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Session:

CFD Simulations of a Vertical Axis Wind Turbine in Dynamic Stall: URANS vs. Scale-Adaptive Simulation (SAS)

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Abstract

Vertical axis wind turbines (VAWTs) are promising candidates for wind energy harvesting in the urban environment. However, their aerodynamic performance still falls behind of their horizontal axis counterparts. This could be associated to the comparatively small research they have received in the past decades as well as their complex unsteady aerodynamics. Computational Fluid Dynamics (CFD) has been widely used to evaluate and improve the aerodynamic performance of VAWTs. An extensive literature study reveals that the 2D unsteady Reynolds-Averaged Navier-Stokes (URANS) approach has been used in the majority of the CFD studies on VAWTs. The current study intends to evaluate the aerodynamic performance of a VAWT, calculated using 2D URANS, and compare it with that of 2.5D URANS and 2.5D scale-adaptive simulation (SAS). SAS is a hybrid RANS-LES model developed by Menter and Egorov [1]. The four-equation transition SST turbulence model is employed in the URANS simulations as well as in the RANS region of the hybrid RANS-LES simulation. The studied turbine is a one-bladed Darrieus H-type VAWT with a solidity of 0.125 operating at a low tip speed ratio of 2.0, which corresponds to the most complex case for VAWTs where dynamic stall is dominant. The reduced frequency is 0.125 representing the high unsteadiness in the flow. Significant benefits of the one-bladed turbine are: (i) less blade-wake interactions while the essential flow features, such as dynamic stall, are still present, (ii) reduced computational costs due to the smaller number of cells. The turbine characteristics is based on the experiment by Simão Fereira et al. [2]. Validation studies for the one-bladed turbine as well as the other turbines have been performed [3]. A comparative analysis of the instantaneous tangential and normal loads on the turbine (see Fig. 1), spatiotemporal distribution of pressure coefficient (see Figs. 2a-c) and skin friction coefficient (see Fig. d-f) on the blade suction side, the evolution of the shed vorticity by the blade, dynamic loads on the blade and the turbine wake are employed to evaluate the performance of URANS modeling in comparison to the SAS model. The instantaneous turbine loads calculated using the 2D and the 2.5D URANS, shown in Fig. 1, are in line with minor differences in the downwind side. Despite the 180 times higher number of cells and 10 times finer time step of the SAS modeling, an overall good agreement exists between the 2D URANS and the SAS results. The predicted thrust coefficients for 2D and 2.5D URANS and SAS are 0.422, 0.424 and 0.430, respectively. Nevertheless, there exist noticeable differences between the URANS and SAS results in the bursting location of the laminar separation bubble (LSB), the evolution of the dynamic stall vortex (DSV), the leading-edge secondary and tertiary vortices and the trailing-edge separation. The findings of the present study help to highlight the deficiencies of URANS modeling of VAWTs in dynamic stall.

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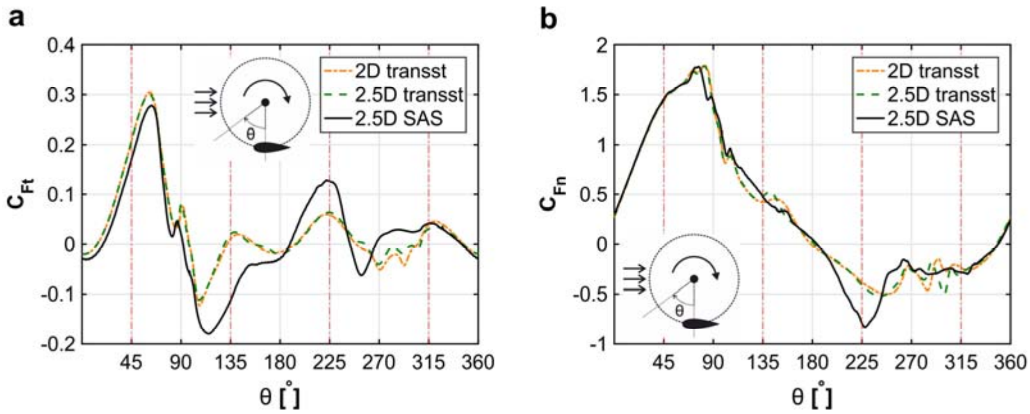

Figure 1. Tangential and normal force coefficients during the last turbine revolution.

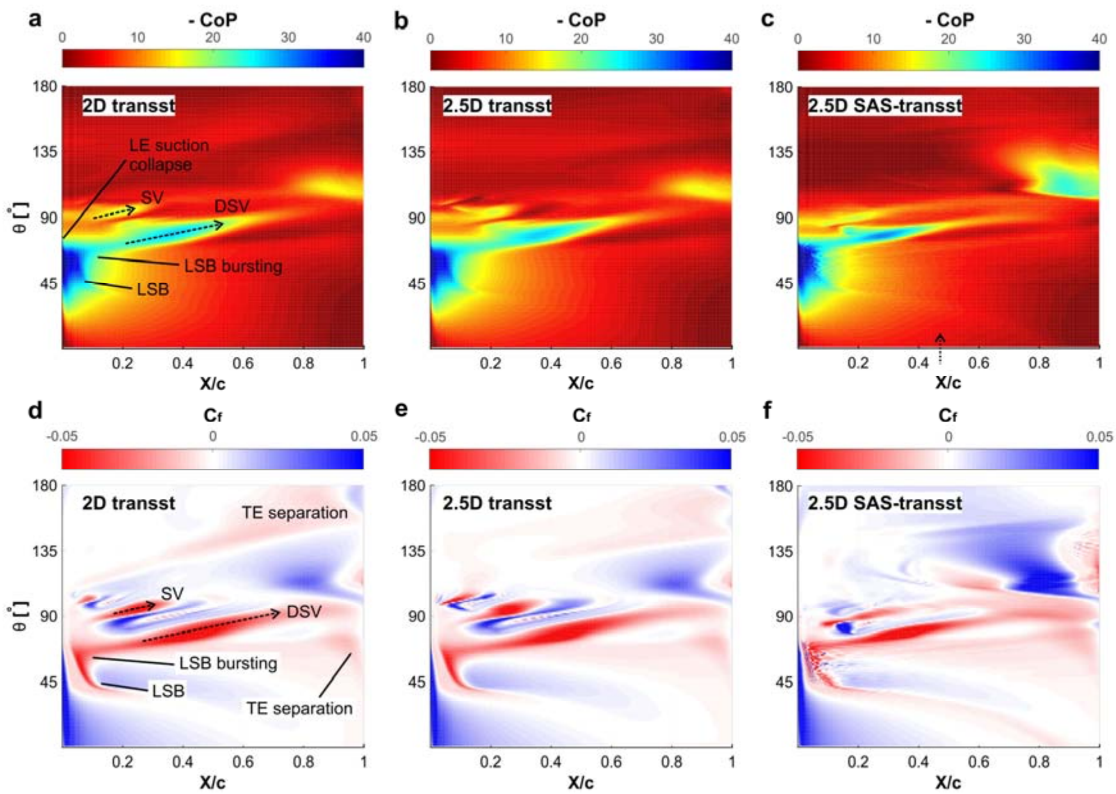

Figure 2. Spatiotemporal distribution of coefficient of (a-c) pressure and (d-f) skin friction over the blade suction side in the fore half of the last turbine revolution. 'LE', 'TE', 'LSB', 'DSV', 'SV' denote 'leading edge', 'trailing edge', 'laminar separation bubble', 'dynamic stall vortex' and 'secondary vortex', respectively.