Hydrodynamics of two closely spaced vertical axis turbine wakes

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Partnership for Research In Marine Renewable Energy
7th PRIMaRE Conference
7-8 July 2020

Introduction

- Horizontal Axis Turbines (HATs), widely adopted option due to their high energy conversion rate are not well-suited for river applications as they are designed to operate in high-velocity environments and rotate at high speeds, which can lead to drastic consequences to ecosystems.
- Vertical Axis Turbines (VATs) are well suited for harnessing kinetic energy from low velocity environments such as rivers, in contrast to their highly efficient and widely adopted horizontal-axis counterparts, which operate at higher velocities [1].
- VATs operate at relatively low rotational speeds which has the advantage of reducing their impact on ecosystems, especially reducing risks for fish collision and noise generation [2].
- Their standalone efficiency is low, which has hindered their development at commercial scales. Research into arrays of turbines has predominantly focused on HATs [3], with scarce understanding of how multiple VATs wakes interact.

Study aim: to quantify the three-dimensional wake hydrodynamics behind twin VATs, with the overarching goal of designing arrays of river stream VATs for use at the project site of Vereda el Salado community on the River San Juan, Colombia.

Figure 1. Google maps image indicating the location of the study site, Verada el Salado, Colombia.

Methods

- The wake hydrodynamics of these turbine arrays were experimentally tested in a recirculating flume, measuring the cross-sectional flow field up to 10 turbine diameters downstream and across the 1.2m width of the flume using an Acoustic Doppler Velocimeter (ADV).
- A sampling frequency of 200Hz and sampling times of 180 to 300 seconds were used.
- The turbines of diameter D=0.12m, made of three NACA 0015 blades, were tested as a single turbine or two turbines laterally spaced by 1.5D and 2.0D.
- Turbines rotated in the same direction, at a constant rotational velocity in order to attain the optimum tip speed ratio of 1.9 [2].
- DC motors were used to impose the turbines rotational speed.

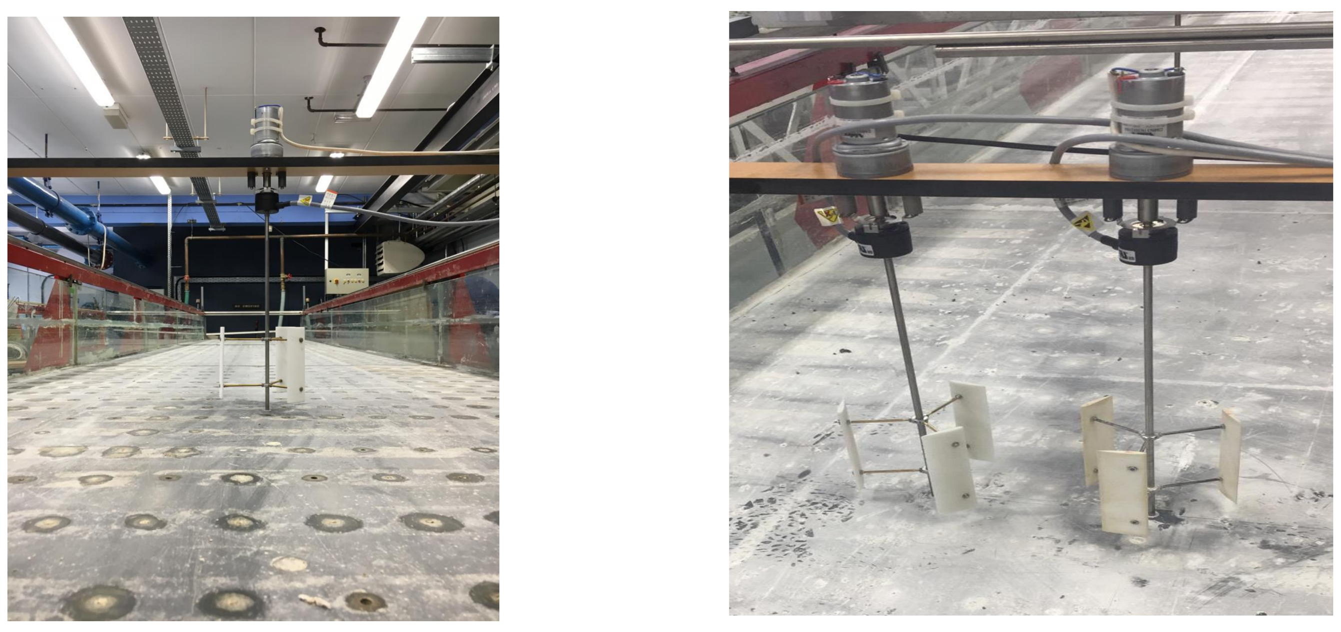

Figure 2. Experimental setup photographs of 1 turbine (left) and 2 turbines tested with lateral spacings of 1.5D and 2.0D (right).

Q (Ls^{-1})	H (m)	U_o (ms^{-1})	Fr (-)
53	0.23	0.19	0.13

Details of flow conditions

Diameter (m)	Height (m)	Area (m^2)	Distance below water surface (m)
0.12	0.12	0.0144	0.09

Details of the turbines' geometry

Results

- The wake of the single turbine was asymmetrical about its centerline and neared full recovery by 10D downstream (Fig. 3).
- Regions of high turbulence intensity delimited low velocity wakes and showed that the individual wakes merge into a single wake for the two-turbine cases.
- The momentum recovery in the far wake, at 10D downstream, was smaller with a lateral spacing of 1.5D compared to the single turbine and 2D lateral spacing cases (Fig. 3).
- A higher blockage by the two VATs and absence of bypass velocity in between them was observed for the 1.5D lateral spacing whilst a high-velocity region in between devices was developed for the 2D lateral spacing case (Fig. 4).

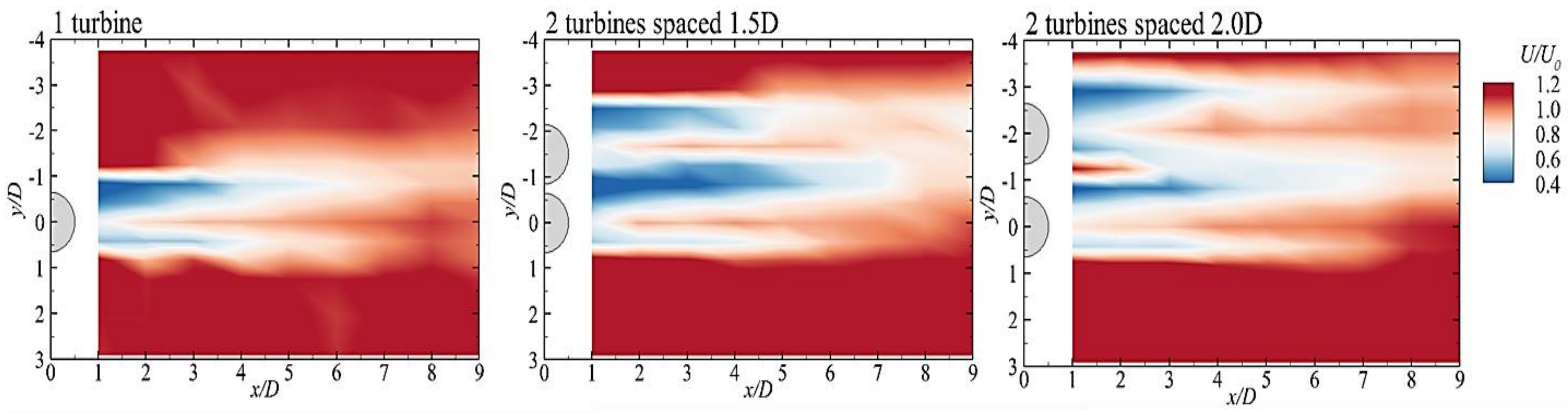

Figure 3. Mean longitudinal velocity fields (U/U_0) across the channel width for three cases with one turbine and two turbines laterally spaced by 1.5D and 2.0D.

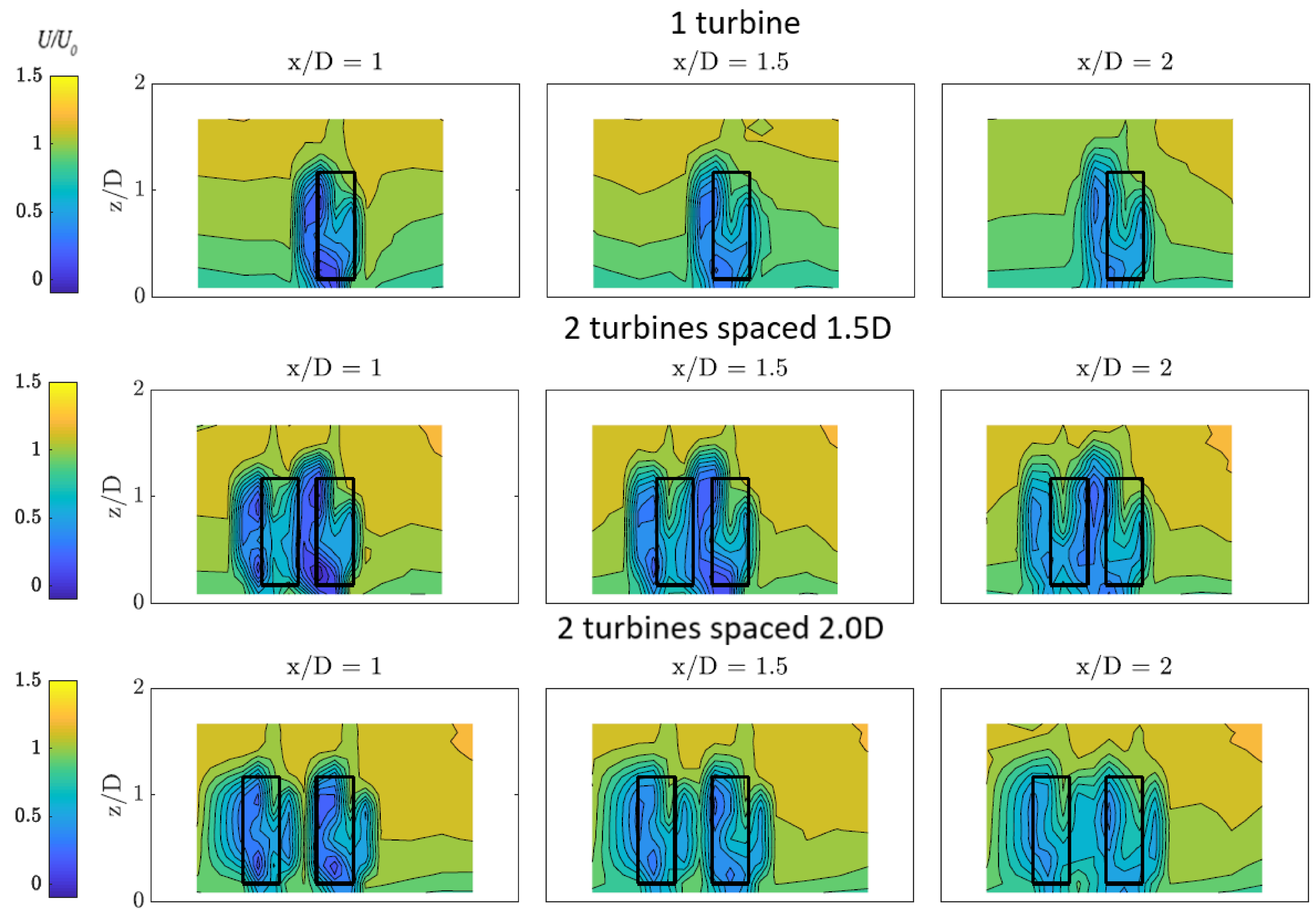

Figure 4. Contours of mean velocities (U/U_0) at three cross-sections at x/D=1.0, 1.5 and 2.0 for three cases with one turbine and two turbines laterally spaced by 1.5D and 2.0D. Rectangular box outlines indicate the location of the turbines

Discussion, conclusions and outlook

Our study will inform the design of turbine arrays for river environments with VATs arrays becoming a financially viable technology solution for developing countries.

- An asymmetric VAT wake distribution was observed for all cases.
- Momentum wake recovery was over 90% by 10D downstream.
- The wakes of the two turbines merged into a single wake.
- A 1.5D spacing between twin turbines led to a higher local flow blockage than a spacing of 2.0D, which delays the wake recovery distance.

Future work will involve turbine array performance measurements, testing of larger scale turbine arrays, and assessment of environmental impact by evaluating the effects of these turbines on fish passage.

Acknowledgement: This research was funded by the EPRSC Global Challenges Research Fund (GCRF). S. Mueller is funded by the Water Informatics Science and Engineering Centre for Doctoral Training (WISE CDT) under grant EP/L016214/1 from the Engineering and Physical Science Research Council (EPSRC).

Keywords: Vertical axis turbine, river turbine, turbine wake interaction, arrays

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