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WIND FARMS OF THE FUTURE

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1\ Introduction

Wind farms are composed of arrays of wind turbines, but turbulence (chaotic air motion) created by the first row decrease the energy output of the turbines behind by up to 40%[1]. A solution might be to use Vertical Axis Wind Turbines (VAWTs) - the blades spin around an axis perpendicular to the ground, since recent studies showed increasing performance up to 20% for the subsequent rows [2]. Yet, VAWTs are not as efficient in isolation as today's propeller design. Thus, the question arised; which design generates the most energy when composed in wind farms? To answer that multiple layouts of VAWTs were analysed.

2\ Methodology

A pair of VAWTs was analysed for different positions of the second rotor (Figure 1) using computer simulations known as computational fluid dynamics (CFD). The CFD model was verified against existing studies in literature [2], and the supercomputer at Oxford Advanced Research Computing and pooled computers at Oxford Brookes University were exploited to solve the billions of equations. Each simulation took on average 3 weeks to solve, and the total simulation time of the project was beyond 12,000 hours.

3\ Results

Figure 2 shows how the pair performed as a unit. If the value was above 1, the turbines generated more energy than if they were operating on their own. In comparison, modern wind farms would generate results significantly below 1, hence why these findings are promising for the potential of VAWT farms. The optimal layout was when the second rotor (R2) was positioned 75 degrees to the wind direction, and this layout exhibited augmentations of 15%.

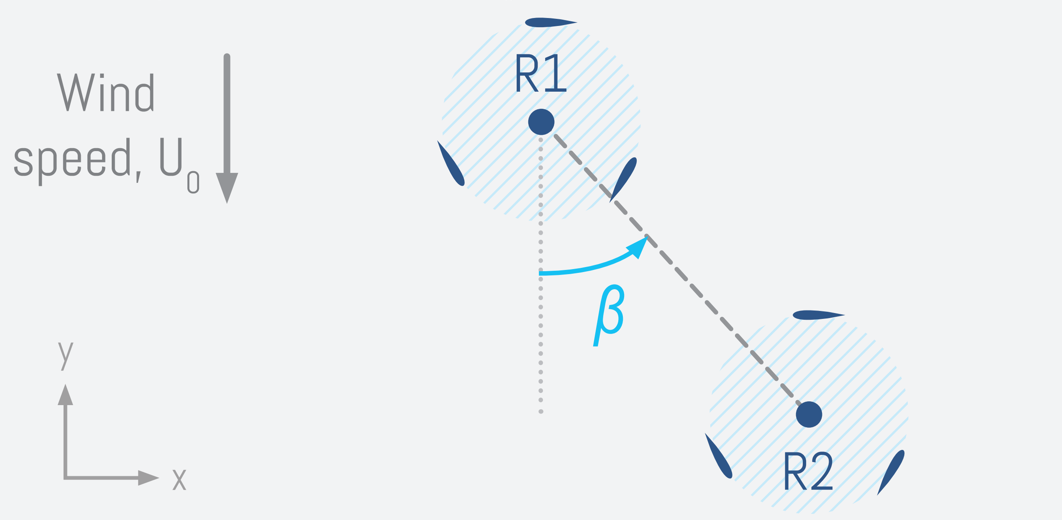

Figure 1: A pair of VAWT seen from above, and β was the array angle.

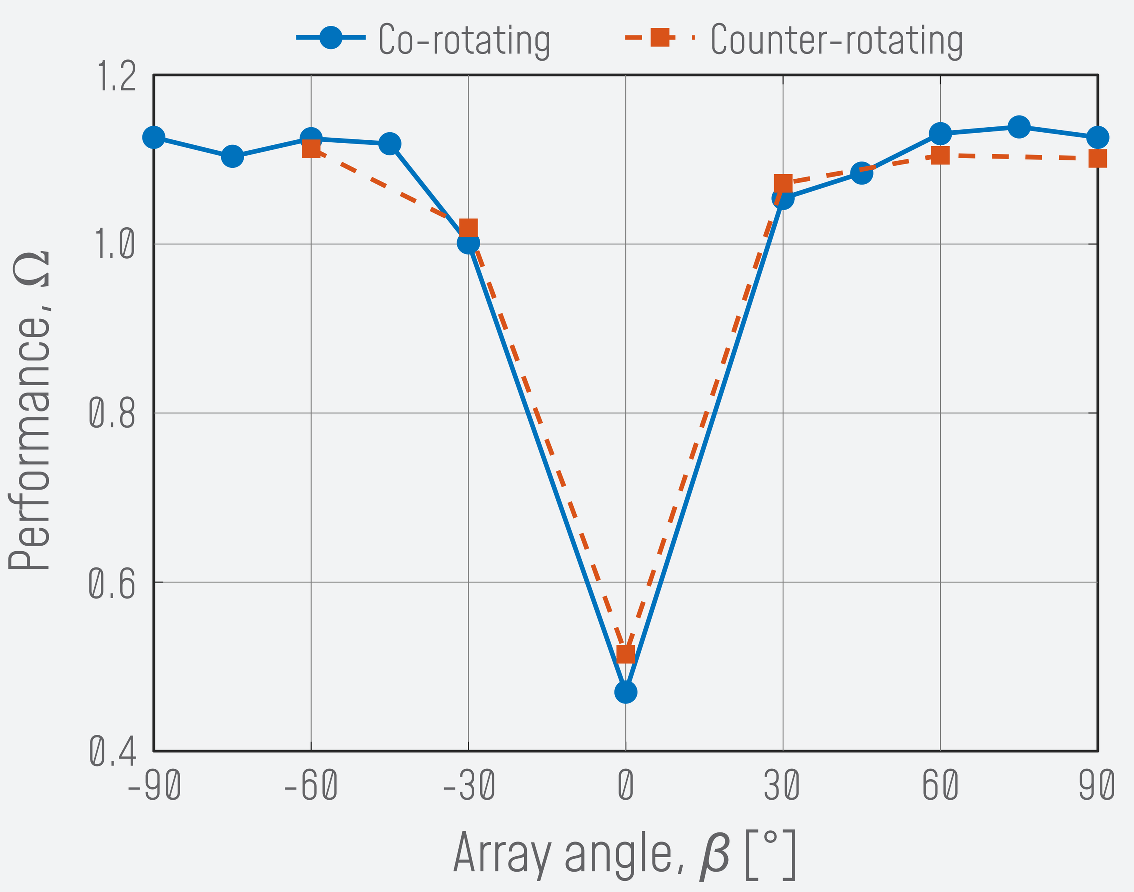

Figure 2: Performance of the pair against array angle. if the value was above 1, the pair generated more energy than if they were operating on their own.

Finally, three rotors in series were also investigated, and here it was found that the efficiency increased as the rotor number increased. Efficiency is a measure of how much of the wind energy was converted into electricity, and the higher, the better. Currently, wind technology is limited by how good the turbines are at not interfering with each other. However, the data showed that for these VAWTs, the trend is likely to be opposite. They are limited by how much wind energy is actually available at a given location, and therefore, oceans can be utilised to a greater extent. In conclusion, fewer wind farms would be required to meet future energy demands, and costs would be lowered too.

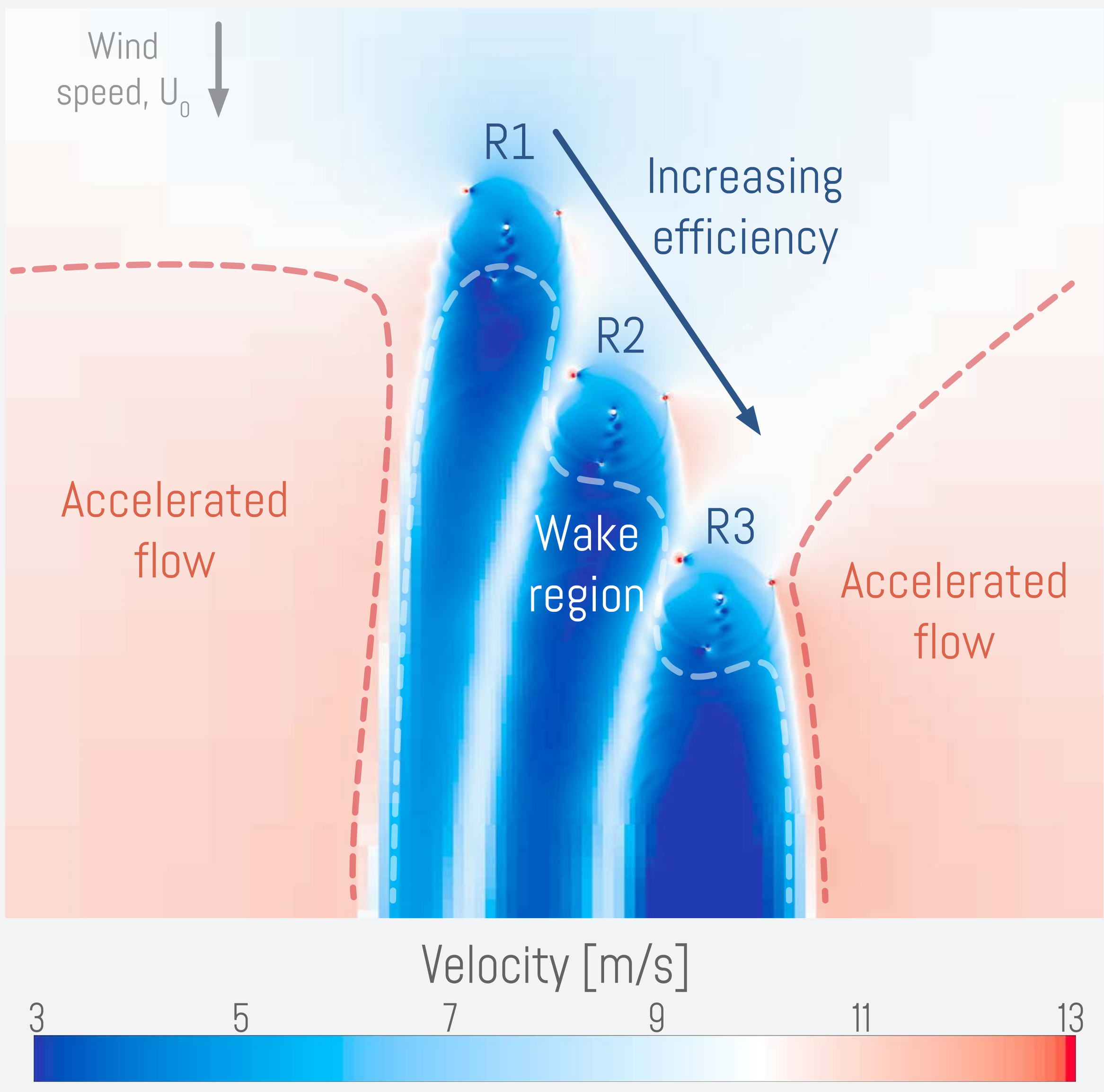

Figure 3: Velocity diagram of three VAWTs in series. The red regions indicate wind was accelerated, and blue areas have smaller wind speed.

4\ Discussion

Researchers are still not certain about the explanation of this phenomenon. Yet, there is one dominant hypothesis that this project confirms too. Figure 3 is a velocity diagram of one of the computer simulations. The white areas show that the wind speed was equal to the freestream velocity, i.e. infinitely far away from the turbines, the red regions indicate greater velocities, i.e. wind was accelerated, and blue areas indicate low wind speed. The energy extracted by a wind turbine depends on the wind speed cubed, U^3, hence if the VAWTs are positioned in the red regions, they will generate more energy than if they were operating in isolation. Presently, wind turbines do not exhibit this behaviour, and as result, for these augmentations to occur for a given wind farm, the VAWT design must be applied.

5\ Conclusion

VAWTs could potentially replace today's propeller design, since they increase each other's efficiencies up to 15% when composed in wind farms. Yet, more research must be carried out to consider manufacturing, maintenance and installation costs too. In the end, it all comes down to lowering the price of electricity. Nevertheless, the findings of this project are expected to be published in a journal article(s) this summer.

References: [1] Ahmadi-Baloutaki, M. (2015) 'Analysis and improvement of aerodynamic performance of straight bladed vertical axis wind turbines'. [2] Brownstein, I. D., Wei, N. J. and Dabiri, J. O. (2019) 'Aerodynamically Interacting Vertical-Axis Wind Turbines: Performance Enhancement and Three-Dimensional Flow', Energies, 12(14), pp. 2724.