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Tow-tank testing of a 1/20th scale horizontal axis tidal turbine with uncertainty analysis

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ABSTRACT

Tidal turbine developers and researchers use small scale testing (i.e. tow tank and flume testing) as a cost effective and low risk way to conduct proof-of-concept studies and evaluate early stage device performance. This paper presents experimental performance data for a three-bladed 1/20th scale NREL S814 tidal turbine rotor, produced at the 4.6 × 2.5 m and 76 m long Kelvin Hydrodynamics Laboratory tow tank at Strathclyde University. The rotor performance was characterised from very low tip speed ratios to runaway for four carriage speeds. A maximum C_P of 0.285 and a maximum C_T of 0.452 were recorded at tip speed ratios of 3.53 and 4.45 for a carriage speed of 1 m/s. The uncertainty in the instrument calibration and experimental measurements was quantified, allowing accurate representation of the experiments in numerical models. The methodology behind the uncertainty calculations is described in this paper. The uncertainty in the experimental measurements was found to be less than 5% for over 87% of the tests. Reynolds number scaling effects were found to be influential on the rotor performance in the range of velocities tested.

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Nomenclature

a	constant in linear equation (–)
b	gradient of the line (–)
C_P	power coefficient (–)
C_T	thrust coefficient (–)
C_{My}	axial bending moment bending coefficient (–)
C_{Mx}	radial bending moment bending coefficient (–)
F_T	force of thrust (N)
g	gravitational acceleration (m/s)
i	sample number, aspect ratio (–)
l	moment arm (m)
M	moment (Nm)
m	mass (kg)
Q	torque (Nm)
U_∞	inflow velocity (m/s)
x	variable (–)
y	variable (–)
λ	tip-speed ratio (–)
μ_x	total uncertainty in variable x
ρ	density (kg/m^3)
Ω	turbine rotational velocity (rad/s)

Subscripts

B	bias uncertainty
calibration	calibration
measured	measured quantity
P	precision uncertainty
SEE	standard error of estimate
SS_R	summed square of residuals
x	along x-axis
y	along y-axis

1. Introduction

Scale model tidal turbine testing is one of the early stages of the European Marine Energy Center's technology readiness levels (TRLs) program [1]. Empirical data obtained from small scale turbine testing can be used for verification or calibration of turbine performance prediction models, and to explore the benefits and downfalls of new ideas at a relatively low cost before developing the idea to a larger scale. Many researchers use scale testing to study effects which are thought to influence turbine performance. Milne et al. [2] undertook a set of tow tank tests to study the effects of unsteady hydrodynamic loading on tidal turbines, and cavitation tunnel test results were used by Batten et al. [3] to verify a blade element momentum theory (BEMT) performance model. Other such experiments, performed in both tow tanks and flume facilities, have been undertaken and are reported in [4–7].

Compared to the steady water of tow tanks, the flowing water in flumes has a shear profile, which can create non-uniform flow conditions across the tested device. The inherent turbulence in the flow can be advantageous if, for example, wake recovery is the subject of study and turbulence has been considered in the testing programme. However, it has been noted that the turbulence intensity of some facilities can be high, of varied intensity, and difficult to scale [8]. The MARINET Round Robin testing programme [9] aims to clarify the differences between testing in tow tanks and flumes, as well as the differences between test results from facilities of the same kind.