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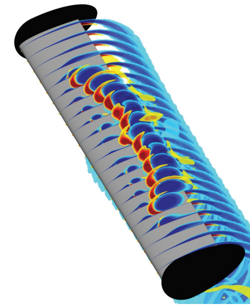
Hydrokinetic Turbine Based on Oscillating Hydrofoils



Optimization by Numerical Simulations (CFD)

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Context

A new concept of **hydrokinetic turbine** using **oscillating hydrofoils** to extract energy from water currents (tidal or gravitational) has been developed.

Numerous aspects of the oscillating foils **hydrodynamics** were studied and **optimized** using **2-D and 3-D URANS CFD simulations** (ANSYS Fluent). Some of these aspects are presented here.

The numerical predictions were validated by the results of an experimental campaign which confirmed that the power-extraction efficiency of the oscillating-hydrofoils turbine is competitive with the performances of the best rotor blade turbines (see poster 4th INORE Symposium).

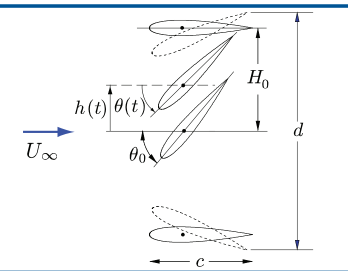
Hydrofoil motion

The hydrofoil kinematics is a combined pitch-heave motion expressed as sinusoidal functions:

pitching $\theta(t) = \theta_0 \sin(\omega t)$

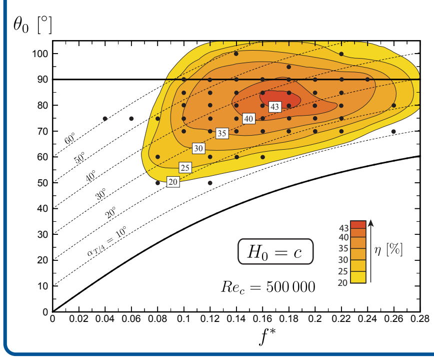
heaving $h(t) = H_0 \sin(\omega t + \pi/2)$

$\omega = 2\pi f$



Parametric study on a 2-D oscillating foil

Based on hundreds of 2-D URANS simulations, the **power-extraction efficiency** η of the oscillating foil turbine has been mapped in relevant parametric spaces of **reduced frequency** f^* and **pitching amplitude** θ_0, all other parameters being fixed.



Reduced frequency

$$f^* = fc/U_\infty$$

Power-extraction efficiency

$$\eta = \frac{\overline{P}}{1/2\,\rho\,U_\infty^3\,d\,b}$$

For a heaving amplitude of one chord, the power extraction efficiency of a single oscillating hydrofoil reaches 43% for a reduced frequency of 0.18 and a pitching amplitude of 80 deg.

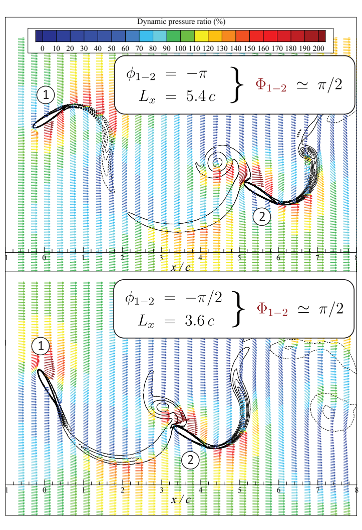
Optimal tandem configuration

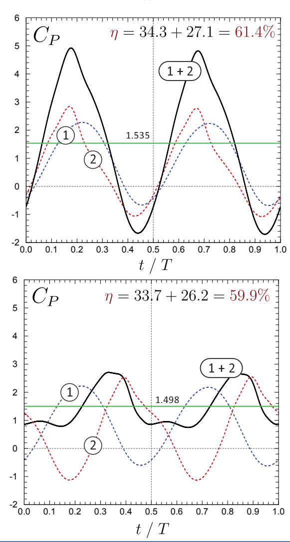
To consider a system of two oscillating hydrofoils in a tandem configuration is interesting when the objective is to maximize the power-extraction efficiency.

An extensive parametric study has shown that best performances were obtained when the **downstream foil interacts closely with wake vortices** such as to benefit from **additional dynamic pressure due to vortex-induced velocities**. On the other hand, some tandem configurations result in a downstream foil contributing negatively to the total power extracted.

The **global phase shift** (Φ_{1-2}) is the dominant parameter related to the **relative positioning in the tandem configuration**. It incorporates both the **inter-foil distance** (L_x) and the **relative phase difference** between oscillating motions (ϕ_{1-2}). Two different tandem configurations exhibit very similar performances when sharing a similar global phase shift. However the instantaneous total power production is strongly affected by the **motion phase** ϕ_{1-2}. It is advised to use a motion phase of $\phi_{1-2} \simeq \pm\pi/2$ in order to **level the power production** throughout the cycle.
The similitude in performance and the impact of the motion phase on the total instantaneous power curve is illustrated below from two cases sharing the same frequency and motion amplitudes.

global phase shift $\Phi_{1-2} = 2\pi \frac{L_x}{U_\infty T} + \phi_{1-2}$ [rad]



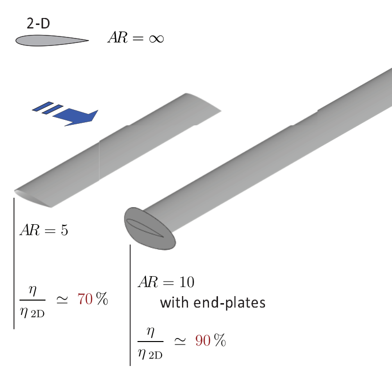


3-D considerations

Drop of performance relative to 2-D prediction

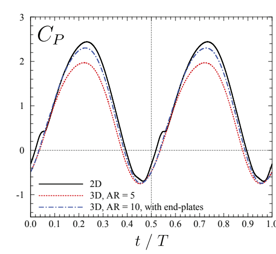
2-D CFD simulations are convenient due to their relatively low computational cost. However, they overpredict the lift force and thus the power extracted from an oscillating-foil turbine. This is due to the condition of zero loading at the wingtips that exist for a foil of finite span (b).
Once the drop of performance with respect to the 2-D prediction is quantified it can serve to estimate the actual 3-D performances from the 2-D predictions at similar operating conditions.

The power-extraction efficiency η of a foil with an aspect ratio (AR) of 5 is 70% the 2-D prediction whereas a foil with $AR = 10$ and equiped with end-plates reaches 90% of the 2-D prediction.



Power coefficient

$$C_P(t) = \frac{P(t)}{1/2\,\rho\,U_\infty^3\,c\,b}$$



Effect of a misalignment with the upstream flow

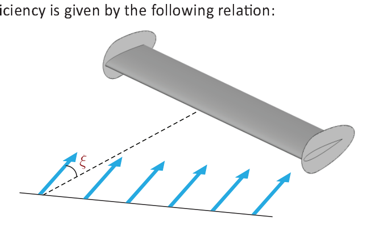
The **drop of performance** predicted for an upstream flow at a yaw angle ξ with the foil chordline is found to be **consistent with the kinetic energy flux projected in the chordwise direction**. Thus a good estimate of the power-extraction efficiency is given by the following relation:

$$\tilde{\eta} = \eta_{\,\xi=0^\circ}\,[\cos(\xi)]^3$$

where $\eta_{\,\xi=0^\circ}$ is the efficiency of the perfectly aligned case.

This results in a relative drop of performance equals to:

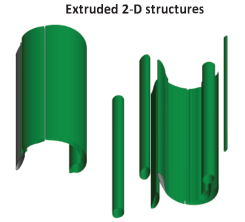
9 % at $\xi = 15°$
31 % at $\xi = 30°$.



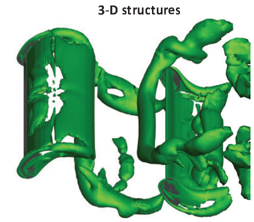
Spanwise coherence of shed vortices

In the case of tandem hydrofoils (one behind the other), the downstream foil contribution to power extraction is found to be affected between 2-D and 3-D predictions due to the broken spanwise coherence of shed vortices in the 3-D reality.

Extruded 2-D structures



3-D structures



Fonds de recherche sur la nature et les technologies Québec

Project website: http://hydrolienne.fsg.ulaval.ca/en

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