WP2: Marine Energy System Testing - Standardisation and Best Practice

Deliverable 2.23

Review of Tow Tank Limitations

Status: Draft
Version: 01
Date: 31-Mar-2014
ABOUT MARINET

MARINET (Marine Renewables Infrastructure Network for emerging Energy Technologies) is an EC-funded network of research centres and organisations that are working together to accelerate the development of marine renewable energy - wave, tidal & offshore-wind. The initiative is funded through the EC’s Seventh Framework Programme (FP7) and runs for four years until 2015. The network of 29 partners with 42 specialist marine research facilities is spread across 11 EU countries and 1 International Cooperation Partner Country (Brazil).

MARINET offers periods of free-of-charge access to test facilities at a range of world-class research centres. Companies and research groups can avail of this Transnational Access (TA) to test devices at any scale in areas such as wave energy, tidal energy, offshore-wind energy and environmental data or to conduct tests on cross-cutting areas such as power take-off systems, grid integration, materials or moorings. In total, over 700 weeks of access is available to an estimated 300 projects and 800 external users, with at least four calls for access applications over the 4-year initiative.

MARINET partners are also working to implement common standards for testing in order to streamline the development process, conducting research to improve testing capabilities across the network, providing training at various facilities in the network in order to enhance personnel expertise and organising industry networking events in order to facilitate partnerships and knowledge exchange.

The initiative consists of five main Work Package focus areas: Management & Administration, Standardisation & Best Practice, Transnational Access & Networking, Research, Training & Dissemination. The aim is to streamline the capabilities of test infrastructures in order to enhance their impact and accelerate the commercialisation of marine renewable energy. See www.fp7-marinet.eu for more details.

Partners

Ireland
University College Cork, HMRC (UCC_HMRC)
Sustainable Energy Authority of Ireland (SEAI_OEDU)

Denmark
Aalborg Universitet (AAU)
DanmarksTekniskeUniversitet (RISOE)

France
Ecole Centrale de Nantes (ECN)
InstitutFrancais de Recherche Pour l’Exploitation de la Mer (IFREMER)

United Kingdom
National Renewable Energy Centre Ltd. (NAREC)
The University of Exeter (UNEXE)
European Marine Energy Centre Ltd. (EMEC)
University of Strathclyde (UNI_STRATH)
The University of Edinburgh (UEDIN)
Queen’s University Belfast (QUB)
Plymouth University (PU)

Spain
Ente Vasco de la Energía (EVE)
Tecnalia Research & Innovation Foundation (TECNALIA)

Belgium
1-Tech (1_TECH)

Netherlands
Stichting Tidal Testing Centre (TTC)
Stichting Energieonderzoek Centrum Nederland (ECNeth)

Germany
Fraunhofer-GesellschaftZurFörderung Der AngewandtenForschungE.V (Fh_IWES)
Gottfried Wilhelm Leibniz Universität Hannover (LUH)
Universitaet Stuttgart (USTUTT)

Portugal
Wave Energy Centre – Centro de Energia das Ondas (WavEC)

Italy
Università degli Studi di Firenze (UNIFI-CRIACIV)
Università degli Studi di Firenze (UNIFI-PIN)
Università degli StudidellaTuscia (UNI_TUS)
ConsiglioNazionaledelleRicerche (CNR-INSEAN)

Brazil
Instituto de Pesquisas Tecnológicas do Estado de São Paulo S.A. (IPT)

Norway
Sintef Energi AS (SINTEF)
NorgesTeknisk-NaturvitenskapeligeUniversitet (NTNU)
DOCUMENT INFORMATION

<table>
<thead>
<tr>
<th>Title</th>
<th>Review of Tow Tank Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution</td>
<td>Deliverable Partners</td>
</tr>
<tr>
<td>Document Reference</td>
<td>MARINET-D2.23</td>
</tr>
<tr>
<td>Deliverable Leader</td>
<td>Francesco Salvatore</td>
</tr>
<tr>
<td></td>
<td>CNR-INSEAN</td>
</tr>
<tr>
<td>Contributing Authors</td>
<td>A.S. Iyer UEDIN</td>
</tr>
<tr>
<td></td>
<td>Sandy Day UNI-STRATH</td>
</tr>
<tr>
<td></td>
<td>Fabio Di Felice CNR-INSEAN</td>
</tr>
</tbody>
</table>

REVISION HISTORY

<table>
<thead>
<tr>
<th>Rev.</th>
<th>Date</th>
<th>Description</th>
<th>Prepared by (Name &amp; Org.)</th>
<th>Approved By (Task/Work Package Leader)</th>
<th>Status (Draft/Final)</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>29-11-13</td>
<td>Preliminary Draft</td>
<td>Francesco Salvatore</td>
<td></td>
<td></td>
</tr>
<tr>
<td>02</td>
<td>31-03-14</td>
<td>Final draft</td>
<td>Francesco Salvatore</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ACKNOWLEDGEMENT

The work described in this publication has received support from the European Community - Research Infrastructure Action under the FP7 “Capacities” Specific Programme through grant agreement number 262552, MaRINET.

LEGAL DISCLAIMER

The views expressed, and responsibility for the content of this publication, lie solely with the authors. The European Commission is not liable for any use that may be made of the information contained herein. This work may rely on data from sources external to the MARINET project Consortium. Members of the Consortium do not accept liability for loss or damage suffered by any third party as a result of errors or inaccuracies in such data. The information in this document is provided “as is” and no guarantee or warranty is given that the information is fit for any particular purpose. The user thereof uses the information at its sole risk and neither the European Commission nor any member of the MARINET Consortium is liable for any use that may be made of the information.
EXECUTIVE SUMMARY

This report presents the analysis of current practice related to testing small scale marine current energy devices in towing tank facilities. The aim is to identify physical and operational aspects that limit the applicability of model test results to simulate the overall performance of the same device in full scale and real operating conditions.

Physical and operational aspects analysed in some details include, among others, flow confinement and blockage effects, modelling onset flow turbulence and velocity profile, as well as the effects of wave-current interactions. Limitations to reproduce full-size device arrangements like mooring systems, supporting structures for bottom-fixed devices as well as floating platforms or submerged bodies are addressed. Operational environment aspects like bathimetry and simulation of device-device interactions in arrays are also briefly considered.

A table summarizing the comparison between model testing in towing tanks versus flume tanks or circulating water channels is proposed as a basis for a future guideline usable by device developers interested to make scaled model tests in a laboratory facility. Although it is recognised that testing a marine current device in a towing tank may have some limitations and introduce some issues, the diffusion worldwide of towing tank facilities is by far higher than flume tanks and hence there is a practical interest to making towing tank testing as an adequate and reliable approach for the development, assessment and optimization of marine current devices.

The present document is written in fulfilment of Deliverable D2.23, classified as internal report not submitted to EU. Partners contributing to the present work are Strathclyde Univ. Edinburgh Univ., and CNR-INSEAN (leader).
## CONTENTS

1 INTRODUCTION ........................................................................................................... 6
2 TOWING TANK FACILITIES .................................................................................. 8
3 TESTING CONDITIONS AND LIMITATIONS .......................................................... 10
   3.1 FLOW CONFINEMENT ...................................................................................... 11
   3.2 ONSET FLOW: TURBULENCE AND VELOCITY PROFILE .............................. 12
   3.3 WAVE-CURRENT INTERACTIONS .................................................................. 13
   3.4 MOORING AND FLOATING PLATFORMS ......................................................... 14
   3.5 BATHIMETRY ................................................................................................. 14
4 COMPARISON WITH FLUME TANKS ..................................................................... 15
5 CONCLUSIONS ........................................................................................................ 17
6 REFERENCES ............................................................................................................ 18
1 INTRODUCTION

This report provides a review of existing practice on testing small scale ocean energy devices in towing tank facilities. The aim is to identify aspects of testing procedures in this type of facilities that may limit the applicability of model test results to correctly simulate the overall performance of a given device in full scale and real operating conditions. The analysis is focused on marine current devices. This includes both ocean current systems designed for unidirectional flows and tidal current systems, designed for bi-directional flows.

The analysis is carried out in the framework of Task 2.2, whose main objective is, according to the MaRINET Project Description of Work, the “standardisation of practices used in the testing of tidal devices across various scales, the specification of instrumentation to be used, robustness testing of protocols and development of normalisation procedures which are to be adopted in all test facilities.”

In particular, the present document covers the definition of theoretical and practical limits of testing tidal energy devices in towing tanks and outlines solutions to extend the range of applicability of this type of model tests. The comparison between testing capability in towing tanks and in flume tanks is also addressed in some detail.

Testing facilities inside laboratories provide a controlled environment and conveniently equipped framework for the analysis of ocean energy devices at early stages of development of their technology. During this phase, tests on small scale models, typically below than 1:10 with respect to full scale, are conducted to make a preliminary validation of a basic concept, to investigate physical properties and device features that affect energy conversion mechanisms, and to optimize device power capturing capability. Using a classification introduced by NASA for aerospace technologies in the 1960’s, the above stages of development correspond to Technology Readiness Levels (TRL) increasing from 1 (proof of concept) to 4-5 (component, sub-system and system validation from laboratory tests with simulated operational environment), see e.g. Mankins (1995).

Dealing with current devices, the ocean energy converted is the kinetic energy of a water mass that flows due to ocean currents or tidal currents. Systems supporting energy conversion mechanisms are kept fixed with respect to the ground. Although only testing facilities like water flumes or circulating water channels allow to directly reproduce such an interplay between a mechanical device and the surrounding water mass, a great quantity of model tests of marine current devices are routinely performed in towing tanks where, contrary to real conditions, the water is at rest and the device is moving through it.

The implications of such a different modelling of real conditions and other aspects related to reproducing energy conversion mechanisms in a confined-flow environment are the main subject of the present study.

The topics of interest here are extensively addressed in many scientific papers in the literature and in many R&D projects. Limiting to consider recent projects, important contributions have been given by studies carried out in the framework of the EU-FP7 EQUIMAR project. In particular, EQUIMAR Deliverable D3.3 analyses in details limitations associated with tests performed in different types of facilities including towing tanks. Limitations related to physical modelling effects, measuring systems are discussed.

In the present report, the subject of towing tank testing limitations is discussed using background studies as a basis and expanding it with the experience matured under the MaRINET project.
The document is structured as follows.
A review of towing tank facilities and approaches used to test marine current devices is presented in Section 2. Section 3 is dedicated to the analysis of towing testing aspects that may have an impact on results. This includes flow confinement and blockage effects, modelling onset flow turbulence and velocity profile, wave-current interactions. Moreover, the possibility to reproduce full-size device arrangements like mooring systems, supporting structures for bottom-fixed devices as well as floating platforms or submerged bodies has been addressed. Operational environment aspects like bathymetry and simulation of device-device interactions in arrays are also briefly considered. Section 4 presents a comparative analysis between testing conditions in a towing tank and in flume tanks or circulating water channels. Concluding remarks are summarised in Section 5.

Throughout the report reference is made to a generic marine current device, without making differences among the various types of devices like turbines (horizontal-axis, cross-flow and vertical axis layouts) and non-turbines like oscillating foils, kites, VIV cylinders.
2 TOWING TANK FACILITIES

A great variety of laboratory testing facilities exists and an accurate classification is complex. Limiting to consider facilities where a model can be tested by towing it with respect to water at rest, there are two main types of environments:

- Linear tanks
- Rectangular basins

In the former case, the basin has a horizontal dimension (length, L) which is quite larger than width D. This type of plant is devoted to testing models that are towed by carriages through basin length. Model ship resistance and propulsion tests, propulsor open water tests are generally conducted in these basins. Usually, the ratio between basin length and width is $L/D = 20$-$35$ and facilities with higher L/D ratios exist. As an example, horizontal dimensions and depths of some linear tanks are summarised in Table 2.1 below. Towing tanks from MaRINET Consortium (Strathclyde Univ. and CNR-INSEAN) and three examples of major European facilities are indicated.

### Table 2.1. Towing tank dimensions.

<table>
<thead>
<tr>
<th>Tank</th>
<th>Length</th>
<th>Width</th>
<th>Depth</th>
<th>Tow Speed</th>
<th>Waves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kelvin H.L., Uni. Strathclyde</td>
<td>76 m</td>
<td>4.6 m</td>
<td>2.5 m</td>
<td>&lt; 5 m/s</td>
<td>Yes</td>
</tr>
<tr>
<td>Wave tank, INSEAN</td>
<td>220 m</td>
<td>9.0 m</td>
<td>3.5 m</td>
<td>&lt; 10 m/s</td>
<td>Yes</td>
</tr>
<tr>
<td>Calm water tank, INSEAN</td>
<td>450 m</td>
<td>13.5 m</td>
<td>6.5 m</td>
<td>&lt; 12 m/s</td>
<td>No</td>
</tr>
<tr>
<td>Towing tank, HSVA (DE)</td>
<td>300 m</td>
<td>18.0 m</td>
<td>6.0 m</td>
<td>&lt; 10 m/s</td>
<td>Yes</td>
</tr>
<tr>
<td>Depress. Tank, MARIN (NL)</td>
<td>240 m</td>
<td>18.0 m</td>
<td>8.0 m</td>
<td>n.a.</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Rectangular basins (also referred to as ocean or manoeuvring basins) are characterised by comparable horizontal dimensions, length and width. In many cases, portions with different depth are present. Also in this case, the facility may be equipped with carriages that in principle can be used in the same fashion as linear tank carriages. In fact, this type of plant is generally dedicated to model ship manoeuvring tests requiring X-Y motions. In most cases, ocean basins are equipped with wave generation devices placed on two edges forming 90 degrees to each other, to produce wave patterns travelling along any direction over 360 degrees. Wave makers are also equipped in linear tanks. In this case, wavefronts are generated from the basin end sides and travel only in one direction along the basin length.
In some rectangular basins, underwater current generation mechanisms are available that may also be used for the analysis of marine current systems as an alternative to towing. An example of this type of facilities among the MaRINE Consortium is the Ocean wave Basin at Plymouth University, see Fig. 2.2. By a recirculating hydraulic system, longitudinal currents up to 0.3 m/s for a 2.0 m water depth can be reproduced. In the case of linear tanks, current generation mechanisms are out of scope.

Finally, very few linear tanks exist worldwide that are entirely located inside pressure controlled spaces. Reducing ambient pressure it is possible to test towed small scaled models in similarity with respect cavitation phenomena. This type of facility is used to analyse cavitation effects on fully equipped ship models.

Guidelines and procedures for testing scaled models of marine vehicles and other marine systems have been the subject of extensive work by the International Towing Tank Conference (ITTC). Procedures are continually updated to account for technology developments. The complete list of Guidelines and procedures is available on the ITTC website: http://ittc.sname.org/.

In 2012, a Specialist Committee for the Hydrodynamics Modelling of Marine Renewable Energy Devices has been created by ITTC for the first time. Aims and objectives of Committee work relevant for the present discussion on marine current energy have been identified, among the others, as follows:

- Develop guidelines for the physical modeling of wind and current/tidal renewable energy systems, both floating and bottom fixed structures.
- Investigate and report on techniques for the modeling of power take-off (PTO) systems.
- Identify the parameters that cause the largest uncertainties in the results of physical model experiments and the extrapolation to full scale.
- Investigate and report on the correct modeling for renewable energy system arrays (farms).

In particular, the following Guideline and procedure on marine current energy device testing have been prepared:

- Model Tests for Current Turbines (ITTC Recommended Guideline 7.5-02-07-03.9)

The final version of this document and corresponding reports on wave energy converters and offshore wind energy systems will be presented and released at the 27th ITTC Conference to be held in August 2014.
3 TESTING CONDITIONS AND LIMITATIONS

In this report, the analysis is focused on linear towing tanks (hereafter simply indicated as towing tanks), where most of marine current device testing is nowadays conducted. Towing tanks used for testing marine current devices have been originally designed and equipped for the analysis of other types of sea craft and marine structures. The problem addressed here is identifying which aspects of model testing practices within towing tanks impact on the reliability, accuracy and consistency of results describing the hydrodynamic performance of a marine current device. Furthermore, the limitations when results obtained under tank test conditions are extrapolated and scaled up to predict the performance of a full size prototype in ‘real sea’ operating conditions needs to be identified.

Generally speaking, towing tanks provide an attractive option for undertaking detailed, highly controlled tests with theoretically the highest repeatability of results. Main testing conditions that may have an impact on the quality of results for marine current devices include:

- Flow confinement
- Onset flow turbulence
- Onset flow velocity profile
- Wave-current interactions
- Mooring and floating platforms
- Bathimetry

Within the following subsections, these aspects are analysed in some detail and main differences between real operating conditions of a device deployed at sea or in a river and those that are reproduced in towing tanks are stressed and discussed.
3.1 Flow Confinement

Table 2.1 above, presents specifications data for some representative European towing tank facilities. From this list, the largest facility is the CNR-INSEAN calm water towing tank in which a width of 13.5 m and depth of 6.5 m which yields a “test section” cross sectional area of just under 90 square meters. Much smaller areas are obtained in the other cases in the table.

The size of a scale model marine current device to be tested in such confined environments has to be sufficiently small to avoid inherent hydrodynamic interference which is induced during testing between the device and tank side walls and bottom. In practice, this interference (flow confinement) will influence the device performance and associated results which will differ from the results obtained if the device were to be tested in a theoretically unbounded domain. In general, the results obtained from testing within non-negligible confinement effects will most likely be non representative of the performance of the device when operating in ‘real sea’ conditions, therefore could be the origins for ill informed design decisions.

Directly associated with flow confinement is the concept of blockage. This term denotes the effect of a massive object inside a streamtube with a finite-cross section obstructing the flow. A global parameter used to quantify the blockage effect is the ratio between a representative cross sectional area of the object and the cross sectional area of the streamtube (blockage factor). Blockage above 10% (blocking factor of 0.1) can introduce questionable results, therefore an additional source of error when assessing device performance.

In order to avoid uncertainty of results due to flow confinement or blockage, a solution could be to test a smaller device. Unfortunately, this would introduce additional inaccuracies on the quality of results obtained because similarity of testing conditions versus full scale ‘real sea’ conditions would not be satisfied. The problem of correctly scaling the physical properties during model tests has been addressed in MaRINET Deliverable D2.7 and should be referenced.

A particular aspect of flow confinement during towing tank testing is that the fluid domain surrounding the model device is confined by solid, impermeable walls within a transversal direction (tank walls) and the bottom whereas on the upper surface the fluid domain is limited by the free surface. Water displacement induced by the perturbation generated by the model device may determine a deformation of the free surface (either flat of waved by the action of any wave makers). This deformation corresponds to momentum transferred from the model device to water that should be taken into account in the overall balance of energy transfer between water and model device.

In principle, the energy lost in free-surface perturbations decreases the amount of energy the model device is able to convert into usable mechanical energy. To correctly account for such interaction with the free-surface it is essential to adequately define the immersion of the model and to check the Froude number similitude between model scale and full scale conditions (see MaRINET Deliverable D2.7 for details).

As a consequence, a necessary trade-off is to test the largest model that can be fitted into the tank without inducing too high confinement effects. It should be noted that there has been limited studies specifically devoted to quantifying confinement effects for marine current devices and as such there is little literature available. Numerical simulations by Computational Fluid Dynamics (CFD) tools can be employed to determine the extension of the device-perturbed region and hence to estimate the size of a device model best tested within a given facility and without the risk that such device-perturbed regions is larger than the available space.

Confinement effects are a major limitation when testing a combination of multiple devices.
3.2 Onset flow: turbulence and velocity profile

In tow tank testing the model is towed against still water at a chosen speed that may be imposed to exactly reproduce, with suitable scaling, a particular marine current intensity. However, during tank testing the water is typically at rest and the turbulence level of the flow incoming to the scale tidal model device is zero or close to zero. This aspect determines a major deviation with respect to real-life operating conditions at sea or in a river. In fact, both ocean and tidal currents are characterised by velocity profiles having turbulence intensity of 15-20% or more, with eddies of variable dimensions incoming to device components devoted to energy conversion (i.e., rotor blades in a marine current turbine).

A different quality of the onset flow in terms of turbulence levels and turbulent kinetic energy may have a non-negligible impact on the hydrodynamic performance of the device for various reasons. In particular:
- Onset flow turbulence affects hydrodynamic forces that are generated on lifting surfaces like turbine blades and oscillating foils.
- Onset flow turbulence affects the rate of decay of vortex structures in the flow including trailing wakes shed by device hydrodynamic surfaces.

A technique to induce the artificial generation of turbulence in the onset flow during towing tests is based on the utilization of grids. These grids consist of regular meshes of rods. Grid size and spacing can be designed to determine a given turbulence intensity downstream of the grid. Mounting these grids at a specific distance upstream of the test model, change the inflow conditions on to the test device to be more representative of dynamic flow conditions experienced in larger scale testing programs. The drawbacks with this solution are that only nearly homogeneous and isotropic turbulence spectra can be realised which are not representative of turbulent structures in ‘real sea’ operating conditions. Furthermore, grid generated turbulence tend to dissipate very quickly at short distance downstream the grid.

Figure 3.2. Left: idealised current velocity profile using the 1/7th power law turbulent profile (source: Ocean Renewable Energy Team, Univ. Strathclyde, UK). Right: tidal current velocity profile and free-surface/bottom effects (source: Sustainable Energy Research group, Southampton Univ., UK).

In addition to turbulence, ocean as well as tidal currents are frequently characterised also by an intense profiling along a vertical direction. A simplified model of current velocity vertical profiles is the 1/7th power law turbulent profile originally developed for pipe flows (De Chant, 2005). Actual conditions in a real environment may have large deviations from such an idealised behaviour. In general, the intensity of the horizontal component of the current speed has a maximum at some immersion below the waterline and decreases towards the free surface and to deep waters as well. Suitable grids can be designed to determine a velocity profile upstream the towed model.
3.3 Wave-current Interactions

Many aspects of the operational profile of marine current devices are largely dependent on the effects of free-surface waves. Two main aspects can be identified:

- Effects related to wave-current interactions and related energy/momentum transfers
- Effects related to station keeping response of device supporting structures.

The former aspect is relevant for any marine current device that is supposed to operate close to the free-surface. The latter is relevant for devices attached to surface or submerged floating structures that interact with free-surface waves.

For the analysis of these problems, towing tanks equipped with wave generation systems provide a useful testing environment. In fact, the same device can be tested in calm water and in waves and some effects can be analysed by comparing results from the two different testing conditions.

What is not possible to analyse is the phenomenon of momentum transfer between wave-generated and current-generated water particle motions.

Some research work has been conducted to analyse the impact of free-surface waves on fluctuations of loads generated by a marine current device. Such transient loads are identified as potentially responsible for fatigue and failure of device components (turbine blades in particular).

An example of studies on this subject is given e.g. in Gaurier et al. (2013) with results from an experimental campaign carried out at the IFREMER flume tank equipped with a wave maker, see Figure 3.3 below. Other studies, e.g. Dodet et al. (2013), analyse wave-current interaction problems with a focus on the effects on the current resource in marine sites characterised by intense tidal ranges.

![Figure 3.3. The open test section and the wave making device of the flume tank at IFREMER, France.](image)

More generally, flow turbulence and vortex structures contribute to determine fluctuations of hydrodynamic loads that are generated on device hydro dynamic and lifting surfaces. Such issues are currently being investigated e.g. in Mason-Jones et al. (2012) who present an experimental study based on field measurements of the velocity profile using an Acoustic-Doppler Current profiler (ADCP) technique. Measured velocity profiles are used as inputs for the analysis by CFD of hydrodynamic loads generated by a horizontal-axis turbine.

Existing knowledge on the subject of interplay between waves and currents rely only on field tests surveys or simulated conditions in flume tanks similar to that of IFREMER’s as shown above. Such results cannot be directly related to towing tank tests performed within wave induced conditions. This represents a limitation of data that can be derived from tow tank model testing of marine current devices.
3.4 Moorings and Floating Platforms

The analysis of device mooring and anchoring systems as well as the station-keeping response of a floating structure supporting device components dedicated to energy conversion (i.e. turbine, power transfer system, generator, etc.) is difficult within CFD simulations. Similarly, station-keeping response of a surface or submerged structure supporting the energy capturing and conversion system may be very different from what should be observed on a stationary device. This problem is particularly relevant if an onset wave pattern is also simulated.

3.5 Bathymetry

Testing conditions where the model device is towed along the tank length make it impossible to simulate sea bottom layouts which are different from a flat horizontal platform. Typically, open sea sites with complex bathymetry, a sea bed with a spatially variable depth surrounding the marine current device, are characterised by currents with non-negligible vertical flow components. These onset flow features cannot be reproduced by towing tests unless special devices fixed to the towing carriage are immersed upstream of the model to induce a suitable deviation of the flow. The inherent set-up complexity makes this type of test practically impossible.

With some limitations and inherent schematizations, bathymetry effect studies can be addressed in flume tanks.

![Figure 3.4. Pentland Firth bathymetry data used in tidal resource modelling studies. Source: http://www.icit.hw.ac.uk/suntans.htm.](image-url)
4 COMPARISON WITH FLUME TANKS

The discussion presented in Section 3 brings to a general conclusion the limitations identified with tow tank testing. In the design of a scaled model test campaign of a marine current device, aims and objectives of tests should be carefully analysed in order to take a preliminary decision whether tests should be conducted in a towing tank or in a flume tank.

Although the two types of facilities are largely equivalent in many respects. For some specific aspects, testing a marine current turbine in a towing tank may present major limitations. Nevertheless, the diffusion worldwide of towing tank facilities is by far higher than flume tanks and hence there is a practical interest to consider undertaking tow tank testing as an adequate and reliable approach for the development, assessment and optimization of a marine current device.

As a basis for future guidelines usable by device developers interested in undertaking scaled model testing in a laboratory facility, a comparative table has been produced to summarise the advantages and disadvantages of undertaking scale device testing in towing tanks and flume tanks/ circulating water channels. This table has to be considered as not being definitive but to give a more general valid picture of test facility selection because the feasibility and the validity of a given testing activity is much dependent on specific details of the candidate facility being used.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Towing tank facility</th>
<th>Flume tank facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow confinement, blockage</td>
<td>Dimensions of model device to be carefully defined. In general, larger test sections than flume tanks.</td>
<td>Dimensions of model device to be carefully defined. Test sections may have critical width and depth limitations.</td>
</tr>
<tr>
<td>Onset flow turbulence</td>
<td>Nominal zero turbulence due to testing in water at rest. Turbulence profilers may be used to some extent but set-up is difficult.</td>
<td>Flowing water has generally a 5% turbulence. Higher turbulence intensities by means of turbulence profilers are possible.</td>
</tr>
<tr>
<td>Onset flow velocity profiling</td>
<td>Grids fitted to the carriage upstream the model required. Difficult set-up.</td>
<td>Grids fitted to the carriage upstream the model required. Set-up easier than in towing tanks.</td>
</tr>
<tr>
<td>Wave-current interactions</td>
<td>Some towing tanks are equipped with wave makers. Limited correspondance with real conditions due to water at rest.</td>
<td>Few flume tanks are equipped with wave makers.</td>
</tr>
<tr>
<td>Cavitation</td>
<td>Towing tanks tests are conducted at atmospheric pressure and cavitating flow similitude with respect to full scale is not possible.</td>
<td>Some circulating water channels can be depressurised to achieve cavitating flow similitude with respect to full scale.</td>
</tr>
<tr>
<td>Mooring systems</td>
<td>Very difficult to include in set-up for a towed device.</td>
<td>Easy set-up, real conditions can be correctly simulated with limitations about scaling deep waters.</td>
</tr>
<tr>
<td>Bottom-fixed structures</td>
<td>Very difficult to include in set-up for a towed device.</td>
<td>Easy set-up, full-scale layouts can be correctly simulated.</td>
</tr>
<tr>
<td>Floating platforms</td>
<td>Platform station-keeping response can be simulated in wave tanks.</td>
<td>Platform station-keeping response can be simulated in wave flume tanks.</td>
</tr>
<tr>
<td>Bathimetry</td>
<td>Onset flow deviation devices to be designed and fitted to the carriage upstream the model. Difficult set-up.</td>
<td>Non-flat seabed can be simulated at relatively low costs.</td>
</tr>
</tbody>
</table>
### Table 4.1. Testing limitations for marine current devices: towing tanks and flume tanks compared.

In addition to the aspects listed in the table above, it is relevant to consider, from a practical viewpoint, the differences between set-up and operation of model tests in towing tanks and in flume tanks:

- In general, flume tanks present easier accessibility to test model set up and configuration within the test section which is better than a towing tank carriage; as a consequence, modifications to set-up and device layout during testing are easier and faster to execute in a flume tank.
- Changing testing conditions is generally faster and easier in tests carried out in flume tanks than in towing tanks.

Investigations on the subject of quantifying the differences between repetitive testing of a common marine current device in a towing tank and in a flume tank/ circulating water channel is underway as part of the program of work within the MaRINET project as art. Work Packages 2 and 4. Specifically, a Round Robin testing program on a tri-bladed horizontal axis turbine has been organised as a joint initiative among MaRINET project partners IFREMER, CNR-INSEAN, University of Strathclyde and University of Edinburgh. The objectives of these tests is, among others, to compare turbine performance results from towing tank tests with results obtained in flume tanks; and identify and where possible quantify the influence of the test facility on device performance. At the present stage of the activity (begin of April 2014), completed model tests have been executed at:

1) Towing tank tests at the Kelvin Hydrodynamics Lab, University of Strathclyde
2) Towing tank tests at CNR-INSEAN
3) Flume tank tests at IFREMER
4) Circulating water channel tests at CNR-INSEAN

Details of test planning may be found as part of MaRINET Deliverable D2.24. A report of this testing program together with analysis of comparative tests will be delivered as part of the MaRINET project in 2015.
5 CONCLUSIONS

A review on the practical aspects relating to testing scale marine current device within a towing tank facility has been presented. The aim of the work has been to analyse testing conditions typical for towing tank set-ups; and identify where potentially negative impacts on the accuracy and reliability of these model test results may occur, especially when undertaking an extrapolation to full-size device performance predictions.

Moreover, limitations with the reproduction of specific parameters influencing the environmental conditions experienced by a marine current device operating within both ‘real sea’ conditions or within a river has been discussed.

Physical and operational parameters analysed in some details include, among others, flow confinement and blockage effects, modelling the onset of flow turbulence and a velocity profile, as well as the effects of wave-current interactions. Moreover, the possibility to reproduce full-size device arrangements like mooring systems, supporting structures for bottom-fixed devices as well as floating platforms or submerged bodies has been addressed. Similarly, operational environment aspects like bathymetry and the simulation of device-device interactions within tidal arrays have been briefly considered.

In this context, important research is underway within the MaRINET project in Work Packages 2 and 4 to increase knowledge and understanding about limitations of testing in a towing tank environment. In particular, towing tank testing conditions are compared with those typically established in flume tanks or circulating water channels. The MaRINET Round-Robin testing campaign using a three bladed horizontal axis tidal turbine is a first attempt to make a systematic comparative analysis on the subject.

A table summarizing the comparison between model testing in towing tanks versus flume tanks or circulating water channels has been proposed as a basis for a future guideline to be used by device developers interested in undertaking scaled model tests in a laboratory facility. Although it is recognised that testing a marine current device in a towing tank may have some limitations and introduce some issues, the worldwide diffusion of towing tank facilities is by far higher than flume tanks and hence there is a practical interest to consider towing tank testing as an adequate and reliable approach for the development, assessment and optimization of a marine current device.
6 REFERENCES


