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Simulating plasma actuators in a channel flow configuration by utilizing the modified Suzen–Huang model

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ABSTRACT

Objective: The present investigation is an attempt to simulate a channel flow driven by two plasma actuators placed on top of each other.
Methodology: The model utilizes a modified form of the Suzen-Huang plasma actuator which accounts for a ’dielectric shielding’ boundary condition for the potential governing the electric field. In addition, the Fokker-Planck (drift-diffusion) characteristics were implemented on the potential governing the surface charge density.
Results: The model is able to correctly predict the maximum velocities for channel flow at larger channel heights. However, at lower channel heights, the model underestimates the maximum velocities.
Analysis and Discussion: An analysis of the body force profile at the centreline region in the vicinity of the plasma actuators indicated that negative vertical body forces may have contributed to the discrepancies. Following this observation, a hypothetical model which does not account for vertical body force contributions on the fluid domain was simulated. While the results from this hypothetical model show marginally improvements to the maximum induced velocities at larger channel heights in relation to experimental data, the model still underpredicts the velocity magnitude at lower channel heights. This could point to the presence of interactions between the induced body force of the top and bottom actuators, specifically at lower channel heights, that have not been captured in the present model.

1. Introduction

The development of the Single Dielectric Barrier Discharge (SDBD) plasma actuator is motivated by applications in flow control. The ability to control the dynamics of fluid flow over a body allows engineers to incorporate designs that will drastically save fuel and energy. Recent research efforts with regards to flow control are being directed towards reducing drag, enhancing lift and augmenting the mixing of mass, momentum or energy. In order to achieve any of these, three issues have to be resolved; (1) transition from laminar to turbulent flow has to be delayed or advanced, (2) flow separation prevented or controlled and (3) turbulence levels have to be suppressed or enhanced.

Many methods have already been formulated to tackle the above mentioned aerodynamics issues but the catch is in discovering a control device or mechanism that is inexpensive to create as well as to operate and has greater savings than penalties involved. These methods are most effective when applied near the transition or separation points, in other words near the critical flow regimes where the instabilities magnify quickly. A review study of flow control by Gad-el-Hak [1] shows that energy wastage due to drag resistance results in losses amounting to billions of dollars in the aerospace industry.

A recent flow control review by Braun et al. [2] categorizes three main forms of flow control actuators: Fluidic, Moving object/surface and Plasma. Fluidic actuators result in suction or an ejection of fluid near separation points. This is the main working mechanism of a synthetic jet, where a zero net mass flux is added to the aerodynamic system. The second group – Moving object or surface – alters wall effects of the flow, similarly reducing boundary layer separation and/or turbulence levels. Plasma actuators have evolved in the last two decades and reviews can be found in Corke et al. [3] and Moreau [4].

The advantages of using plasma actuators for controlling airflow are that the actuators have no moving parts and are light. In addition, activating a plasma actuator results in real-time changes to the aerodynamic system. In the review by Cattafesta and Sheplak [5], flow control utilizing electric fields is described as an exciting topic due to two reasons; its multidisciplinary nature, and more importantly, potentially a long-term research into new

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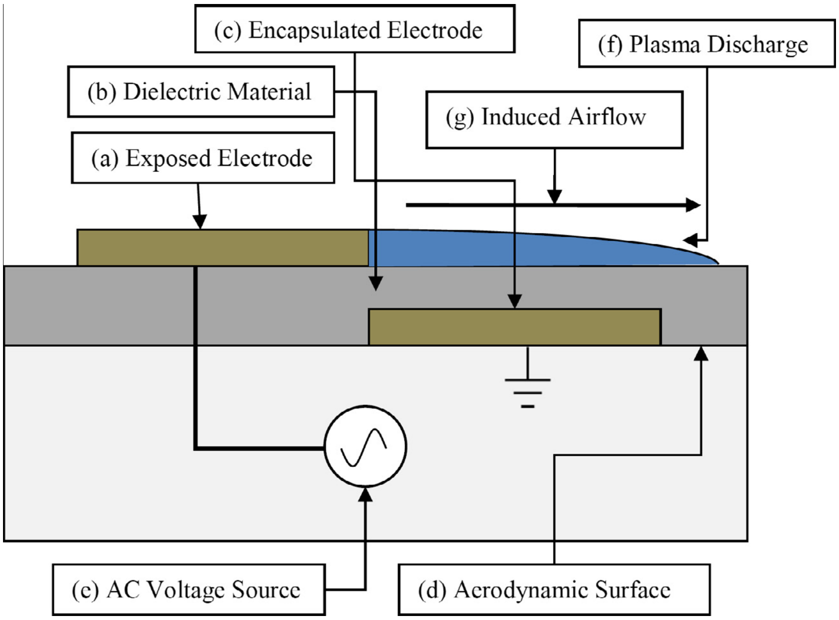

Fig. 1. Features of a plasma induced SDBD.

sources of atomic energy that will eventually produce extremely high power.

Plasma actuators have been tested in various applications, including separation control on a delta wing [6] and variable-direction discharge [7]. In particular, the Single Dielectric Barrier Discharge (SDBD) has been researched widely by the group from Notre Dame [8–11]. The SDBD consists of one electrode exposed to the surrounding air and one electrode completely encapsulated by a dielectric material. This results in an asymmetric geometry as shown in Fig. 1. An alternating current (AC) voltage is supplied to power the actuator. The asymmetric electrode design results in a body force that induces the flow in the direction from the exposed electrode towards the covered electrode.

The multitude of parameters involved in the design of the plasma actuator points to the use of CFD as a tool in the design process. As experimental methods pose a disadvantage because of high costs when designing actual geometries and data, computational models have evolved from the 1990s till today. Generally, all models require a coupling of the ‘plasma’ equations with the ‘flow’ equations. The Lorentz force is used to couple the resultant force produced by the charges to the source terms in the Navier–Stokes equations. Two forms of plasma actuator models exist:

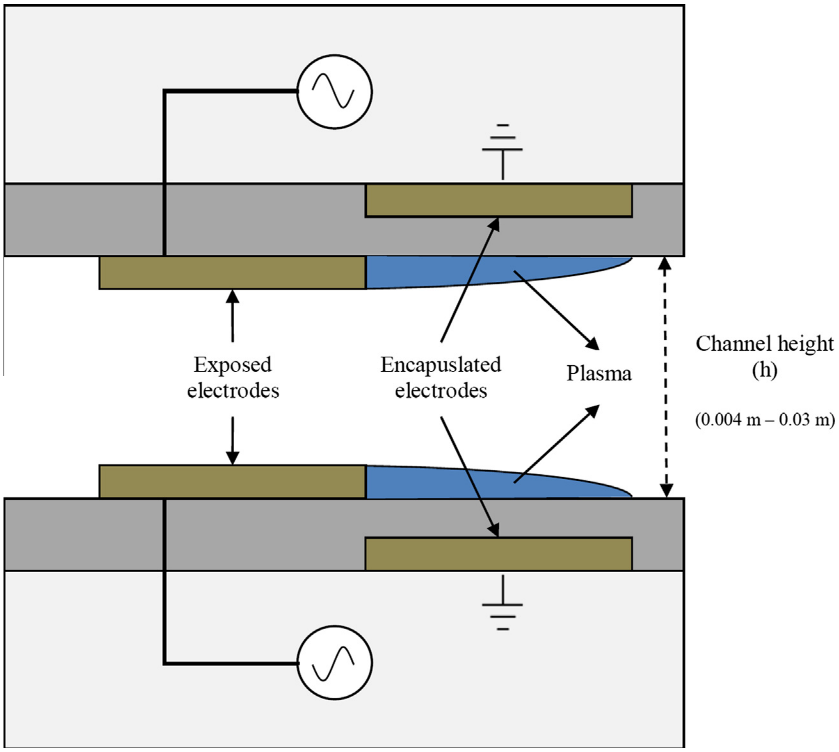

Fig. 2. Features of the SDBD in a channel flow configuration. The configuration is not drawn to scale.