Dielectric Barrier Discharge plasma actuator with periodic spatial oscillations

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DBD (dielectric barrier discharge) plasma actuators have in recent years become increasingly important due to their light structures and easy implementation. But the design of a series of actuators enabling drag reduction depends on many parameters (e.g., the length of the actuator, the space between actuators, voltage applied etc.) and remains a significant issue to address. In this study spanwise oscillated DBD plasma actuators are compared in experiments and direct numerical simulations (DNS). The results demonstrate a good agreement between experiments and DNS.

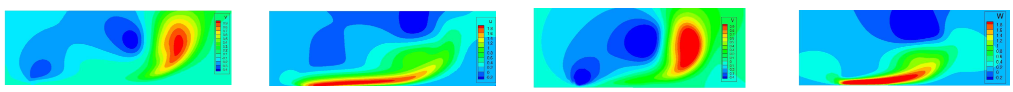
The Shyy model is applied as numerical approach to mimic the effect of DBD plasma actuators, which is given as equation below:

$$E(y,z) = E_0 - \frac{E_0 - E_b}{b} z^+ - \frac{E_0 - E_b}{b\tan(\theta)} y^+. \tag{1}$$

Here, b and θ defines the length and the height of the plasma. E_0 and E_b are the maximum and minimum electric field strength, respectively. The Eq. (1) is divided into spanwise and wall-normal components:

$$E_z(y,z) = E(y,z)\cos\theta, \tag{2}$$

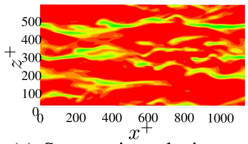
$$E_y(y,z) = E(y,z)\sin\theta. \tag{3}$$



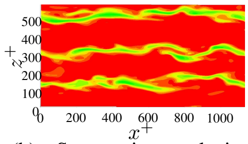
(a) Wall-normal velocity profile, experimental. (b) Actuator aligned velocity profile, experimental. (c) Wall-normal velocity profile, DNS. (d) Actuator aligned velocity profile, DNS.

Figure 1: Ionized air velocity plots for single DBD plasma actuator, stagnant flow.

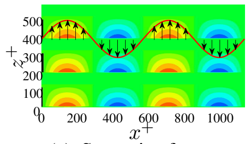
The numerical model is compared with experimental data in a stagnant flow with a single DBD actuator. A DNS study in a turbulent channel flow has been performed, an incompressible, finite volume code is used. The predicted velocities exhibit very similar behaviours to the experimental data. The plasma area creates a negative wall-normal velocity upstream of the actuator and a positive wall-normal velocity downstream of the actuator (Fig. 1(a) and Fig. 1(c)). The negative area entrains



(a) Streamwise velocity, no-force case.

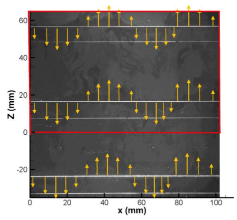


(b) Streamwise velocity, forced case.

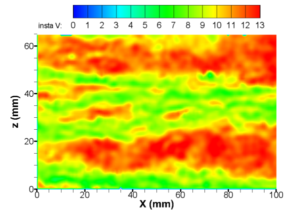


(c) Spanwise force.

Figure 2: DNS. Streamwise velocity (u) contours for the no-force (a) and applied force cases (b) varying in a value of 0-13 ($y^+ = 25$), and spanwise directed force (c).



(a) Applied force configuration.



(b) Streamwise velocity contours in the vicinity of the wall.

Figure 3: Experimental applied force configuration and streamwise velocity contours.

the flow toward wall and the positive area, downstream of the actuator, creates a wall jet which propagates downstream with a velocity parallel to the actuator (Fig. 1(b) and Fig. 1(d)).

In the second phase of the research a spanwise oscillated plasma actuator model is studied for a multiple actuators which are aligned in the spanwise direction. Eqs.(2),(3) are modified as below by applying a sinusoidal variation in the streamwise direction with a spanwise spacing:

$$F_z(y,z) = Dc\ E(y,z)\ \cos\theta sin(2\pi x^+/\lambda_x^+), \tag{4}$$

$$F_y(y,z) = Dc\ E(y,z)\ \sin\theta sin(2\pi x^+/\lambda_x^+). \tag{5}$$

The space between the actuators is $s = 15\Delta z^+ \approx 66$, the plasma length is $b = 27\Delta z^+ \approx 120$. $Dc = \rho_{c0}E_0\delta/(\rho u_\tau^2)$ represents the ratio of the electrical force to the inertial force, where ρ_{c0} is the maximum charge density, δ is the boundary layer thickness. In this study $Dc = 80$, $\theta = 10$. A constant volumetric driving force is used in the streamwise momentum equation. $Re_\tau = 180$ is prescribed based on u_τ (friction velocity) and δ (half channel height). The domain size is $2\pi\delta \times \pi\delta \times 2\delta$ in the streamwise, spanwise and wall-normal directions, respectively with grid size $98 \times 128 \times 98$.

Fig. 2(a) presents the streamwise velocity contour plot for the no-force applied case. The applied force is discribed by Fig. 2(c). An equivalent force is applied in the experimental study (Fig. 3(a)). In order to investigate the effect of the applied force on flow structures instantaneous contours of streamwise velocities are visualized in the vicinity of the wall. While streaks exhibit a regularization, a wide 'ribbon' of high speed velocities are observed in the force applied areas in the vicinity of the wall for both cases (Fig. 2(b) and Fig. 3(b)).

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