Marine Renewables Infrastructure Network

WP2: Marine Energy System Testing - Standardisation and Best Practice

D2.18: Tidal Data Analysis Best Practice

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SEVENTH FRAMEWORK PROGRAMME

ABOUT MARINET

MARINET (Marine Renewables Infrastructure Network for Emerging Energy Technologies) is an EC-funded consortium of 29 partners bringing together a network of 42 specialist marine renewable energy testing facilities. MARINET offers periods of free access to these facilities at no cost to research groups and companies. The network also conducts coordinated research to improve testing capabilities, implements common testing standards and provides training and networking opportunities in order to enhance expertise in the industry. The aim of the MARINET initiative is to accelerate the development of marine renewable energy technology.

Companies and research groups who are interested in availing of access to test facilities free of charge can avail of a range of infrastructures to test devices at any scale in areas such as wave energy, tidal energy and offshore-wind energy or to conduct specific tests on cross-cutting areas such as power take-off systems, grid integration, moorings and environmental data. In total, over 700 weeks of access is available to an estimated 300 projects and 800 external users.

MARINET is consists of five main areas of focus or 'Work Packages': Management & Administration, Standardisation & Best Practice, Transnational Access & Networking, Research and Training & Dissemination. The initiative runs for four years until 2015.

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LEGAL DISCLAIMER

EXECUTIVE SUMMARY

This document briefly summarises current recommendations on data analysis best practice for experiments on tidal devices. Since a considerable body of prior art exists, this document indicates source material from which details may be drawn whilst précising the main concerns.

CONTENTS

1 PREAMBLE

Recommendations for testing of marine energy converters at a variety of scales may be found in a number of published documents, most recently in the deliverables of the FP7 EquiMar project. Other standards and best practice guidelines come from ITTC and EMEC (see the Bibliography in Section 6). The purpose of this document is to confront the issues which may arise in analysing data from experimental work in the area of tidal energy conversion, and to provide an outline of best practice. The EquiMar project in particular went into great detail on these matters, and was recent enough to make it unnecessary to revisit its technical foundations. Its protocols remain the definitive guidelines on the subject.

2 DATA COLLECTION AND ANALYSIS

Data sets for analysis will normally fall into one of two categories:

- measurements of the nature of the tidal resource at a proposed test or production site; or
- results from tests on a tidal energy converter.

2.1 TIDAL RESOURCE MEASUREMENTS

A description of the general characteristics of tidal energy resources is given in D2.15. Detailed and accurate site appraisal requires a considerable amount of time and effort. Site surveys are generally conducted using ADCPs, either as semi-permanent ‘fixtures’ on the sea bed or carried by survey vessels. The problem is that many sites have complex bathymetry, so good spatial resolution is important; but also by their nature tides are continually varying. Fixed ADCPs allow simultaneous recording of conditions at several locations; a vessel allows higher-resolution surveys of the site, but not concurrently. The battery life of bottom-mounted ADCPs must also be considered in planning a testing programme. Limitations on resources are likely to force compromises in the quality and scope of the data acquired.

As a minimum, one would wish to obtain

- tidal flow vertical profiles (velocity and direction) as a function of time over a range of tidal cycles (springs to neaps), at sufficient locations over the site;
- data on the surface wave climate, and its influence on velocity profiles.

Ideally, one would also wish to know about the nature and distribution of turbulence over the site.

The principal problem is likely to be gathering data sets that might be considered adequate. An ADCP gives a series of ‘snapshots’ of conditions at fixed intervals over a range of depths, so that the water column is divided into ‘slices’, conventionally of 1m depth [ref EquiMar D2.7]. The output must be processed to obtain mean values and an indication of turbulence; the recommended procedure is to ‘bin’ data into sets of 10 minutes’ duration. There is likely to be a compromise between sampling frequency and ADCP battery life, with consequences for data quality. The instrument would also be used to indicate surface wave conditions (wave buoys are not recommended for energetic tidal sites). Analysis of results is relatively straightforward, consisting firstly of the treatment of noise and outliers. Judgement must then be exercised in the interpolation or extrapolation of data from a limited number of locations, to make predictions over the full area of the site.

A minimum sampling period of 28 days is recommended. Final outputs might include vertical velocity profiles, tidal ellipses and power exceedence curves for the proposed sites; also some indications of turbulence. For a site where surface waves are likely to influence performance of the tidal energy converter, information gathered over much longer periods would be necessary.

Really precise data on turbulence can only be acquired from ADVs operating at specific points in the flow domain. Simultaneous measurement at several points and cross-correlation of the outputs might yield information about turbulence length scales. In most cases a detailed examination of a site is likely to be impractical.

2.2 Tests on tidal energy converters

Measurements of inflow conditions are required if meaningful device performance metrics are to be delivered. The nature of the inflow data obtained (and the associated uncertainty) is dependent on the venue chosen for the test:

- sea trials will generally use data from ADCPs;
- flume tests are more likely to use ADVs and refer to pre-calibrated velocity and turbulence profiles;
- towing tanks rely on accurate control and measurement of the carriage speed. Surface wave climate (if present) could be recorded by depth gauges.

2.2.1 Device performance

Data analysis is aimed primarily at quantifying performance metrics for the device under test. For a tidal energy converter, these metrics are quite simply defined.

Power coefficient C_P is defined as the ratio $\frac{P}{\frac{1}{2}\rho A {U_\infty}^3}$, where ρ is the water density, *A* is the swept area of the device and U_∞ is the undisturbed stream velocity. The power output from the device *P* may be defined in a number of ways:

- the product of shaft torque and angular velocity for a rotating device;
- the product of force and velocity for a translating or oscillating device;
- or simply the electrical power output.

It is obvious that the value of C_P depends critically on U_∞, so errors or uncertainties in velocity measurement must be minimised.

Velocity ratio or coefficient

- for a rotating machine this is defined as the tip speed ratio $\lambda = \frac{\omega R}{U_\infty}$, where ω is the angular velocity of the rotor and *R* is its tip radius;
- for a translating or oscillating device a definition in terms of the ratio $\frac{V}{U_\infty}$, where *V* is the linear velocity of motion of the device, may be made.

A **thrust coefficient** $C_T = \frac{T}{\frac{1}{2}\rho A U^2}$ may be determined for all devices. Here *T* is the thrust force, measured in the flow direction; again C_T is strongly dependent on U_∞.

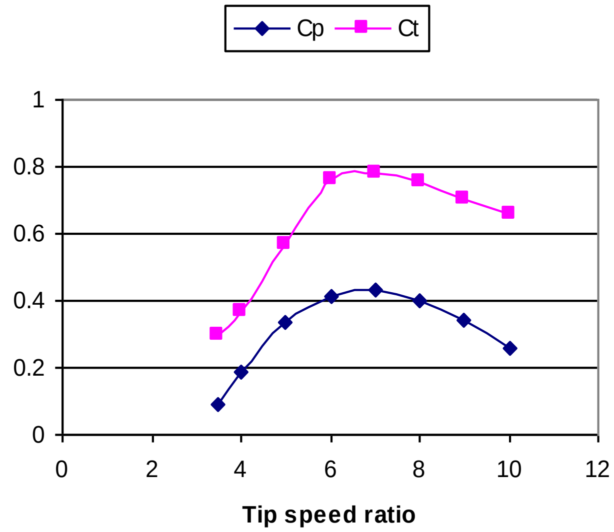

Figure 1: Performance coefficients as a function of tip speed ratio

For a rotating tidal energy converter, performance may be summarised by presenting the variation of its power and thrust coefficients C_P and C_T, as functions of the tip speed ratio λ (see Figure 1).

The inference here is that these dimensionless parameters will be independent of scale, so that values taken from model tests may be applied to a prototype. In practice of course, this is not entirely true (see Sections 3 and 4).

2.2.2 Cyclic loads and motions

A second function of device testing is to investigate cyclic or unsteady loadings, taking high-frequency data from strain or piezo gauges, accelerometers or inclinometers.

Turbulence in flume tests and sea trials will generate stochastic loads and motions. Frequency analysis of time-series data (Fast Fourier Transforms) will extract underlying cyclic loads and yield useful information about the performance of the device. Turbulence will be absent in tow tank tests unless we fail to allow sufficient settling time between runs, but cyclic load patterns may well be observed. Cyclic loads may arise from:

- the effects of surface waves on the water below;
- blade / structure or blade / blade interactions;
- the presence of a vertical velocity shear profile;
- misalignment between the device and the incoming flow;
- Strouhal vortices from structural elements of the device;
- characteristics of the power take-off system (which in a model may not be representative of full scale)

3 CORRECTIONS

The most common effect which may demand corrections to the data is the blockage caused by the model in a confined flow passage. In sea trials such a correction may be irrelevant but in flumes and towing tanks blockage effects are likely to be significant, and will in many cases impose an upper limit on the size of the model to be tested. Despite its low solidity, a marine turbine when operating effectively will create a large blockage, with a drag coefficient approaching unity.

In an unconfined space the flow through the device follows a diverging path. This is illustrated in Figure 2 for a horizontal-axis turbine, and the trend will be similar for any device which extracts energy from the flow. The consequent reduction in mass flow through the rotor swept area limits the power captured by the device. In the well-known 1-dimensional analysis of Betz the axial velocity at the rotor plane *V* is 2/3 of the undisturbed stream velocity, for maximum energy extraction. The maximum attainable power coefficient is then 0.593.

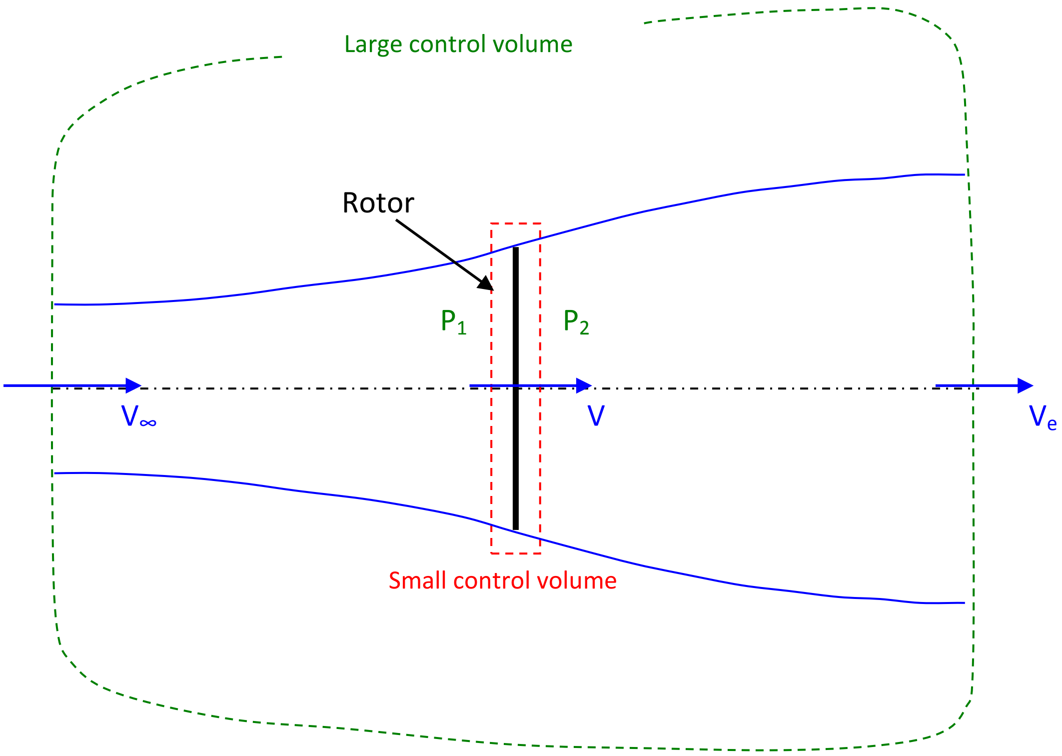

Figure 2: Unconfined one-dimensional flow through a horizontal-axis turbine

In a confined channel there is less room for expansion of the wake and the value of V more closely approaches V_∞. The power extracted will increase, as will the structural loads on the device. Non-dimensional performance coefficients, which are based on the relative velocity of the undisturbed stream, will be affected.

Corrections for blockage have been investigated over many years, primarily for closed-section wind tunnel, and a variety of empirical relations have been proposed. A distinction must be drawn between solid blockage caused by a body with a defined frontal area, and wake blockage where the development of the wake behind a body is inhibited by the walls of the flow passage. A turbine rotor creates a combination of both, so is more difficult to deal with. It seems that a further distinction must be drawn between horizontal-axis turbines where the wake develops axi-symmetrically (in theory at least), and other devices where the wake is deflected laterally. Research is on-going, and a further review within the timescale of the MARINET project would be useful.

4 SCALE EFFECTS

As discussed in MaRINET Deliverable D2.2, Froude scaling is appropriate for effects arising from surface waves, and may be achieved in model tests even at very small scale. But for deeply submerged tidal devices Reynolds scaling is the only relevant parameter. In model tests at small scale it is not practical to reproduce full-scale Reynolds numbers, and some loss of accuracy must be accepted. However the relevant effects are reasonably well understood and the problem is manageable in the majority of cases.

In tests at very small scale it will be impossible to reproduce the structure of turbulent eddies, such as may occur in a tidal flow at sea. This is a well-known problem in assessing patterns of wind flow around buildings and other structures, where model tests in wind tunnels require the creation of artificial 'atmospheric' boundary layers to simulate the approaching flow. In practice the best that can be achieved is an approximation, lacking the complexity of the natural conditions. Model tests of tidal devices will inevitably face similar problems.

As well as this, model tests at low Reynolds numbers may produce anomalies in the way that the flow develops around the device. Boundary layers will generally be thicker; their transition from a laminar to a turbulent state, and their separation from curved surfaces will be affected. The behaviour on aerofoil sections is of course highly relevant, and is illustrated in Figure 3 below.

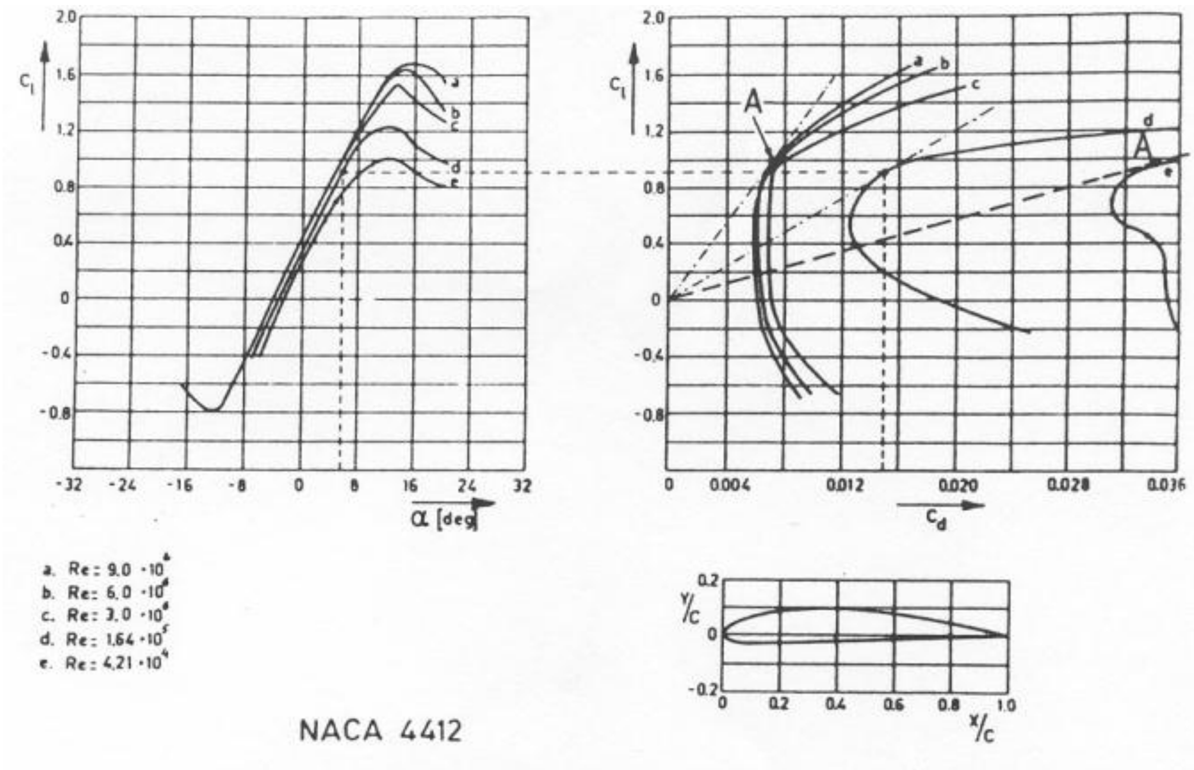

Figure 3: Effects of Reynolds number on the performance of a turbine blade section

The Reynolds number for an aerofoil is defined in terms of the chord length *c* of the blade, so that $\mathrm{Re} = \frac{\rho W c}{\mu}$, where ρ and μ are the density and dynamic viscosity of the fluid and *W* is the relative velocity of the fluid stream. For a typical small model to be tested in a flume or towing tank the Reynolds number would not greatly exceed 10^5. At low Reynolds numbers the lift reduces and drag increases, so the performance of the device is impaired and predictions made from such model tests will tend to be conservative. As seen in Figure 3, the effects are progressive and fairly moderate: tests on a model at 1/10 to 1/20 scale might indicate a 5 to 10% reduction in the value of C_P, compared to full scale.

5 UNCERTAINTY

It is important that sources of error are considered for all experimental data, and their effects on derived quantities are well understood. The examination of uncertainty is covered in detail in EquiMar deliverables D3.3 and D3.4. These reference and build on the two ITTC documents listed in the Bibliography, in Section 6. The EquiMar recommendation that in their final form, data sets achieve a precision of 5% with a confidence level of 95%, in other words 95 times out of 100 the error of a reported value is no greater than 5% of the true value. This remains an acceptable standard.

6 BIBLIOGRAPHY

FP7 EquiMar project: 'Equitable Testing and Evaluation of Marine Energy Extraction Devices in Terms of Performance, Cost and Environmental Impact'.
(https://www.wiki.ed.ac.uk/display/EquiMarwiki/EquiMar) 2011
Relevant deliverables:

- D2.2 Wave and Tidal Resource Characterisation
- D2.7 Protocols for Wave and Tidal Site Assessment
- D3.1 Identification of Limitations of the Current Practices Adopted for Early Stage Tidal Device Assessment
- D3.2 Concept Appraisal and Tank Testing Practices for 1st Stage Prototype Devices
- D3.3 Limitations of Current Practices Adopted for Tank Testing of Small Marine Energy Devices
- D3.4 Best Practice for Tank Testing of Small Prototype Wave and Tidal Devices
- D4.2 Data Analysis and Presentation

International Tank Testing Conference (ITTC) Procedure 7.5-02-01-01 'Guide to the Expression of Uncertainty in Experimental Hydrodynamics'

ITTC Procedure 7.5-01-03-01 'Uncertainty Analysis: Instrument Calibration'

EMEC publications (www.emec.org/standards) 2009:

- No. 2 'Assessment of Performance of Tidal Energy Converters'
- No. 4 'Assessment of Tidal Energy Resource'