-rectilinear trajectory far from the surface.

In this work we undertake flow measurements in the generalised glow regime and figure 2 is a photo (obtained by darkening the room) with wire type electrode at left and the plate facing down at right.

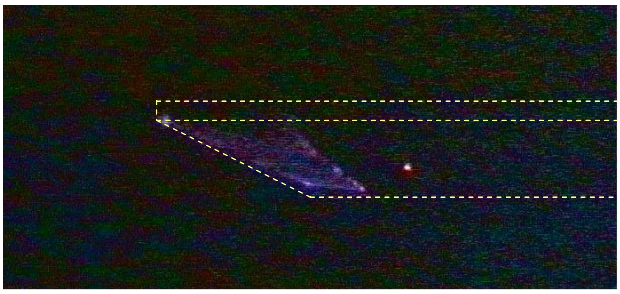

Figure 2: Photo of the generalised glow discharge(plate is dashed line on the photo) (ΔV=34kV, 1000µA/m)

Flow visualisation

Our experimental device has been placed in a wind tunnel (0-15 m/s, 0.45 x 0.45 m rectangular cross section) with the plate horizontally placed parallel to the main flow . A schema of the wind tunnel is shown in figure 3.

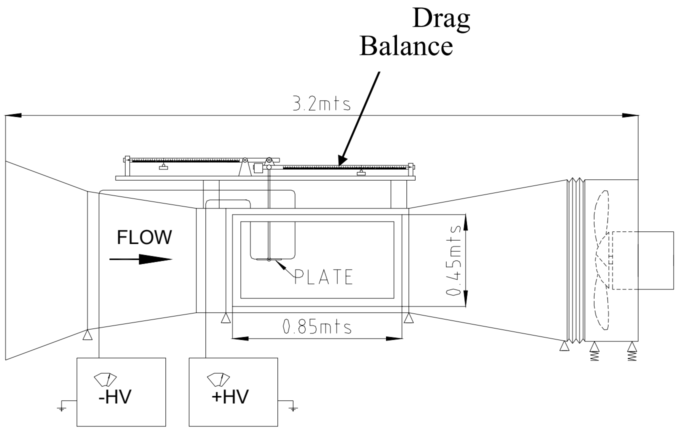

Figure 3: Schema of the wind tunnel

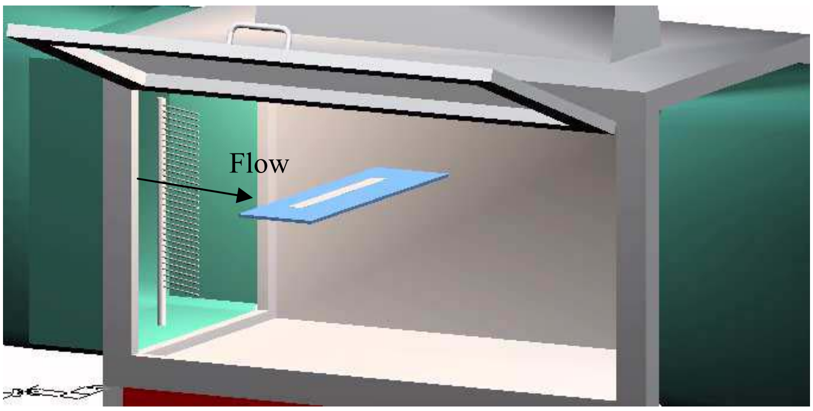

Figure 4:
Injector arrangement and wind tunnel test section

The wind tunnel has smoke injectors spaced vertically at 12.5 mm that are connected to a paraffin smoke generator with adjustable blowing velocity. The figure 4 shows the arrangement of these injectors as seen form the measurement section.

As some smoke particles can be charged by ion impact and coulombian forces would act on them, the analysis via a smoke injection technique may induce to some errors when associating directly tracer's trajectory with the trajectory of the neutral fluid particles. However, the visualisation by smoke injection technique can help in a first approach to have an idea of the changes in the flow field that could be caused by the discharge.

Figs 5 a and b are photos showing typical visualisations that enable to observe the changes on the smoke tracers filaments when the discharge is applied (wire electrode is upstream).

From our experiments, at moderate flow velocities where visualisation can be done (V≈1m/s) it can be seen that when the discharge is applied in the generalised glow regime as a result of the tangential acceleration of the air close to the surface the filaments of the smoke tracers tend to approach to the plate. This intense effect is greatly reduced if the discharge operates in other regime (spot or streamer type [5]) and large vortex appear if the polarity of the electrodes are reversed.

Drag measurements

We measure the drag exerted on the plate by means of a balance that enable us to detect changes of $0.2\ 10^{-3}$ N in the force. The plate is hanged from this balance by two supports and the force is detected by equilibrating the moment of the drag force with the moment of the weights of the balance. (see figure 3)

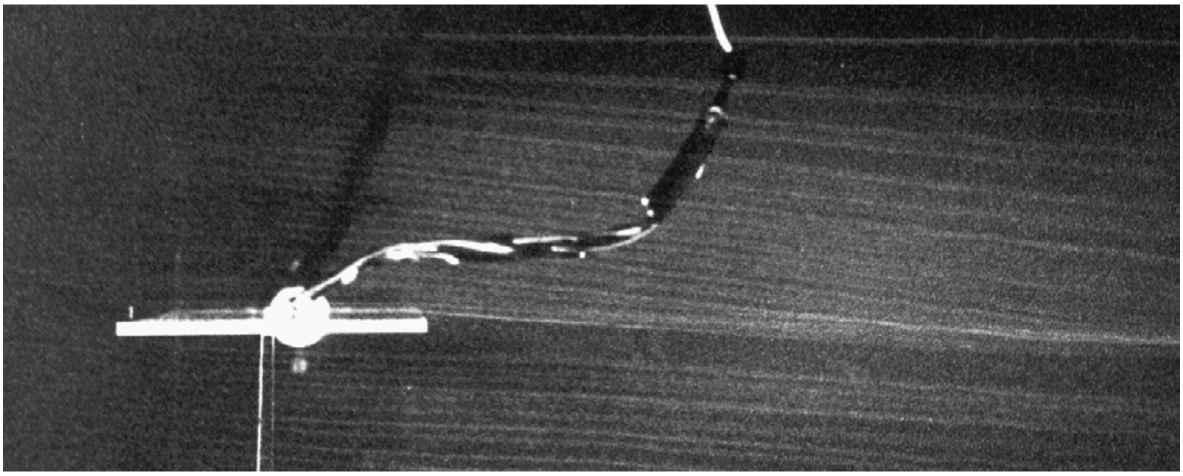

Figure 5a: Flow Visualisation: Voltage Off

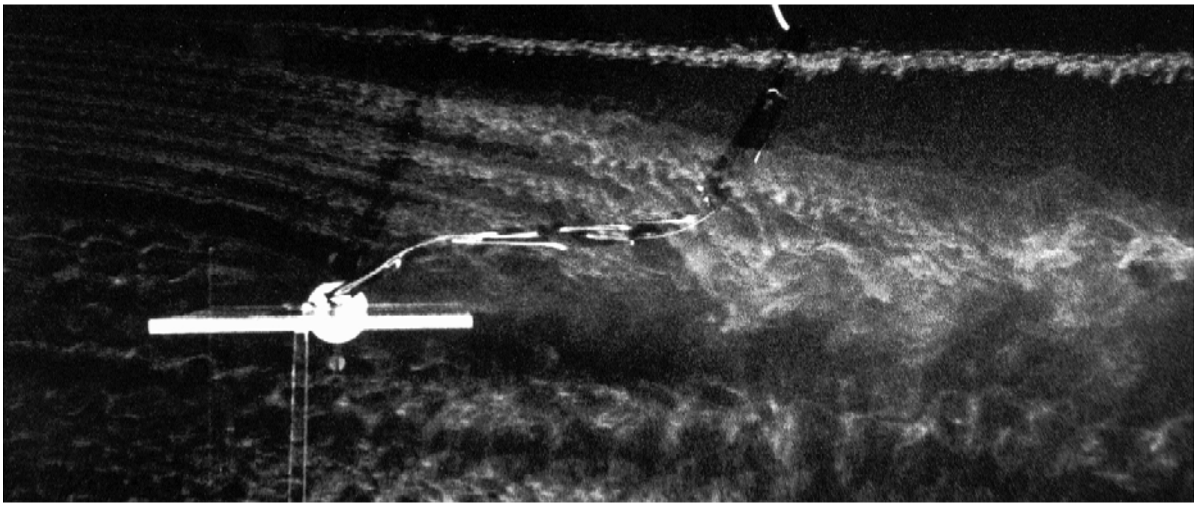

Figure 5b: Flow Visualisation: Voltage on (ΔV=32kV, 715 μA/m)

Figure 6 shows the results of drag forces with discharge on and off.. It can be seen as expected the drag is a function of the flow velocity and that a reduction of the drag is always achieved when the discharge is applied.

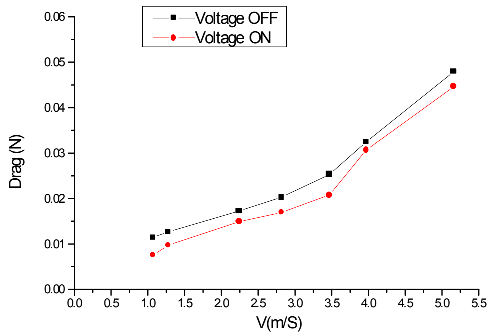

Figure 6: Drag force on one plate surface as a function of flow velocity. (ΔV=33kV, 900µA/m)

Our measurements indicate that even though the discharge occupies only about 20% percent of the plate surface it can be obtained drag reductions for this surface in the range of 7 to 34% (the highest values at the lower flow velocities indicated in figure 6).

3. Conclusions

We show in this article that the characteristics of a corona discharge in the proximity of extraneous bodies are quite similar if this body has a cylindrical geometry or if it is of the flat plate type.
The effect of the dc corona discharge in the generalised glow regime is very distinctive because of two main factors :

- its intensity (luminescence in all the arc distance could be associated to ionisation produced by high velocity charged particles)
- the homogeneity of the discharge occurring all along the electrode length.

From flow visualisation it can be concluded that at low Re number the effect of corona discharge is important and that this effect is highly dependent on electrode polarities
An important effect on drag reduction can be observed in a large range of flow velocities that encourages further research to optimise the device.

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