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Experimental study of the wakes of planar actuator disks

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1 Introduction

Simplified, yet accurate wind turbine wake models are crucial to the design of wind farms. For horizontal axis wind turbines (HAWT), the most used simplified model is based on the model of actuator disk, which has shown its suitability in several studies [1] [2]. For vertical-axis wind turbines (VAWT), existing planar actuator based wake models do not yield power and thrust coefficients accurately at high load conditions [3]. These models usually adopt physical assumptions and simplifications similar to those of HAWT, and the differences between the actuator surface shapes of a HAWT and a VAWT are not accounted for. Considering the wind turbine cross section, the rotor of a HAWT is modelled as a planar actuator disk, while a VAWT extracts energy from a 3D actuator surface4 with a rectangular side view. It is therefore significant to investigate the role played by the planar shape of the actuator in the development of the wake.

Experimental and numerical study on the wake of planar actuator surfaces are conducted to compare the three-dimensional flow developments. In the experimental study, circular, square and rectangular actuators are realized by porous plates with solidity of 56%. The experimental apparatuses are shown in figure 1. The measurement of the flow field from 1 diameter upstream up to 6 diameters downstream of the actuator are conducted using robotic particle image velocimetry (robotic PIV [4]). The study further develops comparing the present experiments with computational fluid dynamics (CFD) simulations of the actuator surface model. The actuator surfaces are numerically realized by force fields distributed in different planar shapes.

The results confirm that the C_T is not sensitive to the shape of the planar actuator. In contrast, the shape appears to produce a significant effect on the 3-dimensional development of the velocity and the vorticity fields downstream of the actuators. The square geometry exhibits corner effects that induce a contraction along the diagonals. The presence of corner vortices for the square actuator, shape the cross-section of shear layers into diamond-like in the far field. The development of the vortex sheet shows a clover-leaf shape (see figure 3).

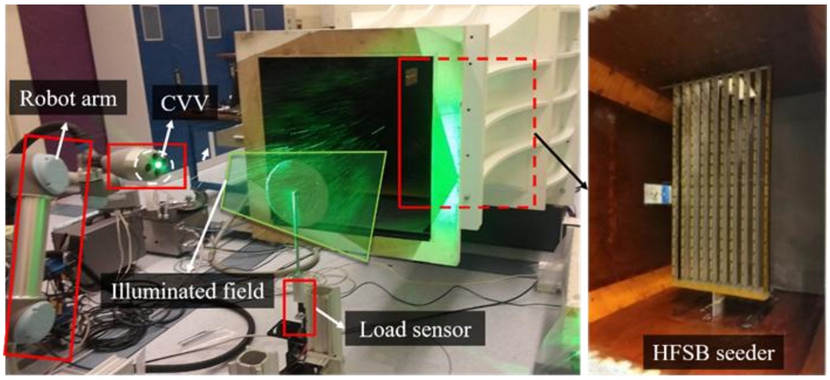

Figure 1 The experimental apparatuses.

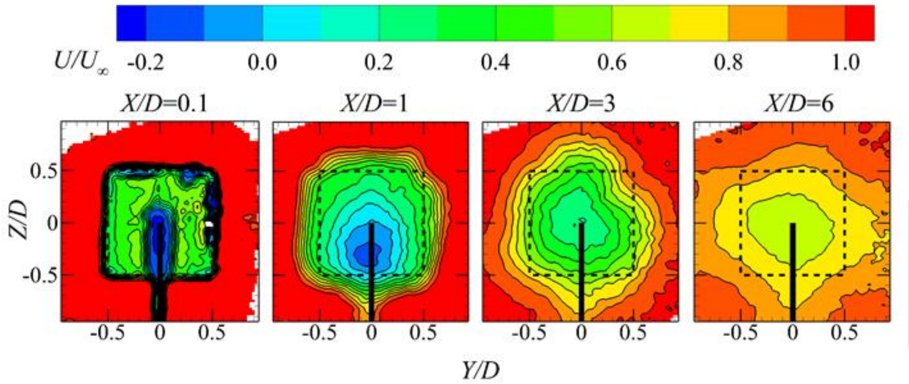

Figure 2 Contours of stream-wise velocity at cross sections downstream of the square actuator (X/D = [0.1, 1, 3, 6]).

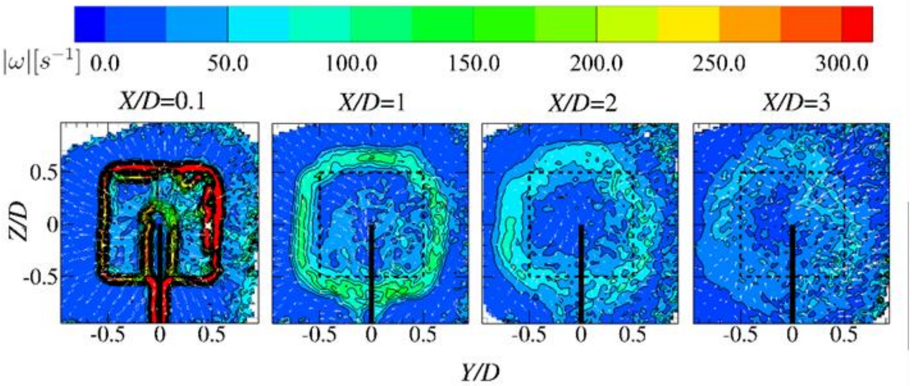

Figure 3 Absolute vorticity distribution over cross sections at different downstream locations of the square actuator (0, 1, 3, 5D)

Acknowledgements

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