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# Winglet Type Dielectric Barrier Discharge Plasma Actuators: Performance Characterization and Numerical Comparison

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**Abstract**

Winglet type dielectric barrier discharge plasma actuator (PA) with two exposed electrodes have been investigated experimentally in a quiescent air and numerically modeled. Three arrangements of electrode positions are used: leading edge type (here after L PA), middle edge type (here after M PA), and trailing edge type (here after T PA) to investigate the effect of electrode position on induced flow. When the electrodes are located at the leading edge of the winglet PA, the stream wise flow is effectively enhanced on the covered electrode; on the other hand when the electrodes are located at the trailing edge, the friction loss is minimized for the near-wall high shear flow over the winglet and thus the highest momentum integral is obtained for the downstream jet-like flow. As all three type of PAs have two exposed electrodes, hence two separate jet flows are induced which are unified to a single jet after the winglet trailing edge. The electrode location also influences the unification velocity at downstream. The longer distance between trailing edge and embedded electrode reduces the downstream unified velocity. Particle image velocimetry (PIV) technique has been implemented to investigate the flow field. Simulation results are found to be consistent and in good agreement with experimental data.


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*Keywords:*dielectric barrier discharge plasma actuator; velocity profile; flow control; PIV; jet; CFD

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## 1. Introduction

Plasma actuators are a kind of aerodynamic flow control actuators which get tremendous research interest for more than a decade as they require no moving parts, easier to construct and control, low power consumption. These actuators hold promise for airfoil leading edge separation control [1,2], control of airfoil dynamic stall [3], bluff body flow control [4,5], boundary layer flow control [6,7], high-lift applications [8], turbo machinery flow control [9,10] and so on. A simple plasma actuator is consists of two electrodes that are separated by a dielectric material.

**Nomenclature**

| | |
|---|---|
| $\phi$ | electric potential |
| $\rho_c$ | charged particle density |
| $\overrightarrow{f_b}$ | body force |
| $\varepsilon_r$ | relative permittivity |
| $U_{max}$ | peak velocity at streamwise locations |

The electrodes are supplied with an AC voltage with enough magnitude which ionize the air over the covered electrode which is also known as embedded or grounded electrode. Here the term ionized referred as plasma, that's why they are referred as plasma actuator. The word ''plasma'' was introduced into the physics literature by Langmuir [11] to denote an electrically neutral region of gas discharge. The ionized air, in the presence of the electric field produced by the electrode geometry produce a body force vector that acts on the ambient (neutrally charged) air. The body force is the mechanism for active aerodynamic control.

The plasma actuator is thin and controllable electrically. Until now, the actuators have been mounted on the wall surface. For example, a vortex generator is located on the wall surface and LEBU (Large Eddy Break Up) device is located with some distance from the wall surface. These devices are composed of thin plates which are requested to have simple structure and minimum sizes. Thus the applications are limited to passive flow control. On the other hand, the DBD plasma actuator has a function of the active control in spite of its simple structure. Thus if the combination of those passive control devices and the DBD plasma actuator is possible, it is expected to bring a new active method for the flow control. From this point of view, a plate-like plasma actuator located with a distance from the wall surface has been developed. In this paper three type of plasma actuators are numerically and experimentally evaluated to figure out their effectiveness so that they can be used as vortex generator to control flow separation.

## 2. Method

### *2.1. Experimental setup*

All of three types of plasma actuators have been investigated here have two exposed electrodes on both sides with common embedded electrode as shown in figure 1; convectional two plasma actuators have been glued together to make such special type of plasma actuators. The width and chord length of mini-plate wing were 96 mm and 19.6 mm respectively. The electric wind was generated in the absence of external flow by the plasma actuator. Exposed and embedded (grounded) electrodes were separated by a Kapton thin wing plate. Detailed dimension (all in mm) have been shown in figure 1. The induced flow was compared as a function of the distance from the leading edge to the actuator position. Due to use of two exposed electrodes plasma was created on both sides of actuator surfaces. All experiments were carried out with a frequency of 5 kHz and the corresponding applied voltage were 2.5kV, 3kV, 3.5kV and 4kV respectively. All experiments were carried out in absence of external air flow.

Particle image velocimetry (PIV) was employed to quantify the behavior of the flow field during testing at AIST Tsukuba [12]. A horizontal laser sheet would strike at the midpoint of the plasma actuator from downstream, so that