Tidal Benchmarking Project: Description of Released Data

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Revision History

Revision	Date	Description
1.0	04/07/2022	Initial release of document
1.1	23/08/2022	Experimental references added. 3D CAD geometry description updated.
2.0	06/10/2023	Experimental results added.
2.1	09/11/2023	Description of experimental results updated.
2.2	27/08/2025	Experimental results and description updated.

1 Introduction

The Supergen ORE Hub tidal turbine benchmarking project[1] has conducted a large laboratory-scale experiment on a highly-instrumented 1.6 m diameter tidal rotor, with the aim of providing a well-documented experimental dataset that will be used in a benchmarking exercise that will compare a range of modelling methodologies for tidal turbines. This document describes the different forms of data that have been released and provide guidance on its use by modellers participating in the benchmarking study.

2 Benchmarking Test Cases and Experimental Parameters

The Excel spreadsheet entitled `Benchmarking Cases and Experimental Parameters.xlsx` can be found at the top level of the data release directory, and contains two tabs: "Cases" and "Experimental Parameters".

The Cases tab contains a table of the cases to be modelled for both the clean and turbulent conditions. Cases are named as "Clean i" or "Grid i", for the clean and turbulence tests respectively, where i is the test number that corresponds to the different turbine RPMs that were evaluated. The turbulent conditions were generated by towing a turbulence grid upstream of the turbine, which resulted in a slightly reduced flow velocity experienced by the rotor. The corresponding tip-speed ratio (TSR) is therefore also provided for each test case.

Within the Experimental Parameters tab, a table of all of the key parameters for the experiment is presented, including the properties of water to be used by modellers. The stated water density and dynamic viscosity are linearly interpolated from the tables provided in the CRC Handbook of Chemisty and Physics [1].

[1]https://supergen-ore.net/projects/tidal-turbine-benchmarking

3 Geometry Data

3.1 Blade Geometry Data

The blade is comprised of a single NACA 63-415 profile that has been thickened using the thickening function described in Section 3.2 to provide a constant non-dimensional trailing edge thickness along the span. There is hence only a single non-dimensional hydrofoil profile that must be scaled and twisted to form the blade.

The data required to generate the blade geometry can be found in the folder path: `R_002\Blind _test_data\Turbine Geometry\Blade Geometry`. This folder contains the following files and folders:

1. `chordandtwist.txt`, a text file which provides, as a function of the non-dimensional radial position (column 1), the twist distribution (column 2), and the chord length (column 3),
2. `Non-Dimensional Blade Profile`, a folder with the coordinates for the NACA 63-415 hydrofoil profile with a sharp trailing edge (`Standard hydrofoil profile.txt`) and the thickened trailing edge (`Thickened hydrofoil profile.txt`),
3. `Blade Sections (Radial)`, a folder with text files that give the blade profile defined on curved sections at constant radial coordinates. The files are named in the format `section_XXXX.txt`, where XXXX is an integer 0000 $\leq$ XXXX $\leq$ 0175 corresponding to the non-dimensional radial positions in `chordandtwist.txt`.

Modelling results will be compared to in-blade measurements via bending moments evaluated at the in-blade sensor locations. The directory `R_002\Blind _test_data\Turbine Geometry\Blade Geometry\Instrumentation Locations` contains tab-delimited text files specifying the normalised radial locations of the sensors for both the strain gauged (`strain_gauged_locations.txt`) and fibre Bragg (`fbg_locations.txt`) instrumented blades.

3.2 Hydrofoil Profile Thickening Function

The thickening function implemented for the blade profile was adapted from Xu et al [2] and is defined by the equation,

$$y_t = \begin{cases} y_0 & 0 \leq x/c \leq x_t \\ y_0 \pm 0.5\delta c \left(\dfrac{x - x_t c}{c - x_t c} \right)^n & \mathrm{x}_t < x/c \leq 1 \end{cases} \tag{1}$$

where c is the hydrofoil chord, x and y are the profile coordinates, with y_0 and y_t denoting the original and thickened y coordinates respectively. The parameters δ, n and x_t are tabulated in table 1.

Table 1: Parameters of thickening function

Parameter	Symbol	Unit	Value
Normalised trailing edge thickness	δ	-	0.006 25
Thickening function exponent	n	-	2.0
Normalised thickening distance	x_t	-	0.349

3.3 3D CAD Data

3D CAD data in STEP format can be found within the `R_002\Blind _test_data\Turbine Geometry\3D CAD Data` directory. The file `blade.STEP` provides 3D CAD data for the blade, with the internal instrumentation channel removed for simplicity and is cut-off where it enters the 0.2 m diameter nacelle. The file `turbine assembly.STEP` provides the turbine assembly including the tower, with the rotor coloured differently from the rest of the nacelle. The internal structure of the turbine has been removed for simplicity.

As the root fillet at the base of the blade can cause difficulties when generating meshes, the geometry is also provided with the root fillet removed. The simplified versions of blade.STEP and turbine assembly.STEP can be found in the R_002\Blind _test_data\Turbine Geometry\3D CAD Data (root fillet removed) directory.

4 CFD Data

4.1 2D Hydrofoil Simulation Data

2D lift and drag coefficients for the thickened NACA 63-415 profile are provided at a chord-based Reynolds number of $Re_c = \rho W c/\mu = 2.88 \times 10^5$, which is estimated for the normalised radial location $r/R = 0.8$ at the design tip speed ratio of 6, where W is the velocity incident on the hydrofoil section at that location. The data are provided for turbulence intensities ranging from 0 % to 10 %. The data files are found in R_002\2D Hydrofoil Profile CFD Data, with files names TuXX.txt, where XX corresponds to the simulated turbulence intensity level as XX%.

The lift and drag coefficients were determined from Reynolds-Averaged Navier-Stokes (RANS) simulations utilising a k-ω SST turbulence model on a wall-resolving mesh with the first cell $y^+ \approx 1$. While the variation of chord-based Reynolds number with radial location is small, the variation in Re_c across the tip-speed ratios evaluated within the benchmarking cases is significant and hence it is recommended that modellers consider this in the construction of their lift and drag tables. The 2D simulation results have been validated against experimental studies at Reynolds numbers of $Re_c = 3.2 \times 10^5$ and $Re_c = 1.6 \times 10^6$ [3, 4].

5 Experimental Results

5.1 General terms

The measurement data from the experiment campaigns can be found within the R_002\Exp _results directory. The presented cases are: low turbulence case with a turbulence intensity TI∼ 0%, and high turbulence case with a turbulence intensity TI∼ 3.1%.

Whole-rotor quantities such as the thrust and power coefficients (C_T and C_P) as functions of tip-speed ratio (TSR) and their uncertainties (noted as CI) quantified at 95% confidence level are presented in the tab-delimited ASCII file named "CtCp.txt". The measured bending moments (BM) in both flapwise (FW) and edgewise (EW) direction and their uncertainties (CI) at different spanwise probe positions r/R are presented in the tab-delimited ASCII file named "BM_x.xxxR.txt", and are denoted as "C_BM(FW)" and "C_BM(EW)".

A sketch presenting the direction of the forces and bending moments can be found in Fig. 1.

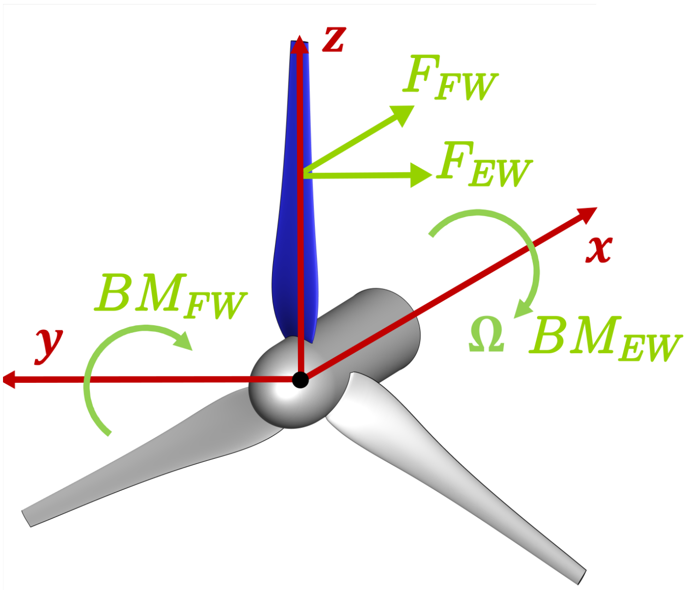

Figure 1: The coordinate system of the forces and bending moments.

The original measured values can be found in the `R_002\Exp _results\original` directory, while the `R_002\Exp _results\interpolated` directory contains the results that have been linearly interpolated to the recommended TSRs for simulation cases (see `Benchmarking Cases and Experimental Parameters.xlsx` as reference).

5.2 Data post-processing

The loading measurements obtained with the benchmarking turbine are foremost considered in terms of their time-averaged values. The performance of the turbine is measured through its power generated, P, and rotor thrust, T, reported as non-dimensional power and thrust coefficients,

$$C_P = \frac{P}{\frac{1}{2}\rho U_\infty^3 \, \pi D^2/4} \quad \text{and} \quad C_T = \frac{T}{\frac{1}{2}\rho U_\infty^2 \, \pi D^2/4}\,, \tag{2}$$

Each flow condition was run three times to ensure repeatability and the time series for each test recorded around $100 - 200$ revolutions depending on tip-speed ratio and the turbine's rotational frequency. The turbine responded well across the entire range of tip-speed ratios tested (approx. $4 - 8$) and was well controlled at a stable rpm even at the lower end of the TSR range where stall effects can start to develop.

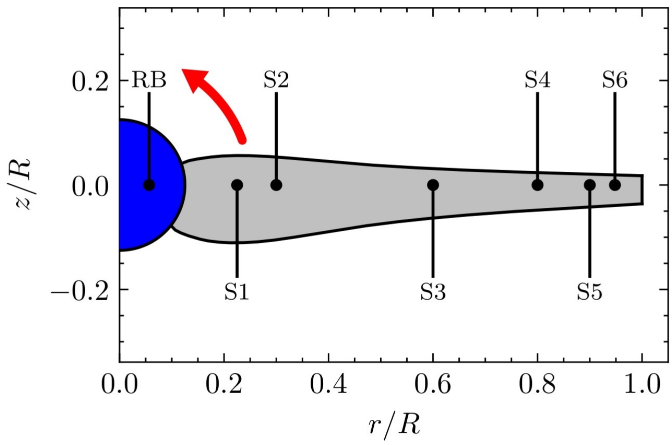

Figure 2: The radial locations of the sensors including the location of the Root Bending (RB) sensor.

The time-averaged bending moments were evaluated using the in-blade sensors and root bending sensors, the positions of which are illustrated in Fig. 2. Note that data from only the RB, S1, S3, S4 and S5 sensors are presented; the data from S2 and S6 were corrupted due to an unresolved failure at the time of publication.

The positions of the sensor locations (RB, S1, S3, S4 and S5) are [$0.057R$, $0.225R$, $0.6R$, $0.8R$, $0.9R$], which is reflected in the filename as "BM_x.xxxR.txt". The bending moment at each sensor location is an integrated contribution from the blade tip inboard to the point of the sensor. The bending moments are reported in their non-dimensional form, which is defined as:

$$C_{\mathrm{BM}} = \frac{M}{\frac{1}{2}\rho U_\infty^2 \, \pi D^3/8}, \tag{3}$$

where M denotes the bending moment.

5.3 Uncertainty Quantification

Uncertainty quantification was undertaken for both the experimental and numerical results. On the experimental side, the ITTC 2014 [5] guidelines were used as a guide to form the uncertainty estimates. Both the bias and precision uncertainty were included, with the combined uncertainty computed as:

$$u_{\mathrm{D}}^2 = u_{\mathrm{b}}^2 + u_{\mathrm{p}}^2\,, \tag{4}$$

where u_D (or noted as CI in the documents) is the total experimental uncertainty estimate, and u_{b} and u_{p} denote the bias and precision uncertainties respectively.

Following the ITTC guidelines, the estimation of the bias uncertainty involved combining uncertainties from various sources within the experiment. A significant contributor was the experimental instrumentation, which included factors such as instrumentation resolution, accuracy, and calibration error. These parameters were assessed for all load measurements conducted in the experiments. Additionally, the uncertainties pertaining to the water properties, specifically density and viscosity, were evaluated with respect to their dependence on temperature. Although they were found to be very small, these uncertainties were combined with those from other sources. The influence of machining tolerances on the turbine swept area and radius, which are crucial for formulating non-dimensional results, was also taken into account to estimate bias uncertainty produced by these parameters. Finally, bias uncertainties associated with carriage velocity and flow velocity measurements were evaluated.

The combined bias uncertainties were not directly estimated in terms of the reported force, moment, and power coefficients. Rather, they were propagated through the data reduction equations before being combined with the precision uncertainties, enabling a more robust and accurate assessment. The precision uncertainty was evaluated using the standard error of three repeated tows at each tip speed ratio, providing an estimate of the statistical variation of the reported force and moment coefficients.

6 List of abbreviations in the dataset

AoA	angle of attack
BM	bending moment
CaseNo	case number
C_BM	bending moment coefficient
CI	uncertainty level
Cd	drag coefficient
Cl	lift coefficient
Cp or C_P	power coefficient
Ct or C_T	thrust coefficient
EW	edgewise direction
FW	flapwise direction
Re	Reynolds number
RPM	rotation per minute
r/R	relative radial position
TSR	tip speed ratio
Tu	turbulence intensity
Uinf or U_∞	tow speed / incoming flow velocity

7 Acknowledgments

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