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DISTRIBUTED FORCING OF THE WAKE OF A BLUNT TRAILING EDGE PROFILED BODY USING PLASMA ACTUATORS TO REDUCE PRESSURE DRAG

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INTRODUCTION

The periodic formation and shedding of von Kármán vortices, which is the primary flow instability in the wake of nominally two-dimensional bluff bodies, is the source of adverse periodic aerodynamic forces. Various flow control approaches have been implemented in the past to modify the wake flow and reduce these forces, with varying degrees of success. The modern flow control approach categorized as "distributed forcing" [2] is among the most efficient of these approaches. This approach is based on the interaction between the von Kármán vortices and the secondary wake instability, which appears as spanwise undulations in von Kármán vortices evolving into pairs of counter-rotating streamwise vortices [3]. Usually, relatively small geometric or fluidic perturbations are used to amplify the secondary instability, thereby disorganizing the von Kármán vortices and reducing the resulting aerodynamic forces. In the case of the blunt trailing edge profiled body (Figure 1), distributed forcing of the wake flow has been previously applied using geometric [1] and fluidic [3] actuation, demonstrating the feasibility of this approach for reducing the fluctuating aerodynamic forces and achieving significant base pressure recovery for a bluff body with forced shear layer separation at the sharp corners of the trailing edge.

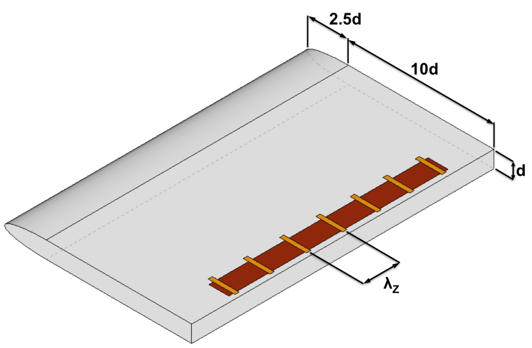

Figure 1: Geometry of the blunt trailing edge profiled body, and the plasma actuator array.

EXPERIMENTAL SETUP

In the present study, control actuation has been applied using an array of dielectric barrier discharge plasma actuators, which eliminate the need for geometric perturbations or external flow sources for fluidic actuation. To maximize the interaction with secondary wake instability, the spanwise spacing and arrangement of the plasma actuator array (shown in Figure 1) has been matched to the characteristics of the dominant secondary instability [4]. Furthermore, the range of Reynolds numbers in which the effectiveness of fluidic actuation for distributed forcing has been evaluated for this bluff body is extended to include the turbulent wake flow regime.

The experiments have been carried out in the closed loop subsonic wind tunnel at the University of Toronto Institute for Aerospace Studies (UTIAS), which is capable of generating a maximum freestream velocity of 40 m/s in a 0.8 m × 1.2 m × 5 m test section, with a freestream turbulence intensity of 0.05% at 10 m/s. The flow control experiments include 3 Reynolds numbers of 2,000, 3,000, and 5,000 based on the thickness of the body, which is 0.0254 m. At each Reynolds number, the actuation level has been varied by changing the excitation voltage of the plasma actuator array between 7 kV_{pp} and 11 kV_{pp} in 1 kV increments. For each combination of Reynolds number and excitation voltage, the velocity field in the wake has been measured using PIV in several vertical and horizontal planes, as shown in Figure 2. The base pressure has also been measured through 4 pressure taps across the span of the trailing edge.

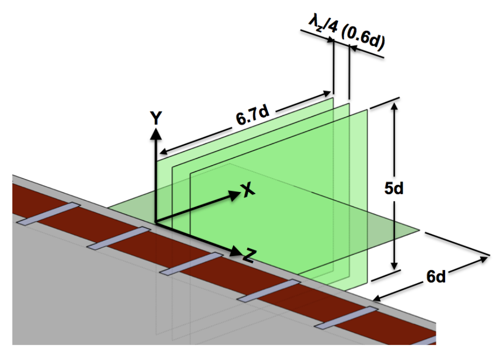

Figure 2: The PIV measurement planes.

RESULTS

The length of the recirculation region in the wake (L_f) is an indicator of the effectiveness of a wake flow control technique for drag reduction [1]. An increase in L_f leads to reduced influence of the low-pressure vortex cores at the base, and therefore recovery of base pressure. The present flow control technique results in a consistent increase of L_f across the span. This effect is illustrated in Figure 3, where variation of L_f with the normalized momentum induced by the actuator array (C_μ) is shown. C_μ is defined as

$$C_\mu = \frac{4n_e\left(\rho l_e h_j \overline{u_j}^2\right)}{\rho b d U_\infty^2}, \tag{1}$$

where n_e and l_e are the number and length of the actuator electrodes, respectively, h_j and and $\overline{u_j}$ are the height and average velocity of the wall jets induced by each electrode, and b is the span of the model. The figure shows that the maximum increase in L_f is caused by a momentum coefficient of $C_\mu = 2.45\%$, approximately, which can be achieved at $Re(d) = 2,000$ and 3,000 using excitation voltages of 9 kV$_{pp}$ and 10 kV$_{pp}$, respectively. At $Re(d) = 5,000$, however, this value of C_μ could not be achieved, due to the limited capacity of the electric power supply.

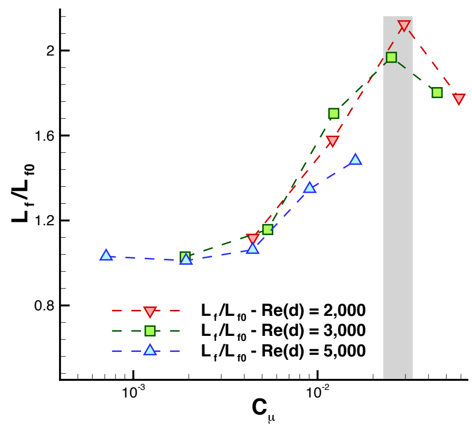

Figure 3: Effect of flow control on length of the recirculation region (L_f). '0' denotes the baseline value (control off).

A similar trend can be observed for base pressure (Figure 4). The maximum base pressure recovery is 44% at $Re(d) = 2,000$ and 3,000 and 21% at $Re(d) = 5,000$. The fluctuating component of drag, caused by the shedding of the von Kármán vortices, is also reduced by 90% when actuation is applied with $C_\mu = 2.45\%$.

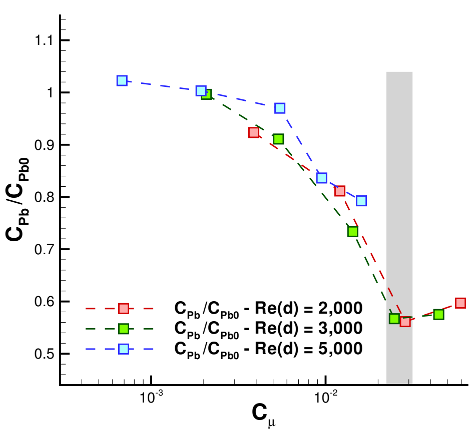

Figure 4: Effect of flow control on the base pressure coefficient (C_{Pb}). '0' denotes the baseline value (control off).

Investigation of the flow structure in the wake indicates that the significant recovery of base pressure and reduction of the fluctuating component of drag at $C_\mu = 2.45\%$ is due to nearly-complete suppression of the shedding of von Kármán vortices in the near wake region. An example of this effect is shown in Figure 5.

Proper Orthogonal Decomposition (POD) analysis has been carried out to investigate the role of secondary wake instability in the present flow control approach. The results show that control actuation reduces the relative energy of

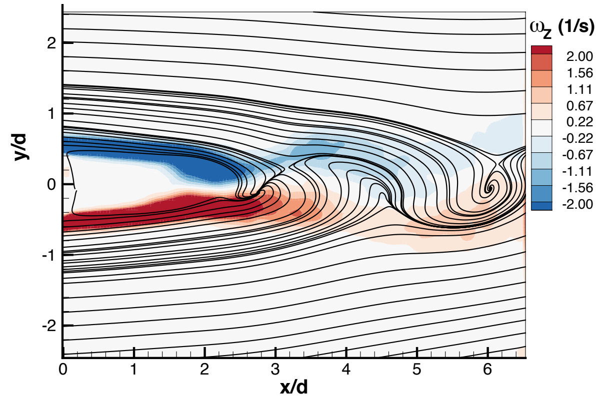

Figure 5: Phase-averaged streamlines and contours of spanwise vorticity (ω_z) in the vertical plane located at $z/\lambda_z = 0$, for $Re(d) = 2,000$ with actuation using $C_\mu = 2.45\%$.

the first two POD modes, which are associated with the von Kármán vortices, and increases the energy of the higher modes representing smaller-scale flow structures (Figure 6). This behavior suggests that the present flow control approach achieves the above-mentioned effects through amplification of the secondary wake instability.

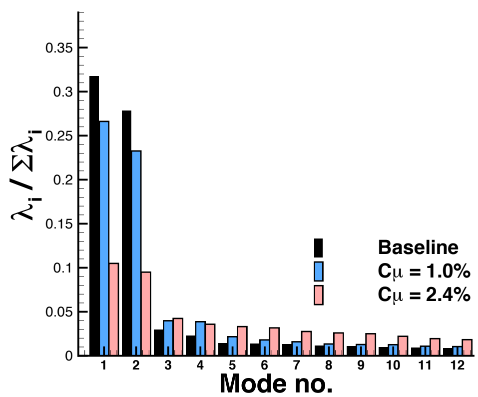

Figure 6: The effect of flow control on the relative energy of the first 12 POD modes in the vertical plane located at $z/\lambda_z = 0$, at $Re(d) = 2,000$.

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