

Chapter 19

Low-Speed Aerodynamic Analysis Using Four Different Turbulent Models of Solver of a Wind Turbine Shroud



M. M. Siewe Ngouani, Yong Kang Chen, R. Day, and O. David-West

Abstract This study presents the effect of four different turbulent models of solver on the aerodynamic analysis of a shroud at wind speed below 6 m/s. The converting shroud uses a combination of a cylindrical case and an inverted circular wing base which captures the wind from a 360° direction. The CFD models used are: the SST (Menter) $k-\omega$ model, the Reynolds Stress Transport (RST) model, the Improved Delay Detached Eddies Simulation model (IDDES) SST $k-\omega$ model and the Large Eddies Simulation Wall Adaptive model. It was found that all models have predicted a convergent surface pressure. The RST, the IDDES and the WALE LES are the only models which have well described regions of pressure gradient. They have all predicted a pressure difference between the planes (1–5) which shows a movement of the air from the lower plane 1 (inlet) to the higher plane 5 (outlet). The RST and IDDES have predicted better vorticities on the plane 1 (inlet). It was also found that the model RST, IDDES, and WALE LES have captured properly the area of turbulences across the internal region of the case. All models have predicted the point of flow separation. They have also revealed that the IDDES and the WALE LES can capture and model the wake eddies at different planes. Thus, they are the most appropriate for such simulation although demanding in computational power. The movement of air predicted by almost all models could be used to drive a turbine.

Keywords Low-speed aerodynamic · Wind turbine shroud · Turbulence models · Coanda effect · Flow direction change

19.1 Introduction

The recent problem of global warming and the concern for a sustainable energy resource for a better world have led to the development of wind turbines technologies to harvest the power of wind anyhow [1]. It has been noted that amongst the categories of wind generators, small wind turbines have been more and more popular for their

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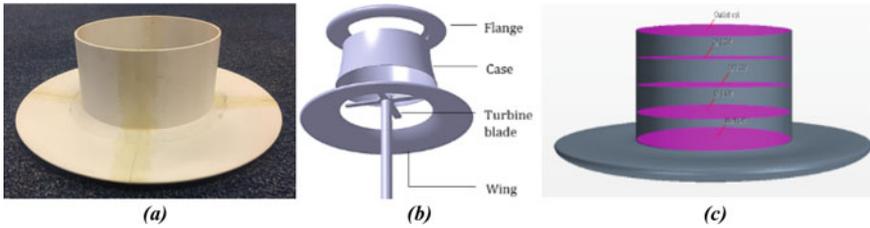


Fig. 19.1 Shroud view: (a) Printed wind turbine case; (b) Overall Schematics of the wind turbine; (c) Planes from which data has been investigated: from bottom to top (plane 1, 2, 3, 4, 5)

excellent adaptability to the urban area in terms of noise pollution and visual impact [2]. However, these small wind turbines have only been operated at wind speeds greater than 6 m/s [3]. In addition they have been found to produce still important turbulences, thus noise [4]. The purpose of this study is to identify the best turbulent model that would properly capture and characterise the nature of air flow inside and around the shroud. Thus, this paper presents a comparative aerodynamic analysis of the performance of a converting shroud to be used in a wind turbine system working at wind speed below 6 m/s using the software package Star-CCM turbulence models. The turbulence models investigated are notably: the SST (Menter) $k-\omega$ model, the Reynolds Stress Transport model, the Improved Delay Detached Eddies Simulation model (IDDES) SST $k-\omega$ model, the Large Eddies Simulation Wall Adaptive model (Fig. 19.1).

19.2 Experimental

19.2.1 $K-\omega$ Turbulent Model

It comprises modifications for low Reynolds number effects, compressibility and shear flow spreading compare to the realizable $k-\epsilon$. It is characterized by the turbulent Kinetic energy and the frequency $\omega = k/\epsilon$, where ϵ is the rate of dissipation of k . The SST model has been widely used in the aerospace industry, where viscous flows are typically well resolved and turbulence models are generally applied throughout the boundary layer. One advantage of $k-\omega$ model is its improved performance for boundary layers under adverse pressure gradients.

19.2.2 The Reynolds Stress Turbulent Model

The RST model has the greatest potential to accuracy. However, its results are still compromised by model assumptions and the use of the RST model does not justify

the extra computational effort for simple flows. They solve transport equations for all components of the specific Reynolds stress tensor. They can account for anisotropy effects due to strong swirling motion, streamline curvature, rapid changes in strain rate and secondary flows in ducts.

19.2.3 Detached Eddy Simulation: DES (IDDES SST $k-\omega$ Turbulence Model)

The DES-SST method is a unified LES/RANS hybrid which separates the domain into a near-wall region where RANS equations are solved and an outer region where LES equations are solved. This method is very dependant of the properties of the grid. The distinction between the two sets of equations is only done by the source term in the transport equation for a turbulence quantity. The idea of DES can however be extended to any specific turbulence model and a combination with the SST model exists which is evaluable on Star-CCM+.

According to Shur et al., the IDDES model provides a more flexible and convenient scale-resolving simulation model for high Reynolds number flows. Due to the fact that IDDES combines DES and wall-modelled LES, this new model helps in solving the grid-induced separation as it increases the modelled stress contribution across the interface.

19.2.4 Large Eddy Simulation (LES WALE)

Another turbulent model used in this research is the Large-Eddy Simulation (LES). However, this model describes high Reynolds Number time-evolving, three-dimensional turbulence. LES methods resolve the largest turbulent scales within a flow, and filter the smaller scales (dependent on mesh resolution) using various sub-grid scale models. The use of this approach requires careful application of the model, and significant computational resource. WALE (Wall-Adapting Local Eddy-viscosity) chose in this study provides zero eddy viscosity when dealing with laminar flow which is important for transition.

19.2.5 Geometry and Mesh Generation

The near wall was set to low y^+ . The number of prism layer used was 20 and the overall boundary layer was resolved. The mesh model was the unstructured polyhedral model. This achieved a number of cells of approximately 13.4 million (Figs. 19.2 and 19.3).

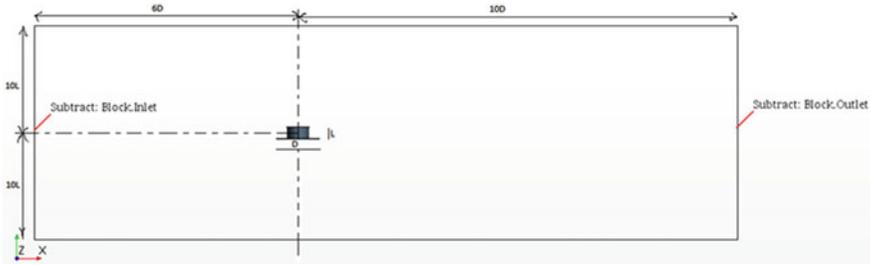


Fig. 19.2 Schematic view of the size of the domain of the CFD simulation within Star-CCM+

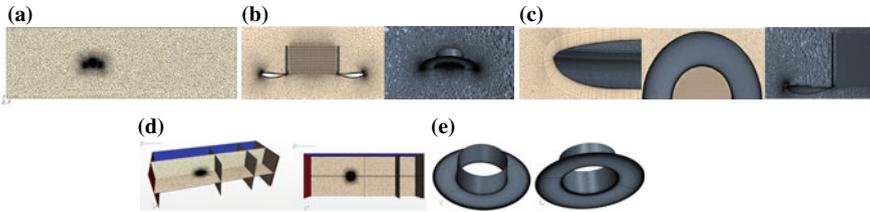


Fig. 19.3 Mesh generation around the shroud: **a** mesh structure within the domain; **b** section cut view of the mesh within the shroud; **c** prism layers distribution near the shroud; **d** mesh in bottom view of the shroud; **e** surface mesh on the shroud

19.3 Results and Discussion

Figure 19.4 shows the internal distribution of velocity and areas of vorticities. It can be seen that; the models RST, IDDES, and WALE LES capture properly the area of turbulences across the internal region of the case. However, only the LES WALE presents area of turbulences at inlet. In addition, all models, clearly show a region of low velocity and a region of high velocity. The latter region represents about a quarter of the whole cross section from planes 2 to 5.

The external velocities and wake distribution in the Fig. 19.5 reveals that the IDDES and the WALE LES can capture and model the wake eddies across the different planes. The SST k- ω does not capture any vorticity at all.

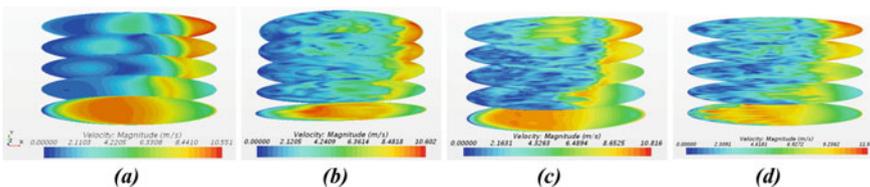


Fig. 19.4 Internal velocity scalar on the planes 1, 2, 3, 4, 5: **a** SST (MENTER) k- ω model, **b** (RST) Reynolds stress turbulence, **c** IDDES SST k- ω turbulence model, **d** LES WALE turbulence model

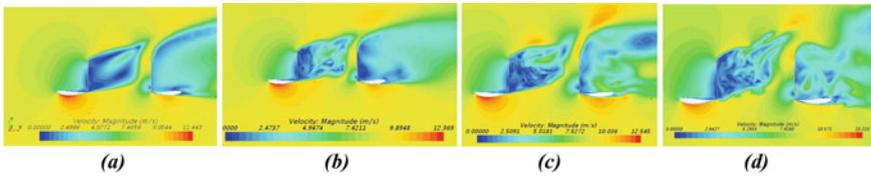


Fig. 19.5 External velocity scalar on coordinate plane (0, X, Y): **a** SST (MENTER) $k-\omega$ model, **b** (RST) Reynolds stress turbulence, **c** IDDES SST $k-\omega$ turbulence model, **d** LES WALE turbulence model

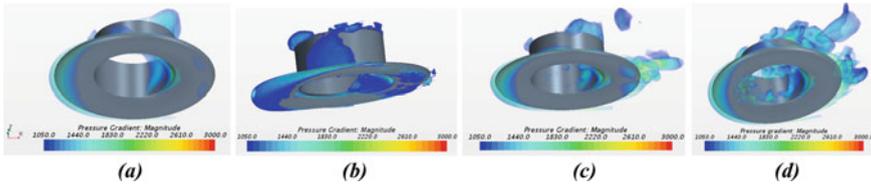


Fig. 19.6 Pressure gradient: **a** SST (MENTER) $k-\omega$; **b** RST model; **c** IDDES SST $k-\omega$; **d** LES WALE

Table 19.1 CFD parameters at 6 m/s

	SST $k-\omega$	IDDES SST $k-\omega$	RST	LES WALE
F (N)	-3.45	-2.56	-2.76	-2.8234
D (N)	2.27	2.29	2.145	2.045
Mass flow inlet plane 1 (kg/s)	0.236	0.242	0.231	0.235
Mass flow outlet plane 5 (kg/s)	0.096	0.13	0.10	0.12

The pressure gradient is an excellent parameter in determining the region of flow separation on the wing-surface or within the region. Hence, it can be observed in Fig. 19.6 that all models have predicted that the front top and bottom parts of the wing are subjected to separation and attachment. The reattachment is shown by the darker blue regions on the surface of the shroud.

Table 19.1 shows a summary of the different aerodynamic parameters calculated in the study. It can be seen that there is a difference in the mass flow rate between the inlet and the outlet. Therefore, there is a speed variation between those 2 planes.

19.4 Conclusion

The CFD investigation of the shroud has involved the use of 4 turbulent models such as: the SST (menter) $k-\omega$ model, the RST Reynolds Stress Turbulent model, the

improved Delay Detached Eddies simulation model IDDES SST $k-\omega$ and the LES large Eddies simulations WALE.

- The study has revealed the RST, the IDDES and the WALE LES are the only models which described external pressure gradient regions well and therefore the shroud turbulent wake.
- Internally, all models predicted a pressure difference between the planes 1 and 5 which shows a movement of the air from the lower plane 1 (inlet) to the higher plane 5 (outlet). This motion could be used to drive a turbine.
- The RST and IDDES predicted better vorticities on the plane 1 (inlet). Although RST, IDDES, and WALE LES captured areas of turbulences across the internal region, only the WALE shows the plane 1 (inlet) turbulences. Subsequently, the study showed that the internal region of the shroud is partially highly turbulent.
- Finally, all models showed that there is a downward lift which is produced due to the wing being inverted with an overestimation on the SST $k-\omega$ model. The drag is relatively the same across the models.

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