Advances in Aerodynamic Modelling of Crosswind Kite Power Systems

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We present numerical results from an ongoing research on the aerodynamics of crosswind kite power systems (CKPS). These results have been obtained from a computational fluid dynamics (CFD) simulation ($\sim$ 51 days of CPU time) for a large-scale kite ($\sim$ 5 MW) flying on a prescribed circular trajectory in the simplified straight downwind configuration, where the tether elevation angle is assumed to be zero. The CFD simulation was performed using a URANS flow solver combined with the $k - \omega$ SST turbulence model. Also, the kite exact geometry was modelled. The results uncover interesting aspects of the flow behaviour in the vicinity as well as downstream of the kite. Most studies on the aerodynamic modelling of CKPS neglect the effects of flow retardation or 'induction factor' as well as the wake flow developed downstream of a crosswind kite. However, results from our previous [1,2] and current studies confirm that such effects exist and may significantly degrade the aerodynamic performance of CKPS, and thus should be considered when designing and optimizing a kite farm layout, as well as when predicting the economical returns of such system.

Our numerical results for the above-mentioned kite system show that the average induction factor over the annular area swept by the kite is $a = 0.12$, which also agrees well with the analytical solution obtained from the theory developed in [2]. If this induction factor is ignored, for example, it will result in nearly 20% power output overestimation and consequently considerable underestimation of levelised cost of energy. In addition, it is found that the span of the near-wake region, within which static pressure is recovered to the freestream pressure, is of the order of 3 to $4R$; R being the gyration radius. Beyond the near-wake region, the wake expands almost linearly with the streamwise distance from the rotor plane, x (positive in the downwind direction) towards the centre of the annulus, while it expands with a lower rate towards the outer flow region. Inside the wake region, it is observed that the flow velocity undergoes a deficit which in shape looks like a Gaussian profile. At $x = R$, the peak flow velocity deficit is around 25% of the freestream velocity. The flow deficit then gradually decreases with x; for example, at $x = 10R$, the peak flow velocity deficit is nearly 10%.

The present results are intended to provide some insights about why the effects of the flow retardation and wake flow of individual kites, which have been ignored so far, should be taken into account for kite farms layout design and optimization. This new requirement should be met in addition to the geometrical interference which is commonly considered as the sole requirement. Further research is certainly warranted on the effects of the tether aerodynamic interference, non-zero tether elevation angles as well as energy harvesting modes on the aerodynamic performance of CKPS.

References:

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