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Prediction of acoustic field induced by a tidal turbine under straight or oblique inflow via a BEM/FW-H approach

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Abstract. This study investigates the influence of loading and inflow conditions on tidal turbine performance from a hydrodynamic and hydroacoustic point of view. A boundary element method is utilized for the former to investigate turbine performance at various loading conditions under zero/non-zero yaw inflow. The boundary element method is selected as it has been selected, tested, and validated to be computationally efficient and accurate for marine hydrodynamic problems. Once the hydrodynamic solutions are obtained, such as the time-dependent surface pressures and periodic motion of the turbine blade, they are taken as the known noise sources for the subsequence hydroacoustic analysis based on the Ffowcs Williams-Hawkings formulation given in a form proposed by Farassat. This formulation is coupled with the boundary element method to fully consider the three-dimensional shape of the turbine and the speed of sound in the acoustic analysis. For validations, a model turbine is taken from a reference paper, and the comparison between numerical predictions and experimental data reveals satisfactory agreement in hydrodynamic performance. Importantly, this study shows that the noise patterns and sound pressure levels at both the near- and far-field are affected by different loading conditions and sensitive to the inclination imposed in the incoming flow.

Keywords: boundary element method; Ffowcs Williams-Hawkings (FW-H) formulation; hydroacoustics; marine current turbine; renewable energy

1. Introduction

In recent years, interest in the energy harvesting system from water resources has been growing because of the need for clean and renewable energy. Among many different types of energy generators based on tidal stream, the horizontal axial tidal turbine has been most frequently installed over the globe because of its high efficiency, similarity to wind turbines, and the analysis tools that were initially developed for propellers but equally applicable to turbine problems without extensity modifications in numerical aspects. Because of the predominantly oblique flow about the turbine axis in most tidal current sites, typical turbine arrangements are subject to unsteady forces on the blade. The potential impacts of the unsteadiness on turbine performance thus need to be studied to understand the overall turbine efficiency in either a single or farm arrangement.

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Appendix A. Selection of the friction coefficient over the blade

C_f in this work is calculated according to the ITTC-1957 friction correlation line

$$C_f(r) = \frac{0.075}{(\log_{10} Re_{local}(r) - 2)^2}, \tag{A.1}$$

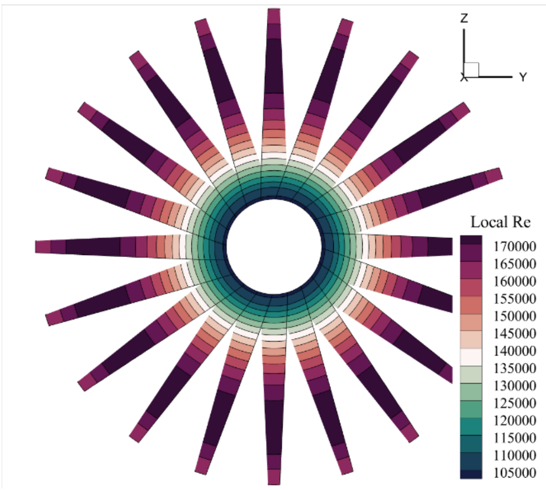
where $Re_{local}(r)$ is the local Reynolds number (Eq. (A.2)) calculated at each station of the blade based on the radial location r of the station, local inflow including rotational component, and global Reynolds number $Re_{global} = 1e6$ given for the cases we looked at

$$Re_{local}(r) = Re_{global} \frac{\sqrt{V(r)^2 + \omega^2 r^2}}{V_R} \frac{c(r)}{D}, \tag{A.2}$$

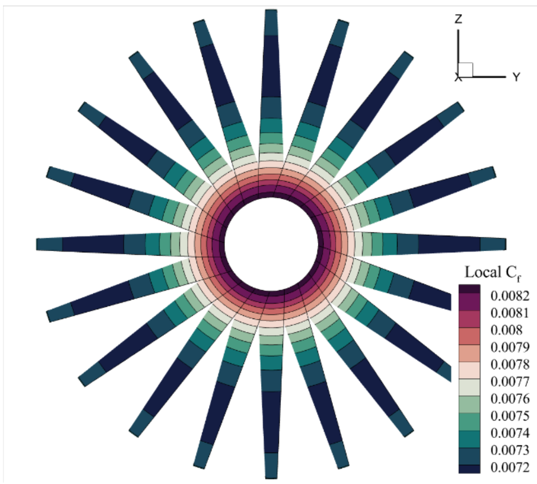
$$Re_{global} = \frac{V_R D}{\nu}, \tag{A.3}$$

where $V(r)$ is the local inflow; $c(r)$ the local chord; D the diameter of the turbine blade; ν the kinematic viscosity; and $V_R = \sqrt{V_{up}^2 + (0.7n\pi D)^2}$ is the reference velocity with V_{up} being the inflow speed far upstream.

Each station is considered independent, and the influence from neighboring stations is ignored during the calculation. Predicted $Re_{local}(r)$ and $C_f(r)$ are in a function of radial distance from the blade center and given constant over the respective station. Fig. A.1 shows the predicted $Re_{local}(r)$ and $C_f(r)$ for the turbine with 25° pitch and 0° yaw at TSR = 6. The range of $C_f(r)$ in this case is predicted $.0072 < C_f(r) < .0082$, based on which the present work selected a constant $C_f = .008$ (over the entire blade surface) that allows the most reliable and stable BEM predictions.



(a)



(b)

Fig. A.1 Predicted (a) local Reynolds number and corresponding (b) local friction coefficients based on the ITTC-1957 friction correction line; 25° blade pitch, 0° inflow yaw, and TSR = 6.