Effect of velocity ratio on interaction between plasma synthetic jet and subsonic turbulent boundary layer

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High-Reynolds number flow control demands actuators that can produce perturbations in sufficient amplitude and bandwidth to interact with the abundant flow structures [1]. Plasma synthetic jet actuators (PSJAs) are tailored to execute this task. Utilizing rapid pulsed arc discharge to pressurize the cavity gas, high-velocity pulsed jets (>300 m/s) can be generated reliably at 5 kHz by PSJAs [2]. For separation suppression cases, these pulsed jets are frequently issued upstream of the controlled flow to interact with the incoming turbulent boundary layer (TBL), and a fuller velocity profile is expected due to mixing enhancement [3]. This study concerns the effect of peak velocity ratio (r) on interaction between plasma synthetic jet (PSJ) and subsonic turbulent boundary layer. The actuator as well as the test section is similar to that adopted in Zong et al. [4]. The jet orifice diameter is 2 mm and the Reynolds number based on boundary layer thickness (δ_{99}=19 mm) and freestream velocity (U_∞=20 m/s) reaches 2.4×10^4. Four cases with distinctive velocity ratios ranging from 1.2 to 3.8 are tested with a high-speed phase-locked Particle Imaging Velocimetry (PIV) system at 200 Hz. Three-component stereo measurements are performed downstream of the jet orifice (coordinate origin) at a streamwise plane of x/D=2.

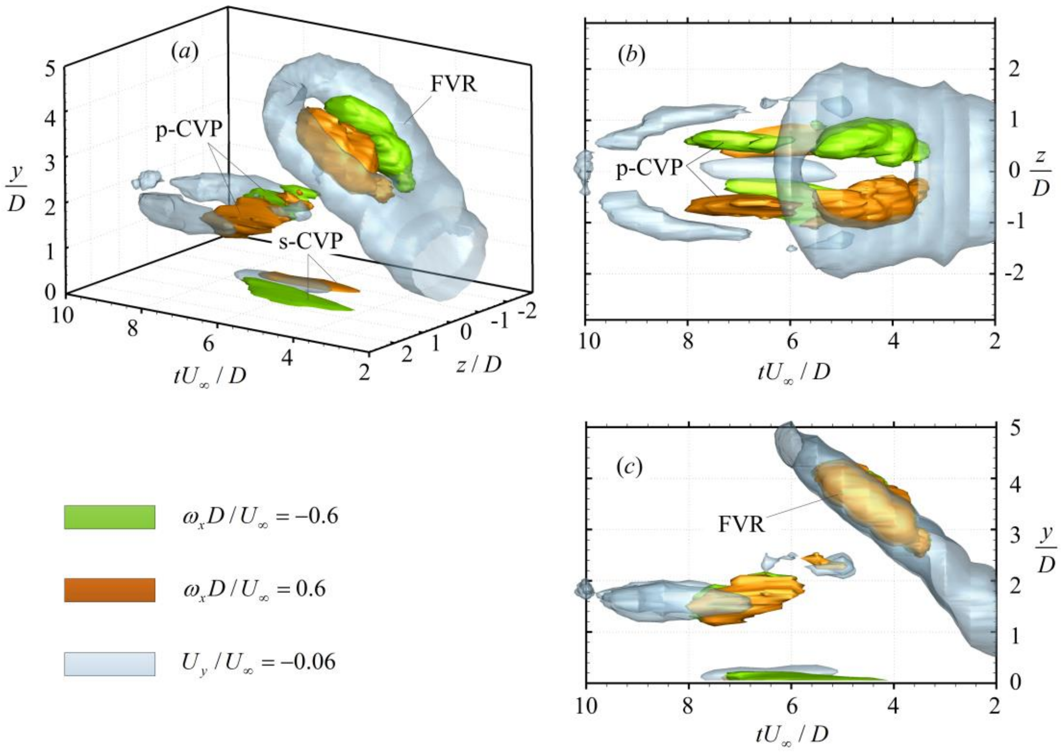

Figure 1: Pseudo-3D vortex structures induced by plasma synthetic jet issuing at a velocity ratio of 3.8 in cross flow. Front vortex rings (FVR), primary counter rotating vortex pair (p-CVP) and secondary counter rotating vortex pair (s-CVP) are visualized by contour surfaces of streamwise vorticity (ω_z) and wall-normal velocity (U_y).

The nondimensional convective length (tU_∞/D), spanwise coordinate (z) and wall-normal coordinate (y) constitute a pseudo three-dimensional space. Based on the velocity fields measured at the same streamwise coordinate (x=2D) but different time instants (t), several vortex structures can be identified in this pseudo 3D space, as shown in Fig. 1 and Fig. 2. In the case of large velocity ratio (r=3.8), a prominent front vortex ring (FVR) is generated, tilted approximately 45 degrees from the streamwise direction. Two contour rotating vortex pairs succeed the FVR during downstream propagation, and the lower one (s-CVP) is subordinate to the upper one (p-CVP). The fluids outside the FOV and p-CVP as well as inside the s-CVP are transported to the near-wall region, which is expected to energize the boundary layer. In the case of small velocity ratio (r=1.2), the counter-rotating vortex pairs disappeared and the FVR always keeps level during downstream convection.

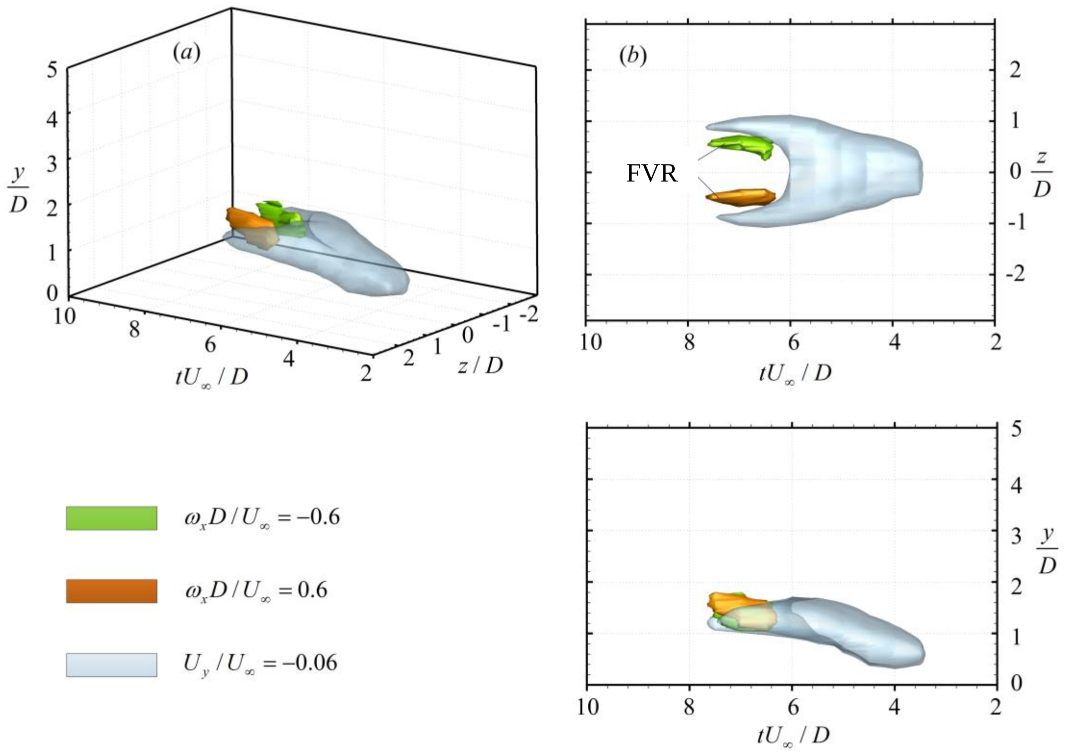

Figure 2: Pseudo-3D vortex structures induced by plasma synthetic jet issuing at a velocity ratio of 1.2 in cross flow. The plotting methods of Fig. 1 are inherited.

References

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