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Comparative Study of RANS and LES for Transient Flow Characteristics in an EC Fan

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Extended Abstract

The selection of turbulence model is critical in computational fluid dynamics (CFD) [1], as it facilitates the understanding and accurate simulation of complex flow phenomena, including aerodynamics, heat transfer, and intricate flow patterns. Choosing the appropriate turbulence model is essential to ensure a balance between the simulation accuracy and computational cost. For highly turbulent flows, Direct Numerical Simulation remains prohibitively expensive for hydraulic machine simulations, even with advancements in computational techniques. Although computationally intensive, Large Eddy Simulation (LES) [2] provides a viable alternative by modeling small-scale turbulence while directly capturing large-scale fluctuations. Nevertheless, for the majority of hydraulic machine design processes, the Reynolds-Averaged Navier-Stokes (RANS) model has become the recognized industry standard [3].

Electrically Commutated (EC) fans, driven by electronically commutated motors, represent a significant advancement in air movement technology. They can offer superior energy efficiency, precise speed control, and quieter operation compared to traditional AC fans, making them ideal for a wide range of applications such as heating, ventilation, air conditioning, refrigeration, or data center. In this study, numerical simulations are conducted on the EC fan to evaluate and compare the effectiveness of two turbulence models including RANS coupled with a shear stress transport reattachment modification turbulence model and LES employing the Wall-Adapting Local Eddy-viscosity sub-grid scale model. To ensure a fair comparison, an identical grid system, time step, total simulation time, and other boundary conditions are utilized for both approaches. The results demonstrate that while RANS struggles to accurately capture small-scale and complex turbulent phenomena near the wall, it effectively predicts hydraulic performance and critical behavior within the EC fan, such as significant flow separation under deep stall condition. In contrast, LES excels at resolving unsteady flow patterns, making it more adept at detecting and forecasting separation flows at the leading edge and vortices at the trailing edge.

Through analysis of turbulence kinetic energy distribution at deep stall condition, it is observed that the flow separation leads to substantial energy loss at the inlet of the impeller. This energy loss primarily occurs at the suction side and propagates not only to the pressure side of the adjacent blade but also along the impeller passage toward the outlet area. At the impeller outlet, although the flow field remains chaotic due to turbulent propagation from the impeller passage, the energy loss decreases sharply, exhibiting minimal influence from the trailing edge vortex. The study further reveals that trailing edge vortices and certain separation flows within the impeller channel manifest primarily as vortex shedding associated with recirculation flows. Additionally, separation flow not only induces significant energy loss at the leading edge of the impeller but also results in a substantial time-varying pressure drop. This research emphasizes the importance of selecting an appropriate turbulence model for accurate performance predictions and flow stability analyses. While RANS effectively predicts steady hydraulic performance, LES proves superior in capturing transient flow phenomena and energy loss within the EC fan.

***Keywords*: EC fan, computational fluid dynamics, large eddy simulation, SST turbulence model, separation flow, energy loss, hydraulic performance.

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