Wind Tunnel Study of Tandem Wind Turbines with Counter-Rotating Rotors: Performance Analysis

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This study examines the power performance of counter-rotating miniature wind turbines in a tandem configuration. Experiments were conducted under a zero pressure gradient, with a Reynolds number of 95,000 and an incoming velocity of 10 m/s. The aim was to assess the viability of the counter-rotating tandem setup and identify the most advantageous configuration for maximizing individual and combined power output. The tip speed ratio (TSR, λ) for wind turbines, which represents the ratio of blade tip tangential speed to actual wind speed, affects efficiency and varies optimally. Consequently, the upstream turbine ($T1$) operated at three TSRs ($\lambda_{T1} = 3.7$, 6.4, and 7.2). In contrast, the downstream turbine ($T2$) operated within a range of $1 \leq \lambda_{T2} \leq 8$ while also varying the separation distance between them at $1.25D$, $1.5D$, $2D$, $4D$, and $8D$, where D represents the turbine diameter. The power output $P_{turbine}$ obtained from the wind turbines is expressed as a function of the available wind power in equation 1, where ρ represents the air density, A is the swept area of the rotor, and V denotes the wind speed. The findings in figure 1a demonstrate that a counter-rotating tandem configuration produces the most favourable results when the separation distance is $1.25D$. However, the benefits of having a downstream counter-rotating turbine decrease as the separation distance increases. For instance, a separation distance of $8D$ as shown in 1b reveals that rotors rotating in the same direction produce higher output than a counter-rotating tandem setup. These results have important implications for the design and operation of wind turbine systems, as they provide valuable insights into the factors that affect their efficiency and performance. Future research should continue to investigate these factors further to optimize the design and operation of wind turbines.

$$C_P = \frac{P_{turbine}}{P_{wind}} = \frac{P_{turbine}}{\frac{1}{2}\rho A V^3} \tag{1}$$

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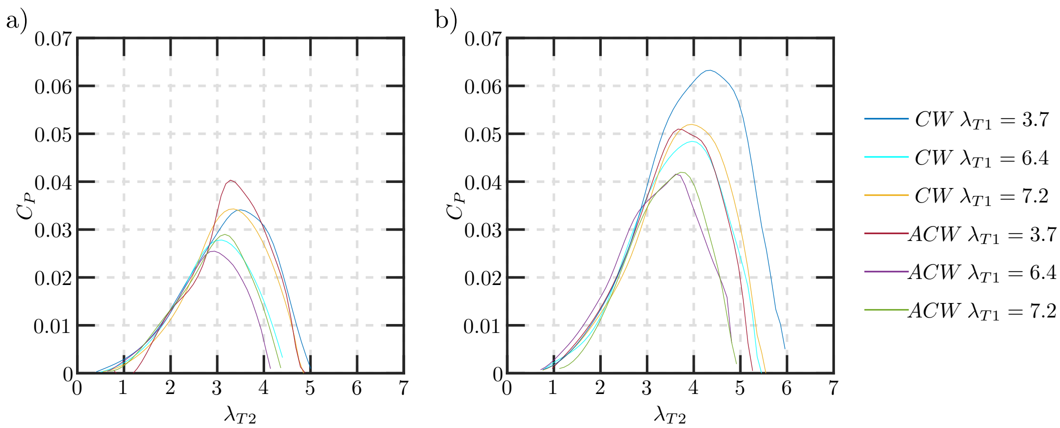

Figure 1: Comparison of downstream turbine performance for various upstream turbine TSR operations ($\lambda = 3.7, 6.4$ and 7.2) at a separation distance of a) 1.25D and b) 8D.