IMPACT OF ROTOR TOWER AND BLOCKAGE EFFECTS IN A HYBRID BEM-CFD SIMULATION OF A VERTICAL-AXIS HYDROKINETIC TURBINE

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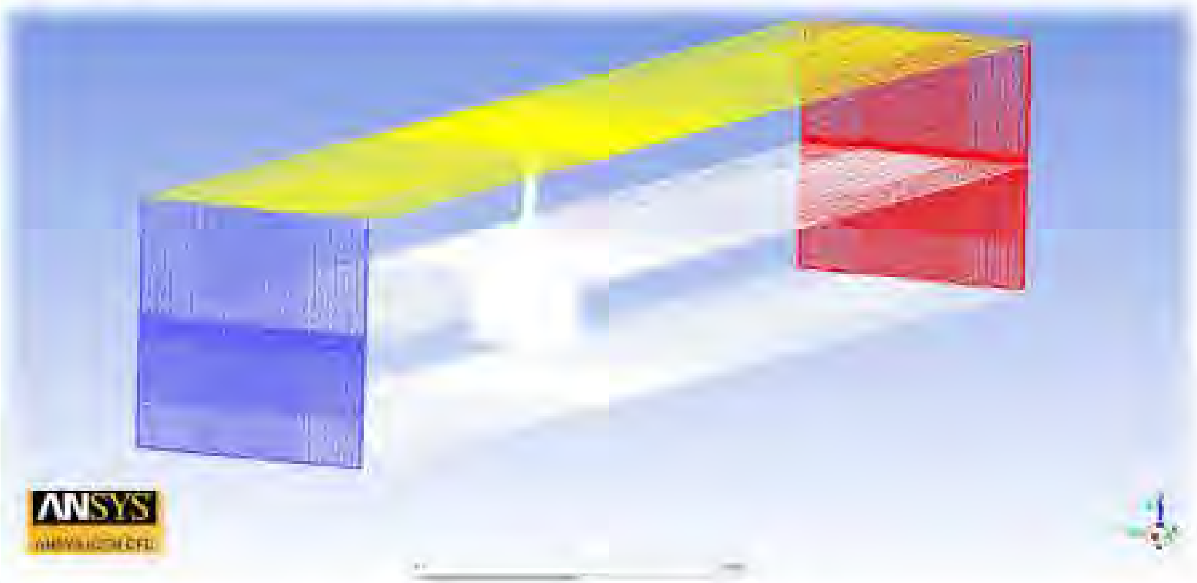
INTRODUCTION

Experimental analyses on the 3D character of straight-bladed Vertical Axis Turbine (VAT) wakes show that vertical advection created by the blade tip vortex shedding downstream the rotor can be deemed the main responsible for an extraordinary wake recovery [1-2] that makes VAT wakes much shorter than horizontal axis turbine wakes. These promising results could make VAT preferable for farms. This study focuses on a vertical-axis turbine performance and wake characteristics in a water channel, simulated by a hybrid Blade Element Momentum (BEM)-CFD numerical model based on ANSYS-ICEM and ANSYS-FLUENT. This model was developed in the DESTEC Department of the Engineering School at University of Pisa [3-4]. The turbine was simulated at different tip immersion depths, with and without its rotor tower, in a narrow channel and in an unconfined environment and the results were compared. Since this numerical study was conceived to help planning a real experimental campaign, turbine and channel dimensions and operating conditions are similar to those of IFREMER laboratory in Boulogne-sur-mer.

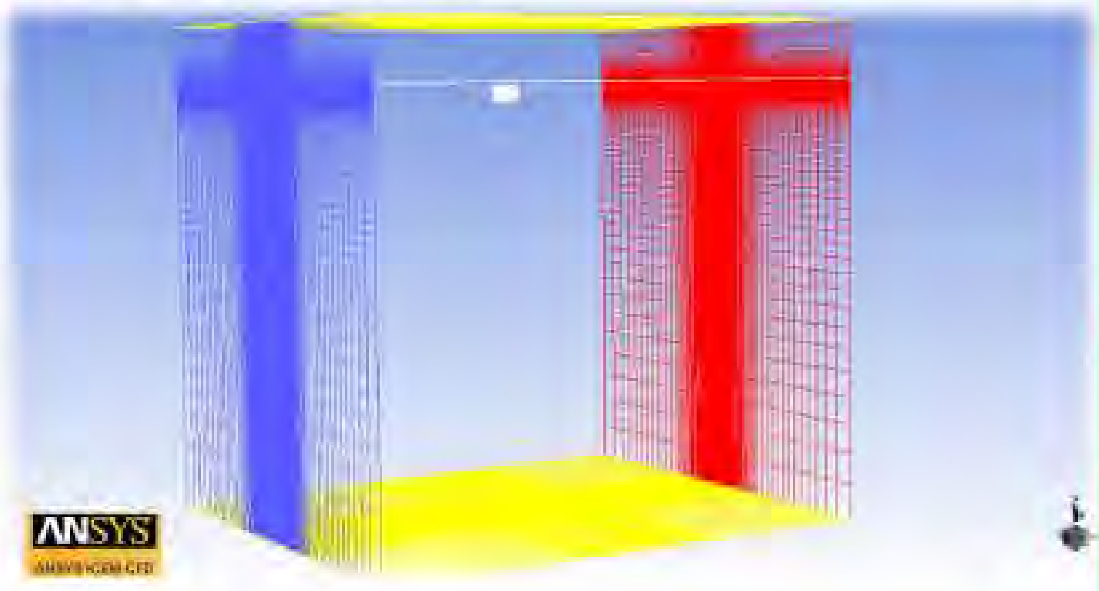
METHODS

The three working grids, generated by means of the ANSYS-ICEM software, are multi-block structured. The first grid has not the rotor tower, while the second one has a 0.17 m diameter tower; both grids are in a narrow channel. The last grid has not a tower but has a very large computational domain compared to the machine dimensions. In the BEM-CFD model, mainly developed by the B. Rocchio [3], the Actuator Cylinder Model has been employed: the blades are replaced by suitable momentum sources and a porous cylinder represents the turbine.



The original turbine is a Darrieus H with a diameter of 1.5 m and 3 blades of 1 m in length. The undisturbed stream velocity is 0.8 m/s and the turbine tip-speed-ratio (the ratio between the peripheral velocity of the blades and the turbine velocity) is 1.8. The analysed tip immersion depths are 0.26 m and 0.50 m for the narrow channel with the addition of 1 m depth in the wide channel. Wake characteristics are studied at downstream distances from turbine axis of 1, 2 or 3 diameters.

In regards of the CFD results, Matlab custom codes were the mathematical instrument used for the evaluation of the turbine global *power coefficient* (C_P, the ratio between the extracted power and the available power in the fluid) and the C_P of the single blade, graphed as a function of θ, the azimuth angle.

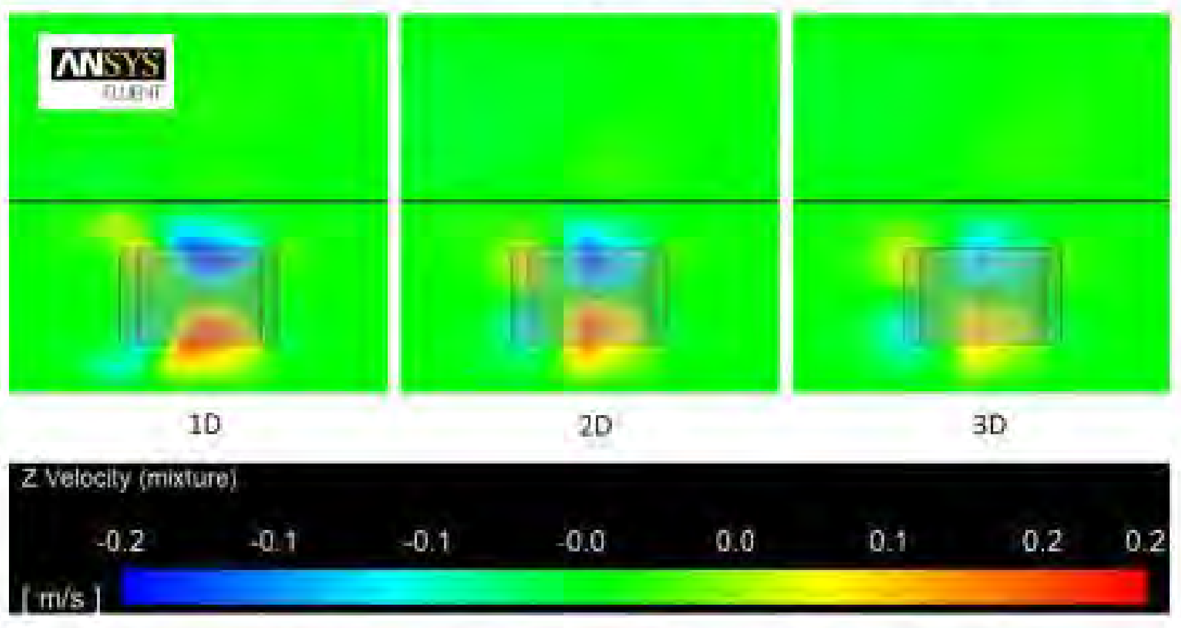


RESULTS

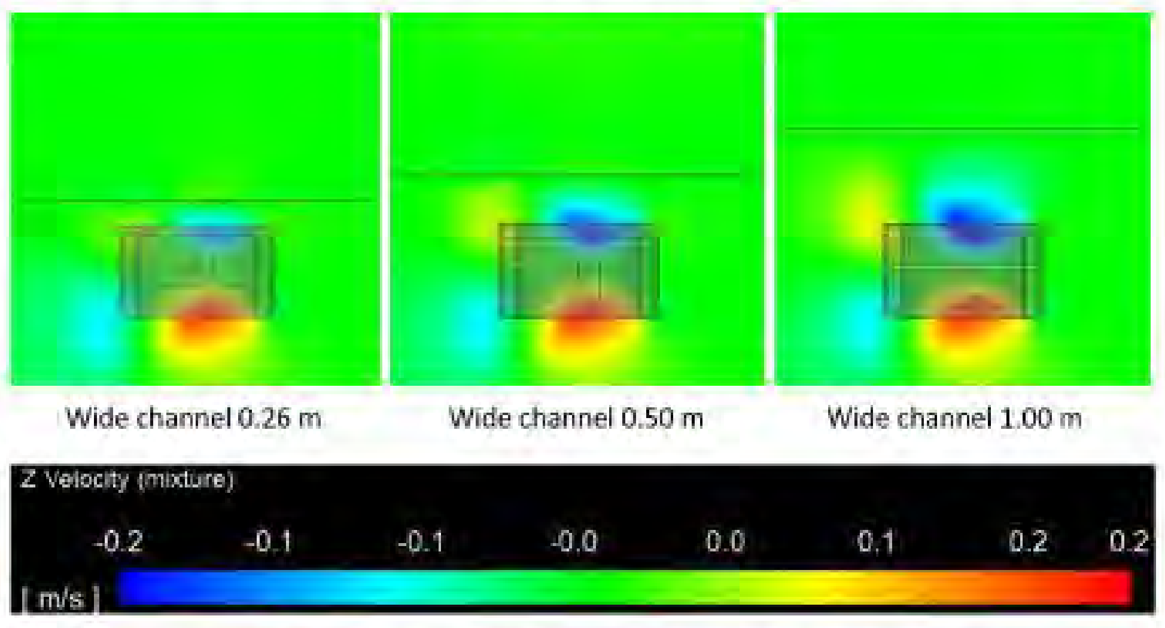
Despite the blades are not physically present in the BEM-CFD model, it can be seen that this low computational cost model is able to capture even the main details of the wakes, such as the two pairs of counter-rotating vortices that are relevant for the phenomenon of wake recovery (as proved by experimental tests performed on vertical axis tidal and wind turbines [1-2]).

Moving further away from the machine in streamwise direction, vortices intensity fades, as shown in the figures, due to the turbulent energy cascade.

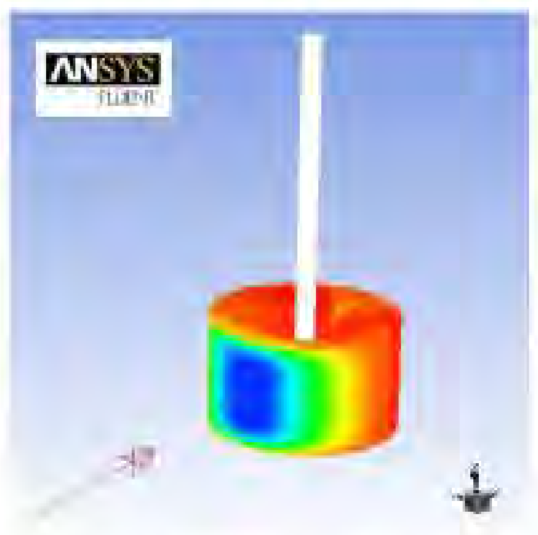
If the turbine is in a deeper place beneath the free surface, there is more high-energy fluid above its top, therefore the vertical component of velocity in the eddies is more intense and the recovery is assisted.



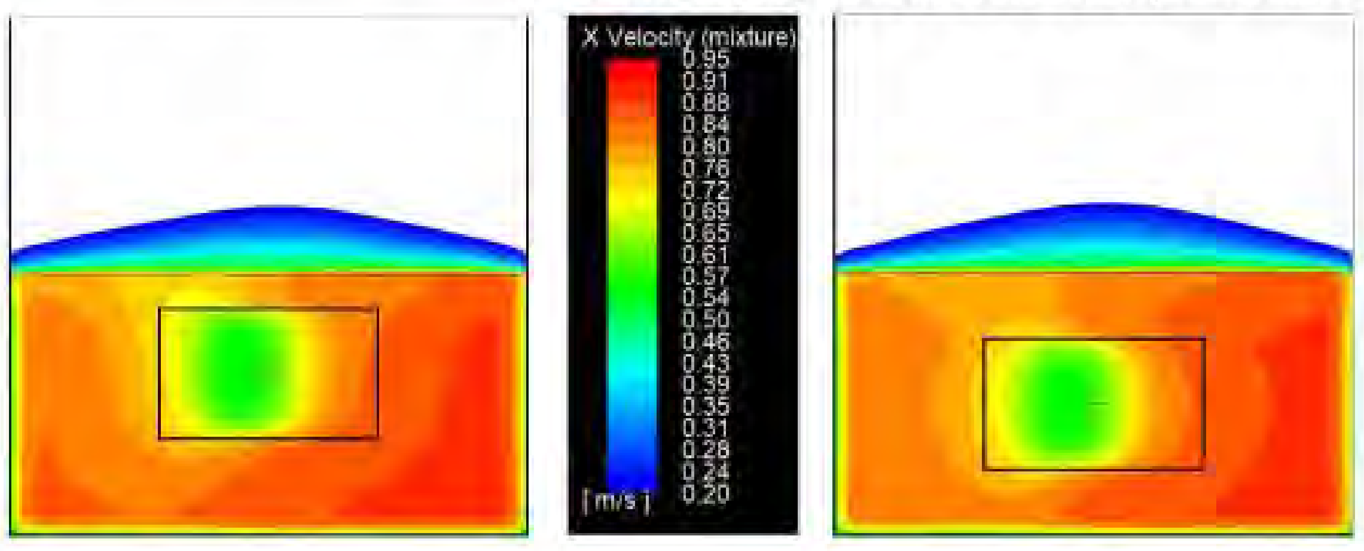
Comparison of the vertical component of velocity, on vertical planes at downstream distances of 1, 2 and 3 diameters, at 0.50 m of depth, without rotor tower.



Comparison of the vertical component of velocity, on a cross plane at downstream distance of one diameter, at variable immersion depth, without rotor tower, in the wide channel.

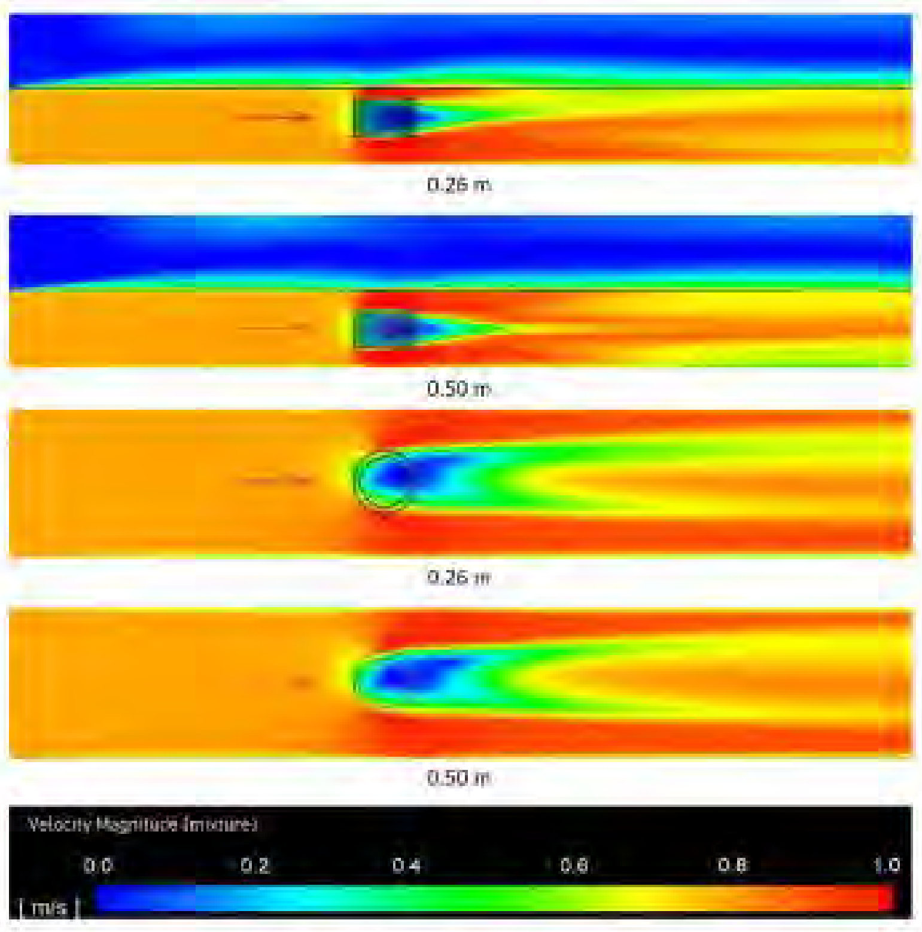


Momentum sources ring.

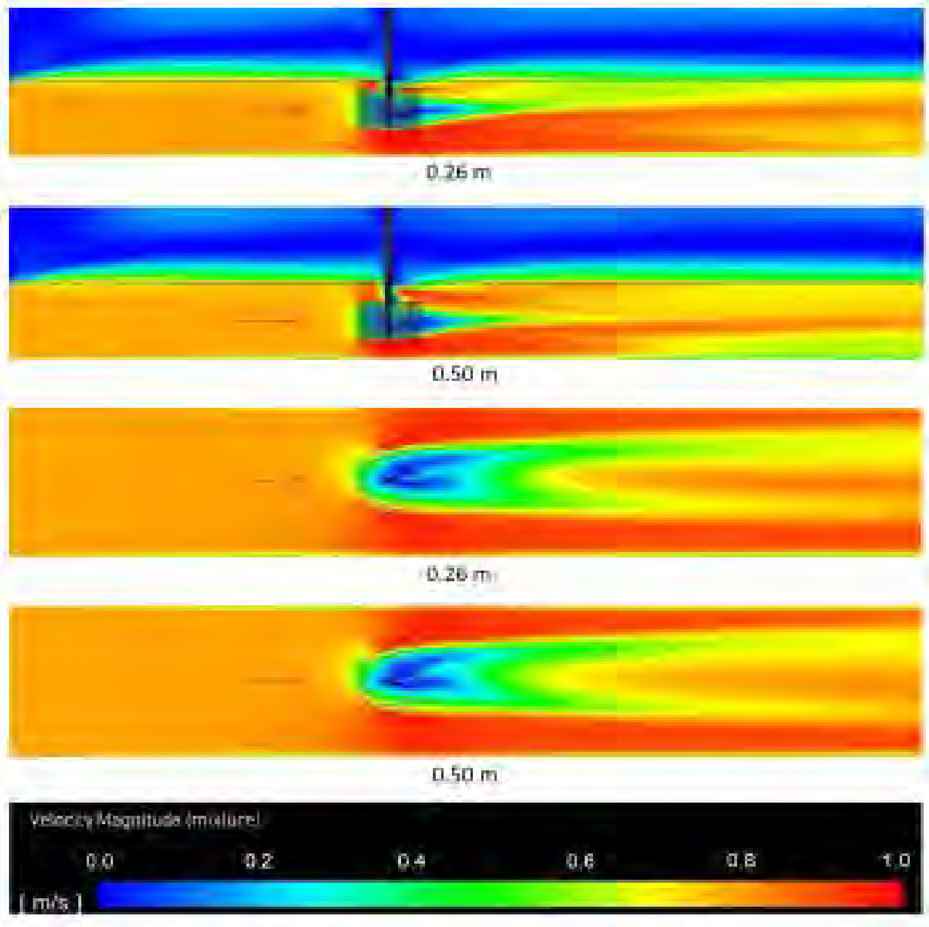


Horizontal velocity intensity on a vertical plane immediately in front of the turbine with tower.

Images are very similar, as confirmed by the proximate mean C_P values. At the tip immersion depth of 0.26 m, immediately in front of the ring, the fluid above the turbine is slower than below due to the free surface proximity.

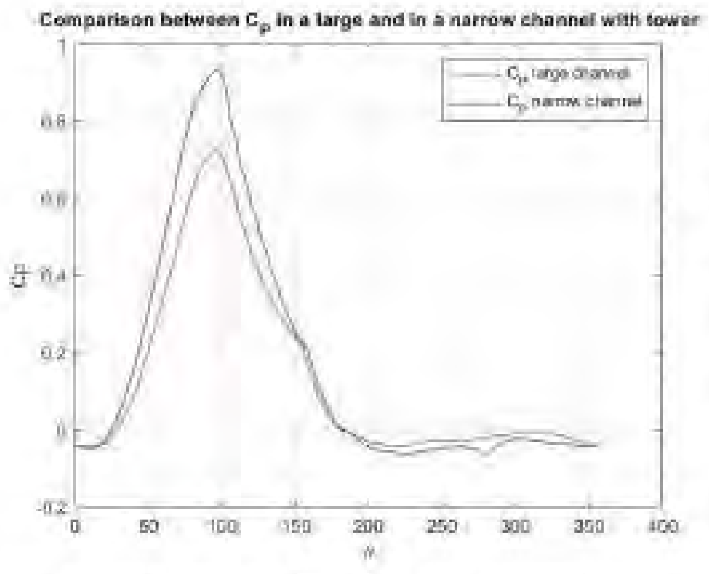


Comparison of velocity, on a vertical plane crossing the turbine axis and on a horizontal plane crossing the turbine centre, at variable immersion depth, without rotor tower.



Comparison of velocity, on a vertical plane crossing the turbine axis and on a horizontal plane crossing the turbine centre, at variable immersion depth, with rotor tower.

The fluid above and below the turbine, in the narrow channel has a high velocity because of the lower crossing area. The asymmetry in the vortices, more evident for the shallow turbine, inclines the wake towards the air-water interface. The rotor tower helps the fluid mixing inside the turbine (as proved by the yellow color, instead of blue-green, on horizontal planes).



Single blade C_P for tip immersion depth of 0.50 m.

The effect of the rotor tower is to reduce the extracted power, both locally and globally, due to the physical obstacle, visible for θ=270° in the single blade C_P graph.

When the same turbine is simulated in the unconfined domain, the C_P is much lower, because of the absence of the wall blocking effects, as shown in the figure on the left (in blue the curve in a narrow channel with the rotor tower, in red the curve in a very large channel without the tower).

CONCLUSIONS

<u>*Up to now:*</u>

- Wake recovery promoted thanks to vorticity at the tips and along the wake.
- At shallower immersion depths, the flow above the turbine is accelerated due to the smaller free passage space and this corresponds to better machine performance, without rotor tower, both for narrow and large channel.
- Turbine tower creates a shadow zone for the blades and slows down the fluid: average global C_P is always lower.
- Turbine tower creates further mixing in the fluid and perturbation of the free surface: the maximum C_P is obtained more far from the free surface (tip immersion depth of 0.50m).
- In a wide computational domain, the blockage due to the channel walls does not occur, so around the turbine the fluid has a lower acceleration: the machine can extract less kinetic energy from the flow.

		Tip depth (m)	C_P mean
Narrow channel	Without tower	0.26	0.5121
		0.50	0.5094
	With tower	0.26	0.5024
		0.50	0.5070
Wide channel	Without tower	0.26	0.3980
		0.50	0.3977
		1.00	0.3963

<u>*Next steps:*</u>

- Search for the upper limits of performance increases as the free passage section decreases.
- Simulations in ANSYS FLUENT at a higher and lower tip-speed-ratio, to look for less similar turbine performances as the depth of immersion varies.
- Tests with surface waves to check the effects on wake recovery at different immersion depths.

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