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Impact of support structures on Turbine farm power

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Summary: The flow characteristics of a channel in the presence of a turbine array are investigated analytically using a 1D model. The impact of support structures on the turbine farm's total power output are not usually considered but we include its influence here and show that it plays a significant role in the power delivered. Also it is shown that installing too many turbines can have a potentially unacceptable adverse effect on the flow rate and the effect of introducing a flow rate reduction constraint is explored.

Introduction

The analytical works of Garrett & Cummins [1], Vennell [2] and Nishino & Willden [3] present various models of flow past turbine arrays but none have extensively considered the impact of support structures. In this paper, we consider the influence of three major factors on the opposing thrust presented to the channel. These components are i. thrust from the turbine rotor, ii. thrust from the support structure and iii. seabed friction. The influence of these factors on various output parameters such as the efficiency of the turbine, number of turbines that can be installed in a channel, total power output from the farm and power output per turbine are studied. These parameters are studied for different channel characteristics.

Method

We consider a channel of rectangular cross section, A_c, length $L = 5\text{km}$, width, $w = 1\text{km}$ and depth, $h = 40\text{m}$. The 1D Euler equation for flow in the channel is given by

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + g\frac{\partial \zeta}{\partial x} = -F \tag{1}$$

where u is the flow velocity, ζ and F are the driving head and resistive force per unit mass respectively. Following Garrett & Cummins [1], we write the flow velocity in terms of volume flow rate ($Q = A_c u$) and integrate equation (1) along the channel. We assume that the flow is drawn into and exits the channel smoothly. Representing the driving head as a sinusoidal tide with amplitude a and frequency ω, we obtain

$$c\frac{dQ}{dt} - ga\cos(\omega t) = -FL \tag{2}$$

where c is the area coefficient given by $\int_0^L A_c^{-1}\,dx$.

The total opposing force in the channel is given by

$$F = \frac{1}{\rho L A_c}\frac{1}{2}\rho u|u|\left[n\left(C_T A_t + C_D A_s\right) + C_f A_b\right] \tag{3}$$

where n represents the number of turbines installed in the channel; C_T, C_D, C_f are the coefficients of turbine thrust, support structure drag and seabed friction; A_t, A_s, A_b are the turbine rotor area, support structure frontal area and channel bed area. The first two terms on the right hand side are due to the presence of turbines and their support structures respectively and the third term is due to seabed friction. The volume flow rate (or velocity) is clearly a function of the opposing force and solution of (2) and (3) is achieved through time marching.

Results

We consider a realistic turbine with a rated power of 1MW achieved at a flow speed of 2.5m/s; see Fig. 1(a). We consider a range of support structure drag coefficients $0 \le C_D \le 1.8$ for the ratio, $\chi = A_s / A_t = 0.2$, resulting in total (rotor and support structure) turbine thrust as shown in the figure. We observe that the efficiency (ratio of power generated to power removed from the flow) of a turbine drops due to its support structure and that this drop is greatest for higher velocities; see Fig. 1(b).

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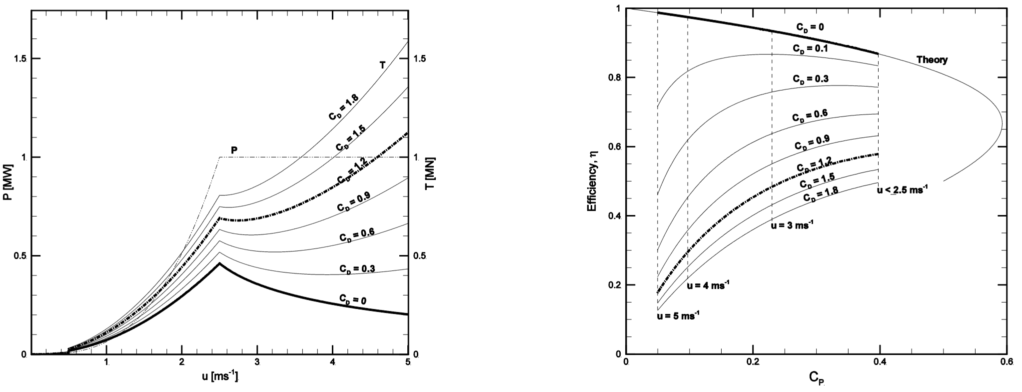
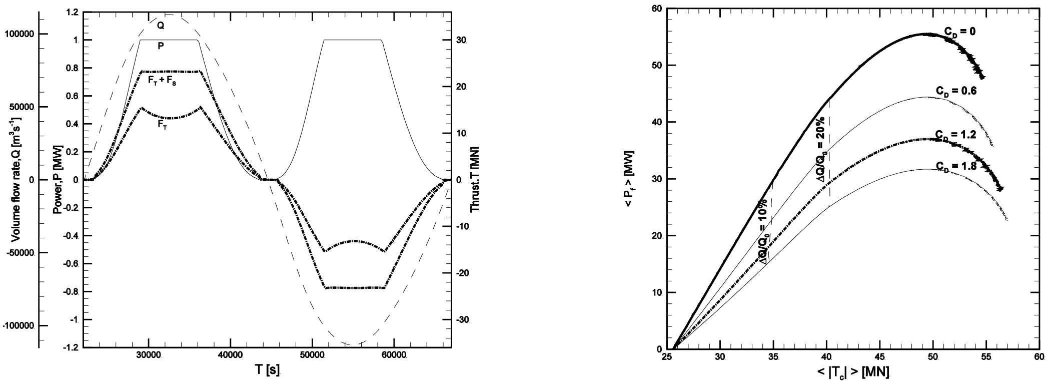
From solution of equations (2) and (3), the volume flow rate, power and thrust curves are plotted for one tidal cycle; see Fig. 2(a). The two thrust curves represent the rotor thrust and total turbine thrust; rotor and support structure. The rotor thrust reaches its peak before and after the peak flow rate due to feathering once rated power has been reached. We can observe that the volume flow rate remains almost sinusoidal whereas the power curve exhibits a capped behaviour due to the rated power constraint.

The power output from the turbine farm has been studied for different numbers of turbines installed in the channel and plotted against the total opposing thrust in the channel; see Fig. 2(b). It is observed that the support structure drag has a significant influence on the total farm power that can be delivered by the turbines. We further explore the reduction in flow rate required to achieve given levels of power yield and observe that even large permissible reductions in flow rate, say 10%, together with realistic values of support structure drag, $C_D = 1.2$, lead to very significant reductions in available power below what might be hypothesized for unconstrained energy extraction.



(a) (b)

Fig. 1. (a) Power-Thrust and (b) efficiency curves of a turbine for different support structure drag coefficients.



(a) (b)

Fig. 2. (a) Flow rate, turbine thrust and power variation over the tidal cycle, (b) time average farm power as a function of farm thrust for various levels of support structure drag; $C_f = 0.002,\ \omega L/\sqrt{ag} = 0.478,\ L/h = 125,\ \chi = 0.2$.

Conclusions

It has been observed that an increase in the support structure drag coefficient leads to a decrease in the efficiency of the turbine and also the power output from the turbine farm. And that flow rate reduction constraints act to further reduce the power that can be developed by a tidal farm. Hence structures with low drag coefficients should be used for the support structures of tidal turbines.

References:

[1] Garrett, C. & Cummins, P. (2005). The power potential of tidal currents in channels. *Proc. R. Soc. A* **461**.

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[3] Nishino, T. & Willden, R. H. J. (2013). Two-scale dynamics of flow past a partial cross-stream array of tidal turbines. *J. Fluid Mech.* **730**.