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A new miniature wind turbine for wind tunnel experiments: design, performance analysis and wake measurements

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Miniature wind turbines, employed in wind tunnel experiments to study the interaction of turbines with turbulent boundary layers, commonly suffer from poor performance with respect to their large-scale counterparts in the field. Moreover, although wakes of wind turbines have been extensively examined in wind tunnel studies, the proper characterization of the performance of wind turbines has received relatively less attention. In this regard, the present study concerns the design and the performance analysis of a new three-bladed horizontal-axis miniature wind turbine with a rotor diameter of 15 cm. Due to its small size, this turbine, called WiRE-01, is particularly suitable for studies of wind farm flows and the interaction of the turbine with an incoming boundary-layer flow. The turbine was designed based on Glauert's optimum rotor, and it was built with three-dimensional (3D) printing technology. Especial emphasis was placed on the accurate measurement of the mechanical power extracted by the miniature turbine from the incoming wind. In order to do so, a new setup was developed to measure the torque of the rotor shaft. Moreover, to provide a better understanding on the connection between the mechanical and electrical aspects of miniature wind turbines, the performance of different direct-current (DC) generators was studied. It is found that electrical outputs of the tested generators can be used to provide a rather acceptable estimation of the mechanical input power. Force and power measurements showed that the thrust and power coefficients of the miniature turbine can reach to 0.8 and 0.4, respectively, which are close to the ones of large-scale turbines in the field. Finally, the interaction of the turbine with a turbulent boundary layer was studied. The comparison of the spectral density of the thrust force and the one of the incoming velocity reveals new insights on the use of turbine characteristics to estimate incoming flow conditions. High-resolution stereoscopic particle image-velocimetry (S-PIV) measurements were also performed in the wake of the turbine operating at optimal conditions. These measurements can serve as a dataset for the validation of numerical models.