Characterization of pulsed corona actuators for separation control

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In the last years, the largest part of the published studies concerns AC-DBD and ns-pulsed DBD, which have proven to be more stable than corona actuators, that can be affected by transient sparks. However, it is reported that for an equivalent geometry and similar induced ionic wind, corona devices require one order of magnitude less power than AC-DBD, and in some cases, for the same input power, corona produces a larger velocity [1, 2, 3]. In [3], we introduced a periodic tips or *multi-tip* geometry for the active electrodes of corona and DBD devices and we investigated the ionic wind dependence on several geometrical parameters of the tips. Furthermore, we observed an improved discharge stability for these corona actuators [4], with respect to the traditional wire-plate configuration. The discharge stability increases for growing tip sharpness, which implies a larger local electric field, with great benefits for ionic wind production. These corona actuators (Fig.1a) have also proven to give comparable separation control performance on an airfoil with respect to AC-DBD, for a much lower power consumption [5].

In the present contribution we carry on the experimental characterization of these devices, by powering some actuators with an oscillating DC-shifted voltage waveform (Fig.1b), obtained by connecting a clamper stage to the output of an AC power supply unit. The multi-tip coronas under test are compared with a reference wire-plate actuator. All the devices are installed on C-shaped PMMA inserts at the nose of a NACA0015 airfoil of chord $c = 0.25$m and span b =0.47m. The anode tips are aligned with the leading edge, so that the discharge acts as much as possible upstream of the separation line. The actuated airfoil is tested in a wind tunnel equipped with micropitot, HWA and force balance. The tunnel is operated at freestream velocities $10 \leq U \leq 20$ m/s, corresponding to $166\mathrm{k} \leq Re_c \leq 330\mathrm{k}$. Lift and drag forces are measured as functions of the angle of attack for different actuation modes. The waveforms are based on a 800 Hz carrier wave modulated by a lower frequency F with different values of the reduced frequency $F_+ = Fc/U$ and of the duty cycle D_c. The relevant parameter space is explored in the range $0.5 \leq F_+ \leq 6$ and $0.05 \leq D_c \leq 1$, including the steady actuation corresponding to the pure carrier wave ($D_c = 1$), not to be confused with the simple DC actuation. Fig.1b shows the details of a sample waveform at the actuator terminals.

The actuators are characterized by their power consumption and some performance parameters accounting for the shift between the plasma off and on force coefficients. Local pitot and HWA measurements are also available. The passive effects of the unpowered actuators are separately analyzed. In general, the multi-tip configurations perform better than the wire-plate in separation control. For all the geometries, steady actuation is better at stall inception, whereas for a deeper stall range unsteady actuation with F_+ around 1 and $D_c \leq 0.5$ is the most performing condition (Fig.2). Furthermore, performance is also improved with respect to DC corona case, in particular for deep stall, with simultaneous consumed power reduction and stability improvement. The discharge stability is presumably favored by the reduced accumulation of charges near the anode, which may lead to a spark, since the voltage is larger than the ignition value only for a short portion of a period. The technology can be applied to the control of internal flows.

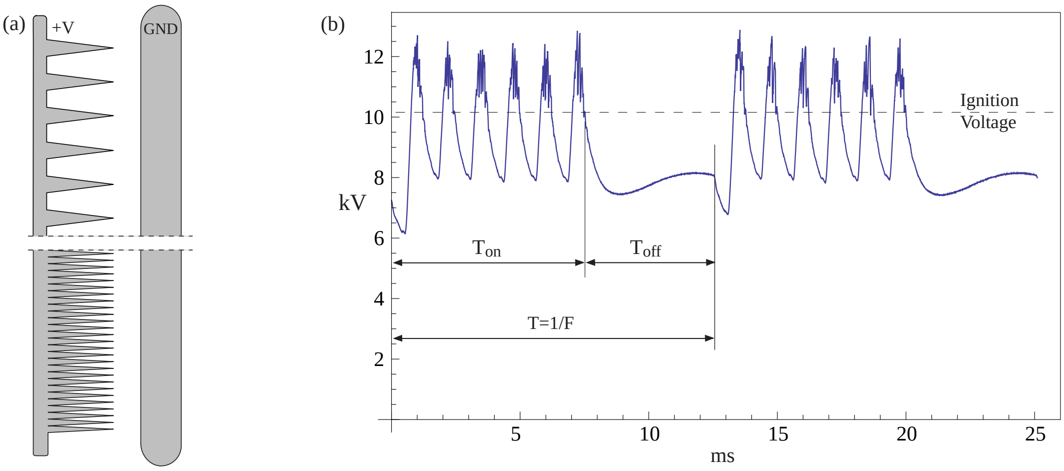

Figure 1: (a): examples of multi-tip corona; (b): a pulsed voltage waveform at the actuator terminals

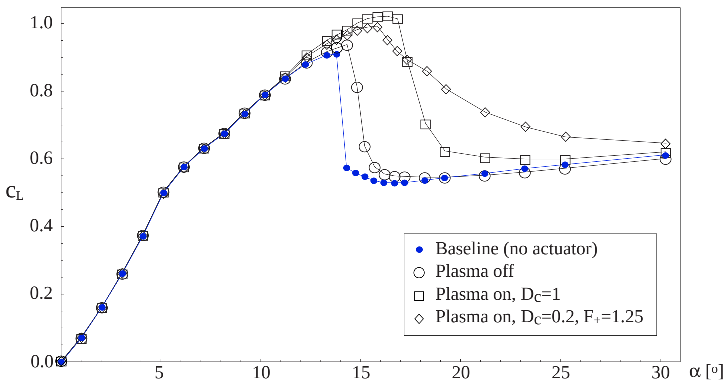

Figure 2: Sample lift coefficient $c_L(\alpha)$, measured at $U = 10$m/s for different actuation modes.

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