Modifications to the flow field around a cylinder by means of electrodes placed on its surface

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We show in this work the experimental results we have obtained concerning the influence of a secondary flow, of coulombian electrocovective origin, on the main flow taking place around an electrically insulating cylinder placed in a wind tunnel. Electrodes of wire and plate type are mounted on the surface of the cylinder parallel to its axis and ion injection is obtained by establishing a voltage difference between them. The corona regime considered in this work is of the generalized glow type as described in [5]. A technique of smoke injection is used to give a first approach to changes that can be detected on the flow and other measurements, like the modifications on the pressure distribution on the cylinder surface that appear when the ion injection is produced, are reported.

1. Introduction

The knowledge of the physics of corona discharge occurring in a fluid 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 (like wakes) 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.

Prior research work has analysed the effects of the forced electroconvection on the main flow like that in an electrostatic precipitator and other flow types such as the wake downstream a cylinder with a point-to-plane electrode arrangement [1], boundary layers on flat plates with razor blade electrodes [2] and Poiseuille flows [3-4]. These researches show that injected ions can modify the characteristics and stability of the main flow. However, it seems that in view of flow control applications the results obtained could attain more dramatic effects if the electrodes were placed on the wall surface and the electrode configuration is optimized to operate the discharge in the most suitable regime. Recent results [5] indicate that the insulating surface modifies some aspects of the discharge close to the electrodes or causes the appearance of new electrical phenomena close to the wall. Under some circumstance a regime can be observed similar to a glow discharge where the drift region of the “normal” coronas almost disappears. We propose in this article to show how this kind of discharge could modify the fluid mechanics in a simple flow like the one occurring around a cylinder when traversed by an air flow.

2. Experimental device

In our study the injection of ions is obtained by a d.c. corona discharge between a wire type electrode (0.90 mm diameter, 275 mm length) and a plane electrode of aluminium foil (25x275mm), both located on the surface of a cylinder of PMMA (32 mm diameter, 450 mm length) parallel to the cylinder axis. 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 cylinder axis normal to the main flow and horizontally placed (see figure 1). The wind tunnel has smoke injectors supplied by a paraffin smoke generator.

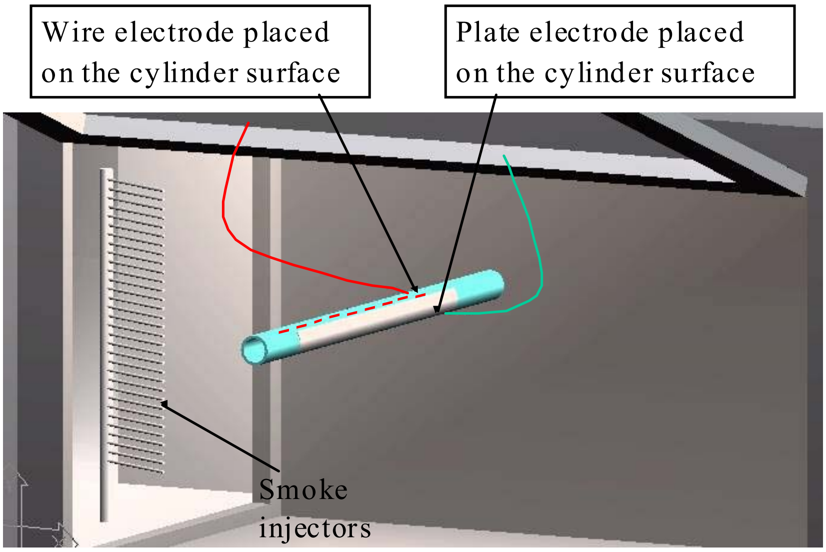

Figure 1: Cylinder placed in the wind tunnel section

Two different H.V. sources (+30kV,-8kV) enabled to impose voltage differences between both electrodes. We established a voltage difference of about 33 kV, with the wire at +25kV and with an electrode spacing of 38 mm. By doing this the discharge occurs in the generalized glow regime and a luminescence occupies the whole arc distance between both electrodes. The discharge is quite homogeneous and it extends almost all along the electrode length making the cylinder surface appear like supporting a thin film of ionized air. Figure 2 is a photo of this discharge.

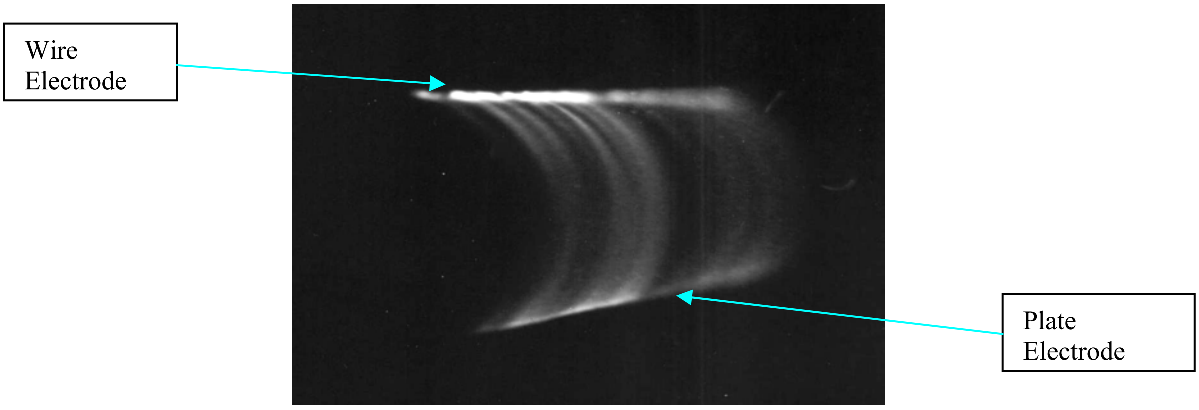

Figure 2: The generalized glow discharge

Orifices practised in a hollow cylinder were used to measure the pressure at different points of the surface connected to a micromanometer that enables measurements of pressure difference with an accuracy of 0.04Pa. Figure 3 shows the distribution of orifices on the cylinder**.** The agreement in measurements of the pressure at the symmetrical points enables to establish the correct position of the cylinder and so the angle of attack of the flow to the cylinder .

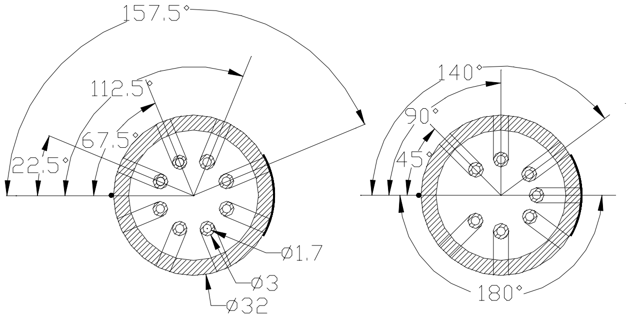

Figure 3: Cylinder for pressure measurements

3. Results and discussion

Figs 4 a and b show typical visualizations of the changes on the smoke tracers when the discharge is applied and the wire electrode is placed on the frontal stagnation point (plate electrode is opposed 180 degrees). As smoke particles can be charged and electric forces would act on them, the analisys via a smoke injection technique may induce to some errors when associating 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.

From our results, as in [1], at the very moderate Re number where visualization can be done it can be seen that when the discharge is applied the wake is largely modified and that vortex streets can no longer be detected. The filaments of the smoke tracers are perturbed or disappear in almost the whole section of the wind tunnel downstream the cylinder and in some cases even upstream. This intense effect is greatly reduced if the discharge operates in other regime (spot or streamer type [5])

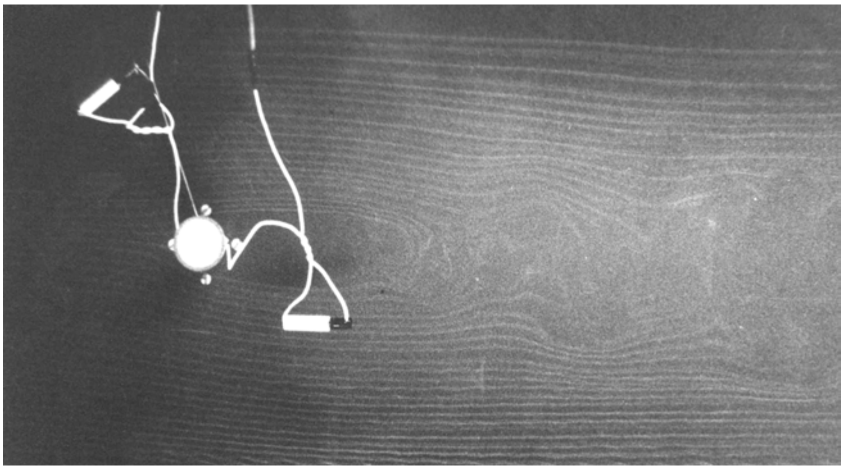

Figure 4a: Re=725, Voltage off

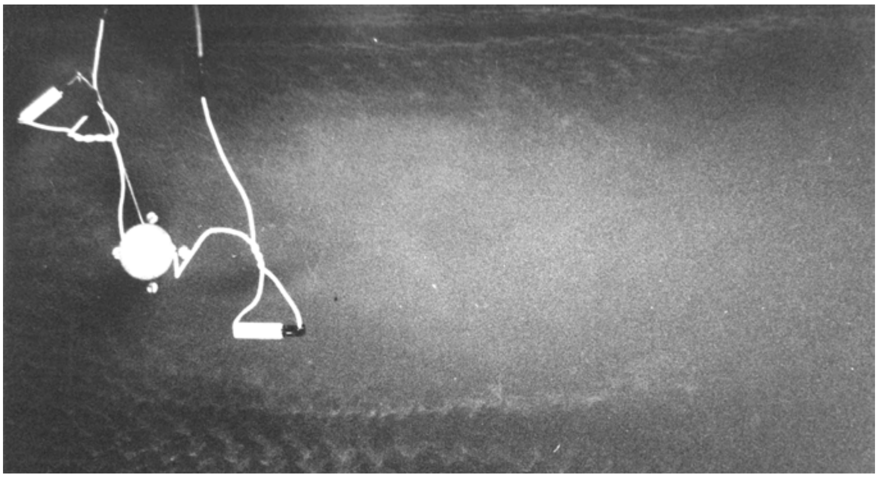

Figure 4b: Re=725, Wire electrode=+25kV, Plate Electrode=-8kV

Figure 5 shows typical results concerning the experiments of the changes in the pressure on the cylinder surface when applying the discharge. The graph shows the pressure referred to the pressure far away from the cylinder (P_0) and it is non dimensionalized with the dynamic pressure of the mean flow at the same remote region. We see that the shape of the curves of both experiments is quite similar and that there is no significant change on the position of the minimum of the curve. Beyond the minimum there is a pressure rise usually associated with boundary layer separation and it seems that in the range of Re numbers studied there is no clear change in the position of the line of separation of the boundary layer. However it should be taken into account that this could be also associated to a relatively large separation of the points of measurement in our experimental device.

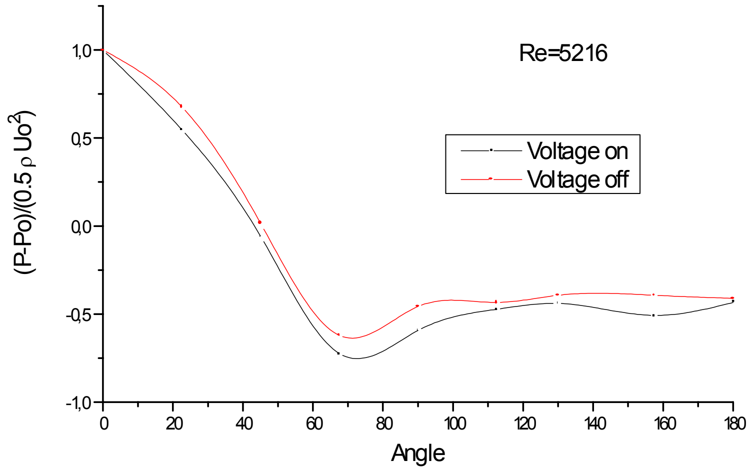

Figure 5: Effect of the discharge on the pressure at the cylinder surface

These curves also show that the effect of the corona discharge on the pressure is not negligible and can be detected in all measurement points. Figure 6 gives for different Re numbers the value of the integration along the cylinder surface of the non dimensional pressure projected in the flow direction. This integral agrees well with the drag coefficient when form drag is dominant and skin friction drag can be neglected. This curve shows that our results with voltage off have a good agreement with those from other researchers (see for instance [6]). Experiments with corona discharge on always yield lower values than the same experiment with voltage off. The effect is more important for low Re numbers where the difference may reach about 10%. At larger Re numbers this effect diminishes and a slight recovery is observed at the end of the Re number range that we have tested.

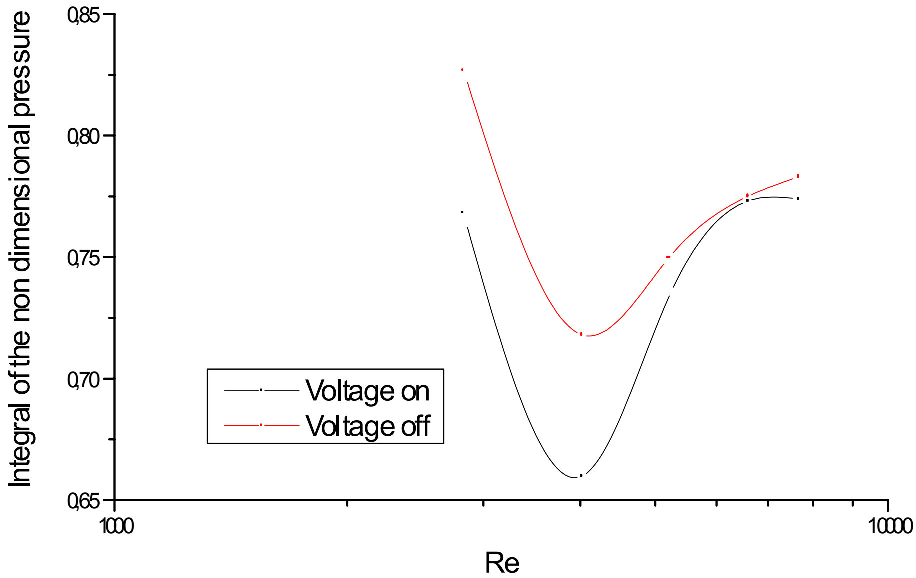

Figure 6: Integral of the non dimens. pressure projected in the flow direction vs Re number

3. Conclusions

The effect of the dc corona discharge in the generalised glow regime is very distinctive because of two main factors :

- its intensity (luminiscence 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 that should lead in regions far from the cylinder's end to a two-dimensional flow field configuration.

From flow visualisation it can be concluded that at low Re number the effect of corona discharge is important and could lead to a larger spreading of the wake

Our results concerning pressure modification indicate that the effect of a corona discharge is not constant for all Re numbers and that a significant form drag reduction could be possible in a certain range of Re numbers.

Further research work should be undertaken considering a larger range of Re numbers. A planar geometry should be also tested to determine the capability of a corona discharge to operate as an actuator on flow fields to control instability development.

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