PHENOMENOLOGICAL MODELS FOR PLASMA FLOW CONTROL

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1. Introduction

The use of plasma actuators for active flow control has been demonstrated to be an effective method in several flow-control-related applications including flow separation and boundary layer control[3,13]. The plasma actuators consist of two electrodes that are located on a surface separated by a dielectric material as shown in Figure 1. A high-voltage AC supplied to the electrodes causes the air in their vicinity to weakly ionize. The ionized air (plasma), in the presence of the electric field gradient produced by the electrodes, result in a body force vector acting on the external flow that can induce steady or unsteady velocity components. The effectiveness of plasma actuators in controlling flow separation has been demonstrated by several researchers (See ref. 3 for a review of this topic). These experiments showed that a range of parameters have to be taken into consideration for effective flow control including the location of the actuators on the surface, orientation, size, and relative placement of the embedded and exposed electrodes, applied voltage, and frequency of the actuation. Due to a large number of parameters involved, optimizing the performance of actual applications can be a fairly complicated task. CFD simulations can provide a useful tool in design and optimization of such complex flow control systems.

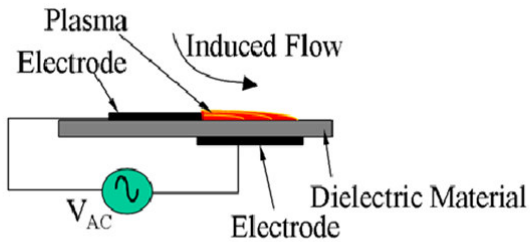

Figure 1. DBD plasma jet and actuators.

Computational studies of plasma flow control have been limited in comparison to the vast number of experimental studies reported. Most of the CFD approaches so far is to provide an estimate of the extra body force field per unit volume, $\vec{f}$, appearing in the momentum equation:

$$\rho \frac{\partial u_j}{\partial t} + \rho u_i \frac{\partial u_j}{\partial x_i} = -\frac{\partial p}{\partial x_j} + \frac{\partial \tau_{ji}}{\partial x_i} + f_j. \tag{1.1}$$

The modeling of the body force produced by the plasma on the neutral air can be of many different types, ranging from a simple algebraic model to complex multi-equation models. By neglecting magnetic forces, the electrohydrodynamic (EHD) force can be expressed as

$$\vec{f} = \rho_c \vec{E} \tag{1.2}$$

where ρ_c is net the charge density and $\vec{E}$ is the electric field. If the time variation of the magnetic field is negligible, as is often the case in plasma, the Maxwell's equations give rise to $\nabla \times E \approx 0$. This implies that the electric field can be derived from the gradient of a scalar potential: