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WALL-TURBULENCE CONDITIONING WITH STEADY CROSSFLOW-DIRECTED PLASMA JETS

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INTRODUCTION

The viscous drag exerted by turbulent wall-bounded flows can be reduced by a Stokes layer of flow right at the wall [5]. Many numerical studies have been carried out in the last years [e.g. 8, 4], whereas experimental efforts are rather limited [e.g. 1, 3]. This because of the difficulty to physically induce the desired forcing. Recently, dielectric-barrier-discharge (DBD) plasma actuators (PA) have been considered as plausible flow actuators as they can induce a mainly-wall-directed jet near the wall [e.g. 2]. Moreover, their technological embodiment is much simplified when compared to mechanical or piezo-electric devices [6]. Nevertheless, it is not straightforward to operate large PAs and this can limit the flow diagnostics and the related analyses and conclusions to reduced flow portions which risks to capture only a part of underlying flow mechanisms. In this study, two large PAs were built and installed in a ducted-flow facility. The extent of the performed actuation is such to assess the effect on the operated flow and its evolution.

EXPERIMENTAL SETUP

The ducted-flow facility has permanently-assembled side-walls that are in near-perfect alignment, with exchangeable top and bottom plates. The full length of the test section is 3950 mm, consisting of 950 mm of flow development area and 3000 mm of the actual measurement area. A schematic of the facility can be seen in figure 1. A total of 21 pressure-taps pairs is located on each side of the channel sidewall. The taps span the full test section length at 200 mm apart in the stream-wise direction, with the first tap located 100 mm after the test section inlet. These pressure taps are connected in series to a high-precision pressure transducer (MKS Baratron 698A) with an accuracy of ±0.05% of its full scale (100 Torr). The measurements were performed at friction Reynolds numbers (Re_τ) ranging between $250 \leq Re_\tau \leq 405$.

The DBD PAs in this study used Polyethylene terephthalate (PET) sheets as the dielectric layer. The electrodes were made with copper tape and the isolation of the encapsulated electrodes was guaranteed by multiple layers of Kapton tape. To ensure there is no undesired plasma formation between the electrodes and the wind-tunnel itself and to avoid influencing the static-pressure measurements, a distance of 20 mm from the tunnel side-walls was left clear of electrodes. This results in PAs of 290 mm in width and 730 mm in length. The PAs generated a mono-directional forcing similarly to the numerical setup of [7] with the crossflow-directed jets spaced at a distance of 15.12 mm. This value leads to 378 viscous units for the test case at $Re_\tau = 315$ and was found by [7] to lead to the highest value of drag reduction. A schematic of the induced effects they generated is shown in figure 2 whereas figure 3 shows a picture of one of the actuators being operated. The

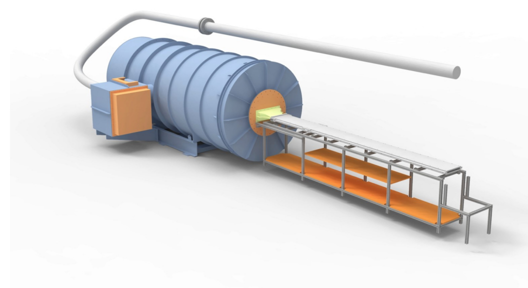

Figure 1: Schematics of the ducted-flow facility at the ISTM.

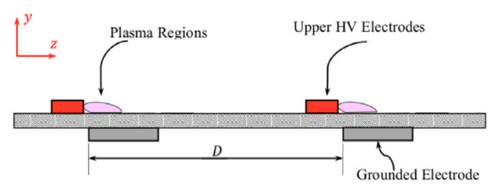

Figure 2: Schematics of the DBD plasma actuators' induced jets.

PAs were mounted in two configurations. One (parallel configuration) featured them one mounted on the upper and one on the lower wall of the tunnel, at the same streamwise station, and blowing in opposite crossflow directions. The other (series configuration), instead, considered both of them mounted on the upper wall, one after the other in the streamwise direction and both blowing along the same crossflow direction.

The power supply used in this experiment is an HP 6269B which is capable of up to 40 V and 50 A. This was used to power two, one per PA, high-voltage transformers: Minipuls 6 by GBS Elektronik GmbH. An Agilent Technology DSOX2004A oscilloscope was used to generate the input signals and to measure the voltage and the charge on the PAs by means of two HV probes and of two 104 K capacitors. These signals allow to assess the power consumed by the actuators. Finally, a peak-to-peak voltage (V_{pp}) of 7-10 kV was supplied to the PAs at the AC frequency of 4 kHz.

RESULTS & DISCUSSION

First, some tests were done to investigate whether the actuators would directly impact the measured static pressure. The actuators were tested in the tunnel but without incoming flow and showed just mildly lower values of static pressure compared to the ambient. Also the two electrodes of the actuators closer to the tunnel edges were de-activated and measurements

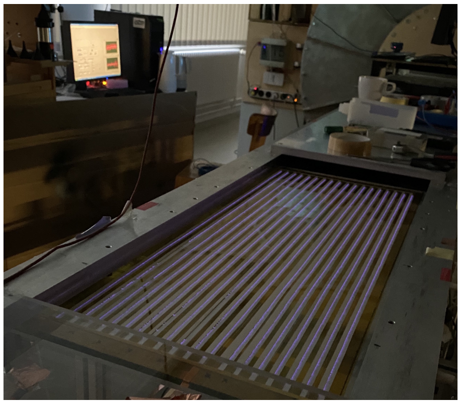

Figure 3: Photography of the operated array of DBD plasma actuators installed on the lower wind tunnel wall.

were performed under these actuation conditions. Small deviations, compared to the full-width actuators measurements, were observed thus making us confident about the validity of the reported data.

Preliminary results showed an increase of the static pressure loss, and equivalently an increase of the flow-exerted drag right at the upstream edge of the actuator for all the tested cases when the actuators were operated. This can be seen in table 1, where for both the tested Reynolds numbers and for all the supplied voltages, the drag modification ($DM = (D_0 - D_a)/D_0$, where D_0 is the reference un-actuated value and D_a is the actuated value) attains to negative values at the streamwise station 1 right downstream of the actuators' upstream edge. The same happens also at the second streamwise station which is at about the middle of the streamwise extent of the actuators. On the other side, right downstream of the actuators, namely at station 3, the actuated flows feature lower values of exerted drag. We cannot prove what the cause of this behaviour is but we can elaborate about it. Besides, being the reference study of [7] based on numerical simulations exploiting the periodicity of the streamwise boundary conditions, we cannot compare these results with the literature. What we propose that is happening here is a mix of drag-increasing effects both related to the downwash motions caused by the continuity of mass and related to the approximately-wall-tangential acceleration induced by the actuators. These motions bring closer to the wall larger streamwise-momentum particles which might increase the local viscous drag. Nonetheless, this happens throughout the streamwise extent of the actuators. On the other side, it is believed that, due to these downwash motions, the fluid particles suddenly, while flowing over the actuated walls, face a blockage effect reducing the static pressure. More downstream, instead, it is believed that the beneficial effects of the performed actuation on the turbulent flow and its exerted drag start occurring and building up. Downstream of the actuator, where these beneficial effects might still be there but the downwash motions are not, large values of drag reduction are measured for all the tested conditions. Yet, these beneficial effects soon decay while going even more downstream (not reported). The reported values allow also to see that these trends are increased for the higher value of the supplied voltage, and thus of the actuation strength, with this being valid for both the measured flows. On the other side, for a given operating voltage, it appears that the actuation for higher-Re_τ flows leads to beneficial effects: milder values of increased drag at the upstream and middle stations and higher values of drag

V_{pp} [kV] Re_τ	Station 1 360, 405	Station 2 360, 405	Station 3 360, 405
7	-14.65, -13.16	-15.66, -12.99	6.68, 10.90
8	-33.27, -22.48	-31.56, -22.88	15.58, 19.18
9	..., -34.84	..., -34.58	..., 31.22

Table 1: Percentage drag modification (DM) for different forcing amplitudes and Re_τ and evaluated at three different streamwise stations. Actuators in parallel configuration.

reduction at the downstream station. This is also an interesting aspect which should be further addressed as the actuator spacing was expected to be optimal for $Re_\tau = 315$. Considering the cases with strongest effects, and the spatial resolution of the measurements, a streamwise extent of 900 mm is shown to feature an increase of the flow-exerted drag due to the actuation and a length of 400 mm reports feature drag reduction with the latter being proportional to the supplied voltage, i.e. the actuation intensity.

These preliminary results evidence the deviations occurring between numerical studies based on simplified assumptions and experimental efforts with limited diagnostics and actuation lengths, power and strengths. More in the specific, the streamwise evolution of the operated forcing appears to play a major role and this should spark the demand for further investigations with possibly both methodologies. It appears, in fact, that the initial effect of the operated actuation on the flow has detrimental effects which can overcome or hinder the beneficial ones caused by the conditioning of the wall turbulence mechanisms. This aspect could be here evidenced by manufacturing, installing and operating two large PA arrays covering the whole tunnel width and a streamwise extent of $> 29h$, with h being the channel height of 25 mm (for a total length of the plasma discharge of ≈ 14 m per actuator). Furthermore, to further inspect this effect, the performed experiments consider also the case where the actuators were mounted one after the other both blowing in the same crossflow direction. Finally, power consumption measurements were also performed allowing to retrieve efficiency evaluations.

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