Numerical modeling of flow over a curved blade applied to low-Reynolds-number wind turbines

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ABSTRACT

Curved blades are an alternative for wind turbines operating at low Reynolds numbers, where aerodynamic performance is strongly influenced by viscous effects, transition, and flow separation (FAGBENRO, 2013; SOUSA, 2026). This study presents the numerical validation of the flow over a circular-arc curved blade using Computational Fluid Dynamics (CFD). The CA2 profile is considered, with a chord of 0.150 m, 10% camber, and 2% thickness, under a Reynolds number of approximately 1.0×10^5 (BRUINING, 1979). The simulations are performed in OpenFOAM 13 using the transitional k - ω SST-LM turbulence model. A mesh convergence study is carried out at an angle of attack of 8º, considering three meshes with 97,286, 171,806, and 284,068 cells. The intermediate mesh, with 171,806 cells, is selected as the best compromise between aerodynamic accuracy and computational cost. Compared with the finest mesh, differences of approximately 3.31% and 5.77% are obtained for the mean lift and drag coefficients, respectively, while the computational cost of the finest mesh is about 65% higher. The aerodynamic validation is subsequently performed for angles of attack from 0º to 12º, using time-averaged lift and drag coefficients over the simulated interval. The numerical results showed satisfactory agreement with the experimental trends reported for the CA2 profile, particularly for lift in the intermediate range of angles of attack. Drag showed greater sensitivity to the numerical model and mesh refinement, with larger discrepancies at the highest angle investigated. Overall, the results indicate that the adopted CFD methodology is capable of reproducing the main aerodynamic behavior of curved blades at low Reynolds numbers and can be used as a basis for subsequent analyses of wind turbine blade configurations.

Keywords: curved blade; computational fluid dynamics; low Reynolds number; mesh convergence; aerodynamic validation; wind turbine.

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REFERENCES

BRUINING, A. Aerodynamic characteristics of a curved plate airfoil section at Reynolds numbers 60,000 and 100,000 and angles of attack from -10 to +90 degrees. Delft University of Technology, Report LR-281. 1979.

FAGBENRO, K. A. Cascade Effects on Circular Arc Airfoils for Windmill Analysis. M. Sc. Thesis. University of Calgary, Calgary, Alberta, Canadá, 2013.

SOUSA, D. L. P., NOBRE, J. C. A., VAZ, J. R. P., VALE, S. B., ITOJE, H. J., PEREIRA, T. M. An empirical formulation for the cascade effect on multibladed horizontal axis wind turbines. *J Braz. Soc. Mech. Sci*. Eng. 48, 219. 2026. https://doi.org/10.1007/s40430-025-06199-0.