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PLASMA VORTEX GENERATORS USED FOR SEPARATION CONTROL AND DRAG REDUCTION ON A BLUFF BODY

P. Sujar-Garrido
Department of Engineering Mechanics, KTH Royal Institute of Technology, 10044 Stockholm, Sweden

R. Örlü
Department of Engineering Mechanics, KTH Royal Institute of Technology, 10044 Stockholm, Sweden

INTRODUCTION

Plasma actuators have become a quite effective technique during the last two decades. This is mainly due to their peculiarity to transform electrical power into mechanical power without the need for moving/mechanical parts nor do they require large spaces. Dielectric-Barrier-Discharge (DBD) plasma actuators have predominantly been used as momentum injectors in the near-wall region of aerodynamic surfaces [1] and as vortex generators [2]. For the latter, an array of DBD plasma actuators are oriented in the streamwise direction, thereby producing an electric wind perpendicular to the flow direction, known as plasma vortex generators (DBD-VGs). This technique used the actuators as a mixing tool instead of the classical injection of momentum.

The suppression of separated flow regions around road vehicles is key to reduce their aerodynamic drag and optimize their power consumption. When considering a zero degree yaw angle, the front drag of heavy-duty vehicle accounts for about 20% of the total energy loss and the trailer base drag is around 30%. The front drag contribution comes from the flow separation from the truck surface while passing the A-pillars (front corners) of the tractor. The aerodynamic design of these corners has improved during the last decades considering zero yaw angle (i.e., for headwind). However, the side winds can have a significant detrimental effect on the drag.

The present investigation is part of the PROMETHEUS (Plasma drag ReductiOn METHodology for effective Energy USage) project, as an extension of the FRANCE (Flow Research on Active and Novel Control Efficiency) project. Previous results of a scaled truck [6] showed that a reduction of the total drag of up to 20 % could be achieved for a yaw angle of 9°. These results can be improved operating the DBD VGs in an unsteady actuation mode. A pulsed actuation with an optimal duty-cycle would reduce the power consumption while keeping the effectiveness [5]. The effect of the excitation amplitude and duty-cycle parameters on the evolution of the starting vortex has been studied in quiescent air [4], concluding that the burst mode created greater mixing than continuous operation. Nonetheless, there is still a lack of studies exploring these advantages in complex flow-control configurations such as the 3D flow around an A-pillar.

BLUFF BODY SETUP

The main objective of the present investigation is to study a flow configuration close to an A-pillar that is still generic enough and can be simulated and compared with other existing cases as in [3]. Besides of studying the wake generated by a standard 3D bluff body. Thus, the chosen geometry is a modified bluff body (Figure 1) with a square-back and round corners on the leading edges. The main characteristic of our geometry is its flexibility to study separation on different front and back designs and with yaw effects to demonstrate the potential of unsteady plasma VGs. The body also includes pressure taps distributed along the model surface and is, in a first step, implemented with tufts.

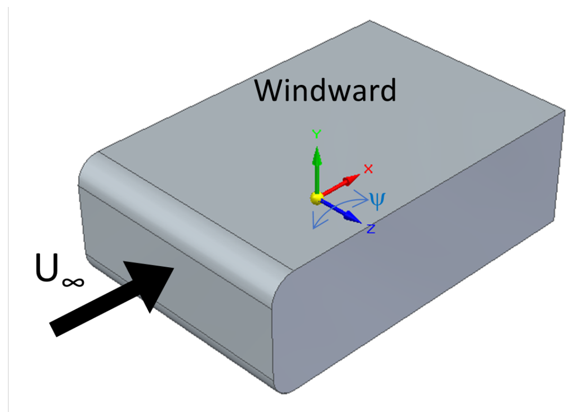

Figure 1: A 3D sketch of the model indicating the wind direction and windward side.

BASELINE FLOW

In a first stage, flow tuft visualizations were chosen as a quick and simple manner to asses the flow behavior at different velocities $U_\infty(m/s)$ and different yaw angles $\psi(°)$ on the leeward side. Although the body is three-dimensional, the spanwise dimension was chosen to have at least 1/3 of two-dimensional flow after the A-pillars' separation. This is corroborated by the tuft visualizations. Several inlet velocities up to 20 m/s were operated for two yaw angles: 0° and 10°. At the maximum velocity (20 m/s) and $\psi = 0°$, the reattachment of the separation bubble is at the middle of the length of the leeward side, while the reattachment increase by around 50% at 10°.

For a more quantitative result, pressure measurements are acquired on each side of the BB (i.e., front, back, windward and leeward). A Scanivalve MPS4264 digital pressure scanner was used to compute the pressure coefficient. The scanner is able to simultaneously sample 64 pressure ports with a stated accuracy of 0.20% of its full scale range of ±1 kPa (corresponding to a measurement error of ±2 Pa). Here, time-averaged pressure distributions are evaluated with 25 pressure taps on the surfaces of each side (windward or leeward). The front and back sides are equipped with 15 pressure taps symmetrically distributed. For the time-averaged results, the acquisition runs for 2 min at 10 Hz.

Figure 2 indicates the overlapping, on both windward and leeward sides, of the C_p distribution for the symmetric case ($\psi = 0°$). The C_p distribution increases with the yaw angle in the windward side, while in the side of the separation bubble the effects are not evenly coupled with the yaw angle. In fact, the separation behaves very similar for angles ranging between 0° and 5° and in another way in the range of 7° to 10°. It seems that a threshold exits between 5° and 7°. This is being investigated further with planar PIV measurements. Moreover, hot-wire anemometry (HWA) is used to acquire and analyze the incoming flow conditions as well as the characteristics of the wake.

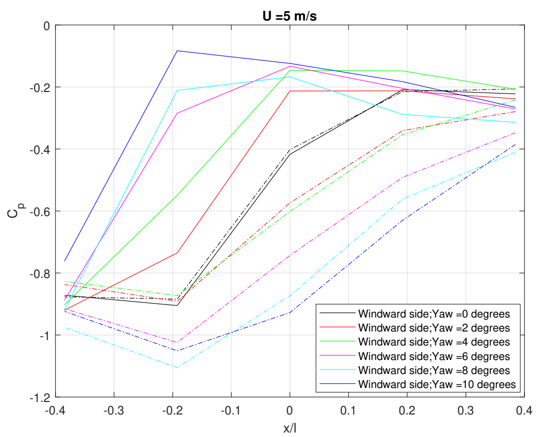

Figure 2: Example of C_p evolution on the windward (solid lines) and leeward (dashed lines) sides at different yaw angles for an incoming velocity of 5 m/s.

DBD VORTEX GENERATORS

The actuator used is the same as in Ref. [6]. Their results showed a reduction of the total drag of up to 20% for a yaw angle of 9° using a "steady" vortex generator. In the current case, the applied voltage has a sinusoidal waveform modulated by a low-frequency function (Figure 3). This modulation means that the applied voltage is switched on and off at a frequency equal to 5 Hz and a duty-cycle of 25 %. This "burst signal" is relevant since it has been demonstrated to be effective for flow control configurations with lower power consumption [5].

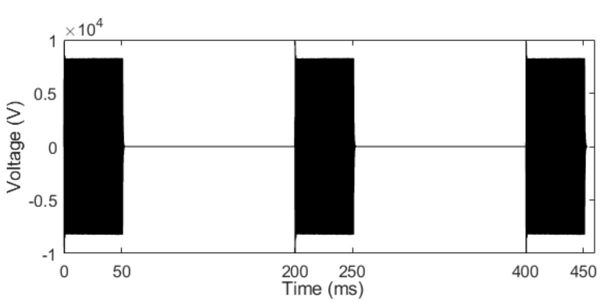

Figure 3: Example of a full envelope of the high voltage signal applied to the DBD actuator.

CONCLUSIONS & WORK IN PROGRESS

A modified 3D bluff body with front-round corners is studied using pressure measurements. Currently, single hot-wire measurements are conducted with and without control to analyze the influence of the discharge on the wake dynamics. Two point-correlation measurements can be added in the near future.

Regarding the actuator, planar PIV measurements are performed to give details of the effects of the unsteady actuation for separation control and provide more information about the effect of the train of vortex on the A-pillars. To complement these results, a 3D LDV system from TSI is being used to get the spectral characteristics on the wake.

REFERENCES

[1] T. C. Corke, C. L. Enloe, and S. P. Wilkinson. Dielectric Barrier Discharge Plasma Actuators for Flow Control. *Annu. Rev. Fluid Mech.*, 42:505–529, 2010.

[2] T. N. Jukes and K. S. Choi. On the formation of streamwise vortices by plasma vortex generators. *J. Fluid Mech.*, 733:370–393, 2013.

[3] G. Minelli, M. Tokarev, J. Zhang, T. Liu, V. Chernoray, B. Basara, and S. Krajnovic. Active aerodynamic control of a separated flow using streamwise synthetic jets. *Flow Turbulence and Combustion*, 103(4), 2019.

[4] B. K. Mishra and P. K. Panigrahi. Formation and characterization of the vortices generated by a dbd plasma actuator in burst mode. *Physics of Fluids*, 29(2), 2017.

[5] P. Sujar-Garrido, N. Benard, E. Moreau, and J. P. Bonnet. Dielectric barrier discharge plasma actuator to control turbulent flow downstream of a backward-facing step. *Exp. Fluids*, 56:70, 2015.

[6] J. A. Vernet, R. Örlü, D. Söderblom, P. Elofsson, and P. H. Alfredsson. Plasma streamwise vortex generators for flow separation control on trucks: A proof-of-concept experiment. *Flow Turbulence and Combustion*, 100:1101–1109, 2018.