Comparisons of computational predictions and experimental measurements of ducted tidal turbine performance

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Summary: A computational model is developed for comparison with a recent experimental study of a ducted tidal turbine. The performance of a ducted turbine (modelled as a porous disc) is examined relative to two unducted turbines of equal rotor area and blockage respectively. Comparisons of device thrust, power and wake velocity deficit are made between the experimental and computational models.

Introduction

The effect of a bi-directional duct on the performance of a turbine in confined flow was examined by Fleming et al. [1] using a computational model. This work found that a bare turbine performed better than a ducted turbine for equivalent area blockage. Recently, Stallard et al. [2] constructed a physical model of this ducted turbine, and tested it alongside two unducted turbines of equivalent area blockage based on duct area and rotor area respectively.

In this work, comparison is drawn between experiment and numerical predictors of device thrust, power, and wake velocity deficit, and the effect of the duct is discussed.

Methods

Ducted and unducted tidal turbines are modelled physically in a 1.5 m wide flume with water depth of 0.8 m and nominal flow velocity of $0.55\ \mathrm{m\ s^{-1}}$. Each turbine is represented by a series of porous discs of varying porosity, which mimic the axial thrust of a real device at a range of operating states. The duct measures 0.311 m in diameter at the mouth, and 0.27 m in diameter at the throat, where the porous disc is located. Thrust and wake velocity measurements are taken for a series of 0.27 m diameter porous discs, with and without a duct. The area blockage of the device, $B = A_{\mathrm{device}} / A_{\mathrm{channel}}$, is altered by the presence of the duct, changing from a value of 4.8% for the bare disc to 6.3% for the ducted disc. To enable comparison of a ducted and unducted device at equal blockage, a bare disc of 0.311 m is also tested.

Conventionally, the operating state of a porous disc is identified by its induction factor, a (defined as $u_{\mathrm{disc}} = u_\infty(1-a)$). As the disc velocity, u_{disc}, cannot be measured directly, the operating point is instead identified by the local thrust coefficient, $c_x = T / 0.5\rho A u_{\mathrm{disc}}^2$. Local thrust coefficient is deemed to be a physical property of a disc, and its relationship to disc porosity is determined in preliminary experimental work [2].

Streamwise thrust is measured via a strain gauge on the shaft supporting the device, and flow velocity is measured by acoustic Doppler velocimeters at specific downstream locations. Values for disc velocity and induction factor are estimated from the thrust measurements.

The experimental model is replicated computationally using the Reynolds-averaged Navier-Stokes equations (RANS) solver ANSYS Fluent®. The *k-ω* SST model is used for turbulence closure, and the flow field is assumed to be steady. A numerical analogy of a physical porous disc is used to model the rotor. The local thrust coefficient c_x is set corresponding to experimental measurements of thrust on each porous disc. As the solution develops, the resistance of the numerical porous disc is altered until the target c_x is achieved and the flow field has converged.

The sheared velocity profile observed in the flume is reproduced by prescribing an appropriate velocity profile upstream of the device, and is maintained through the application of shear forces along the bottom and sides of the computational domain. Disc thrust and wake flow velocity are retrieved from the solution data for comparison with the experimental results.

Results

The power and thrust of the ducted device is compared to two unducted discs, which allow for comparisons based on equal rotor diameter and equal device blockage respectively. Computed predictions of thrust and power

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coefficients for the ducted and unducted devices are presented in figure 1. Corresponding experimental measurements are shown in figure 2. Reasonable agreement is observed between computation and experiment for the bare discs. However, a significant discrepancy exists betweent the computed and experimental results for the ducted disc, particularly at high local thrust coefficient. Investigations into the physical cause of this disparity are ongoing. Overall, the experimental results appear to show that a duct has a negative influence on turbine performance, in line with computational predictions.

Conclusions

Computer simulations of a model scale tidal turbine show that a duct has a negative impact on the performance of a tidal turbine. The effect of a duct on rotor performance has recently been investigated experimentally. Comparisons of thrust, power and wake velocity are made between the computational and experimental models to gain a better understanding of ducted tidal turbine flows.

Acknowledgements:

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References:

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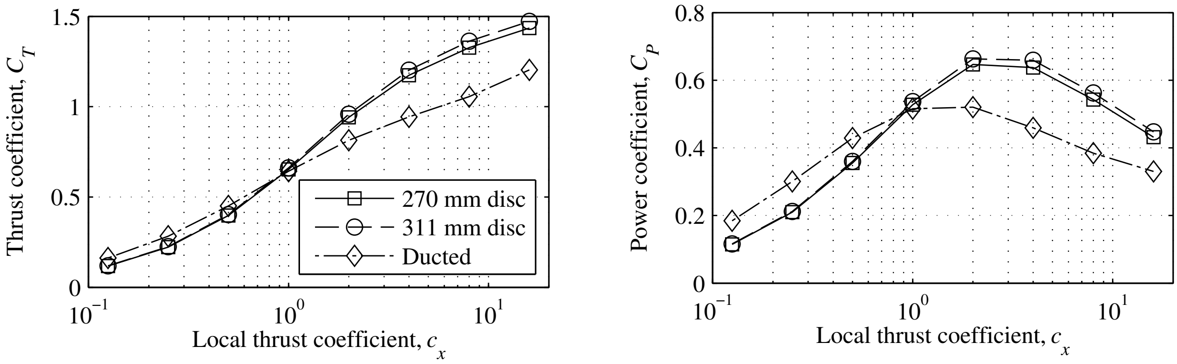
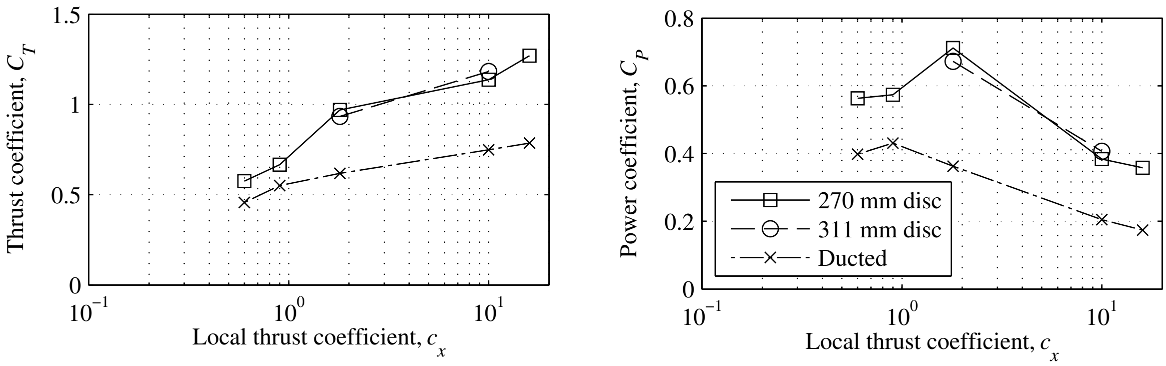


(a) (b)

Fig. 1: Computed predictions of (a) thrust coefficient and (b) power coefficient for ducted and unducted devices.



(a) (b)

Fig. 2: Experimental measurements of (a) thrust coefficient and (b) power coefficient for ducted and unducted devices.