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PERFORMANCE EVALUATION OF THE VERTICAL AXIS AUTOROTATION CURRENT TURBINE (VAACT) VIA CFD

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INTRODUCTION

The increasing demand for renewable energy has driven the development of innovative hydrokinetic turbines, especially for environments with low current velocities, such as rivers and shallow channels, etc. Among these technologies, the Vertical Axis Autorotation Current Turbine (VAACT) represents a promising and cost-effective solution for small-scale hydrokinetic applications due to simple manufacturing, installation, and maintenance, and surprisingly higher efficiency. The concept introduced by Fernandes et al. (2009) has presented good performance at low Reynolds regimes (Rostami & Fernandes, 2015; Soares et al., 2023).

MATERIALS AND METHODS

This research implements a two-dimensional CFD model using Ansys/Fluent (Ansys Inc., 2021) to evaluate the hydrodynamic performance of the S-shaped VAACT. A User-Defined Function (UDF) is employed to incorporate the structural mass moment of inertia (I). The constant Power Take-Off (PTO) torque, is modelled by a weight-lifting system, and the external damping torque, representing system losses. This is applied as follows:

$$T^{ext} = \underbrace{mgr_p}_{PTO\ torque} + \underbrace{K_t \cdot \Omega(t)}_{Damping\ torque} \tag{1}$$

where m is the mass lifted, g is gravity, r_p is the pulley radius, K_t is the damping coefficient, and $\Omega(t)$ is the rotational speed.

The S-shaped turbine has a chord length of 0.3 m, a swept height of 0.47 m, and a thickness of 5 mm. The computational domain consists of 13 zones, using a sliding-mesh approach to simulate the rotor's rotation while maintaining high mesh quality in the wake and near-wall regions. A structured grid with layers near the rotor ensures accurate resolution of boundary layers and vorticity.

The model underwent comprehensive verification procedures, including domain size sensitivity, mesh refinement studies, and time-step analysis. Following the International Towing Tank Conference (ITTC, 2023) guidelines, the uncertainties related to the grid, domain, and time-step were quantified, resulting in a global simulation uncertainty of approximately 3.21%.

Experimental validation was performed in the 22-meter current channel of the Laboratory of Wave and Currents (LOC-COPPE/UFRJ), with tests at Reynolds numbers ranging from 64,500 to 134,100. The experimental setup used an optical tracking system (Qualisys) to measure angular displacement and an Acoustic Doppler Velocimeter (ADV) to capture flow velocity and turbulence intensity. The PTO system was implemented mechanically through a weight-lifting device, allowing direct comparison with the numerical model. A similar experimental setup is employed in Soares et al. (2023).

RESULTS

The numerical and experimental results revealed that the drag force is the main contributor to the instantaneous efficiency, while the lift force governs the hydrodynamic torque. When the drag coefficient (C_D) is low, the lift coefficient (C_L) compensates, maintaining the turbine’s rotation and contributing to energy extraction (see Figure 1).

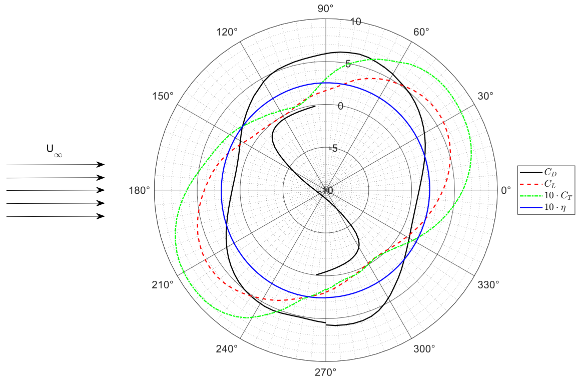
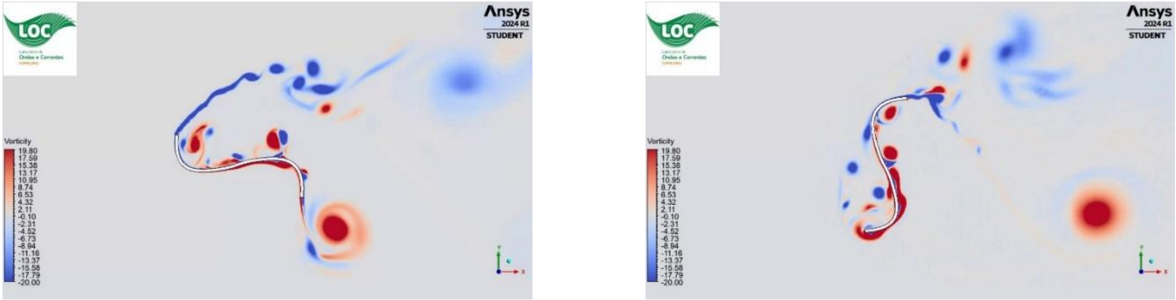


Figure 1. – Polar diagram identifying the efficiency (η), drag (C_D), lift (C_L), torque (C_T) coefficients as a function of the azimuth angle; the S-shaped turbine developed by LOC is also presented



(a) (b)

Figure 2. – Vorticity field around the rotor with profile: (a) parallel to the flow; (b) perpendicular to the flow

The polar diagrams show critical azimuth angles where the lift-to-drag ratio is maximized, particularly at −10° and 170°. At these positions, the device achieves peak efficiency. However, as the Reynolds number increases, the turbine's efficiency decreases, confirming that the S-shaped VAACT is optimized for low to moderate flow speeds.

Flow visualization highlighted the generation of opposing vortices by the returning and advancing blades (see Figure 2). The returning blade produces negative torque due to high-pressure zones when perpendicular to the flow, acting as a brake on the system. In contrast, the advancing blade operates in a low-pressure region, generating positive torque and sustaining rotation (see Figure 3).

This resisting torque is a key factor limiting performance. To mitigate this, literature (He et al., 2019) suggests using deflectors upstream of the returning blade to prevent flow stagnation and reduce negative torque contributions.

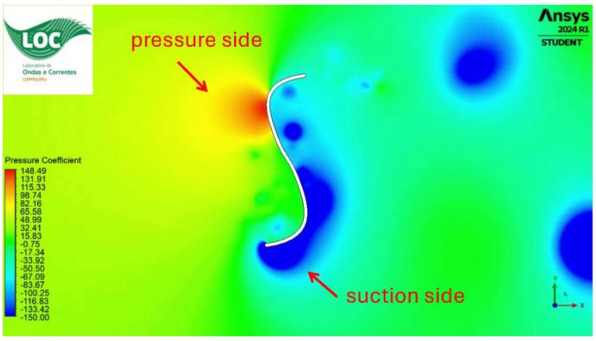


Figure 3. – Pressure coefficient around VAACT profile, identifying pressure and suction sides

CONCLUSIONS

This study presented a validated CFD model for the LOC´s S-shaped Vertical Axis Autorotation Current Turbine, coupled with a Power Take-Off system modeled as external damping and torque application. The main conclusions are:

1. The hydrodynamic performance is driven by both drag and lift, not only drag or only lift;
2. Synchronizing the PTO system with the hydrodynamic torque could improve efficiency, suggesting the use of advanced generators or adaptive control mechanisms.
3. The returning blade generates significant resisting torque, limiting performance. Deflector-based solutions could reduce this effect.
4. The model's predictions were validated against experimental data following the guidelines.
5. Up to now, the highest efficiency reached 25 % at TSR = 1.5, but still there is room for improvement.

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