MARINET

Marine Renewables Infrastructure Network

WP2: Marine Energy System Testing - Standardisation and Best Practice

D2.2: Collation of Tidal Test Options

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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 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 in 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 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

The experimental performance appraisal of tidal energy devices is a crucial aspect of their design and ensures optimality and confidence in performance. The information obtained during testing is used to secure funding and promote device development. The MaRINET project seeks to make available facilities in Europe for testing tidal (and also wave and wind) devices at small, medium and large scales.

This report is concerned with aiding in the identification of the appropriate experimental facility for a scale test of a tidal energy converter. To this end, the principal scaling laws are identified in order to ascertain the potential penalties associated with scale testing, and then the options available in the MaRINET project for tidal testing are collated. Finally, a decision making tool is presented to aid the process of arriving at an appropriate MaRINET facility for a device test.

DEFINITIONS

TTC	Tidal Test Centre
EMEC	European Marine Energy Centre
CNR-INSEAN	Consiglio Nazionale delle Ricerche - Istituto Nazionale Per Studi Ed Esperienze Di Architettura Navale (Italian Institute for Naval Hydrodynamic Research and Ship Model Basin)
EquiMar	Equitable Testing and Evaluation of Marine Energy Extraction Devices in terms of Performance, Cost and Environmental Impact
DoE	Design of Experiment
PTO	Power Take Off
TRL	Technology Readiness Level
TEC	Tidal Energy Converter
LDA	Laser Doppler Anemometry
PIV	Particle Image Velocimetry
ADP	Acoustic Doppler Probe
ADCP	Acoustic Doppler Current Profiler
Reduced Angular Velocity	Angular velocity rendered in dimensionless terms using a characteristic length and speed. A prominent example is tip-speed-ratio given by $\lambda = \frac{\Omega R}{U_\infty}$

CONTENTS

1 INTRODUCTION

Tank testing is primarily to establish at scale the behaviour of a tidal energy converter and the impact of different conditions, configurations and dimensions. Testing at scales of c.1:50-1:10 indoors is particularly desirable as it is inexpensive and modifications can be made quickly and easily. The convenience of having a controlled environment where each set of experiments can be repeated is also highly valuable. Initial testing is to establish proof-of-concept; therefore it is ideal for testing individual subsystems and it is not necessary for all parts of the model to be fully functional.

Once the small scale experiments are performed and the proof-of-concept is attained, an investigation devoted to understanding the involved physical phenomena is mandatory; a better knowledge of the hydrodynamic features of the system under investigation gives the tools to optimize its performance. At this stage, sub-system hydrodynamics need to be characterized too and this is possible only at larger scale. The reference scale for this kind of investigation is typically the medium one, c.1:10 - 1:4, at which all the most energetic hydrodynamic effects are observable by standard measuring tools, e.g. Laser Doppler Velocimetry, Particle Image Velocimetry. To this aim, medium scale tank testing represents a necessary step before prototype manufacture.

At medium and larger scales, testing can be complex, therefore initial testing should ideally start at small scale to understand the energy converter’s characteristics. As understanding improves testing at larger scales and sea trials add vital knowledge that can establish the device’s full functionality. Tidal energy turbines find their application in the open sea, in dikes and in barrages. In dikes the water flows through channels that separate the two basins. The difference between the water levels causes the water to flow. From this flow, turbines can extract power and convert this into electricity. Even if a turbine is meant to go offshore and to perform in open sea, it can be tested in these channels. Because the distance to the grid and all kind of support systems is small, the cost and risks are limited.

In a large-scale test, the system should be ready for a ‘shake-down’ period to prove the TEC’s behaviour. Devices should not be subject to significant modification at this stage as most revisions are expected to be done during medium scale testing. Full scale testing is for practicing systems operation and control, finally enabling verification of all aspects of the device’s performance.

A balanced portfolio of low-carbon technologies is the best way to ensure that the targets set by EU are met by 2050 and beyond. In order to obtain this, testing at different scales throughout the different Technology Readiness Levels (TRL) stages is desirable as a way of reducing risk for Marine Renewables. Although some Marine Renewable technologies have proven themselves, there is as yet very little understanding about how to make them bankable. The deployment of commercial scale arrays will be capital intensive and will require input from large utilities and venture capitalists. Full scale prototypes at sea can cost in the order of £10-30 million, with arrays in the order of £30-£100 million (Carbon Trust).

However, not all the prototypes being tested will successfully evolve into the commercialisation stage. Therefore as a technology moves forward, it is necessary to optimise the design and parameters in order to make them efficient and cost effective (as suggested by ETI, see Figure 1). Each engineering decision should reflect the learning that evolves through different stages of testing.

A trial programme of scaled testing and full scale prototype tests should substantially reduce the risk as potential failures should be identified during the testing stage. This should therefore inspire confidence in the device’s ability to perform as expected. Ultimately, performance is the key to attracting investment and the technology will only be able to obtain this by showing that it is cost competitive. Additionally, third party validation and verification can form an important part of the process and will be instrumental in attracting further investment.

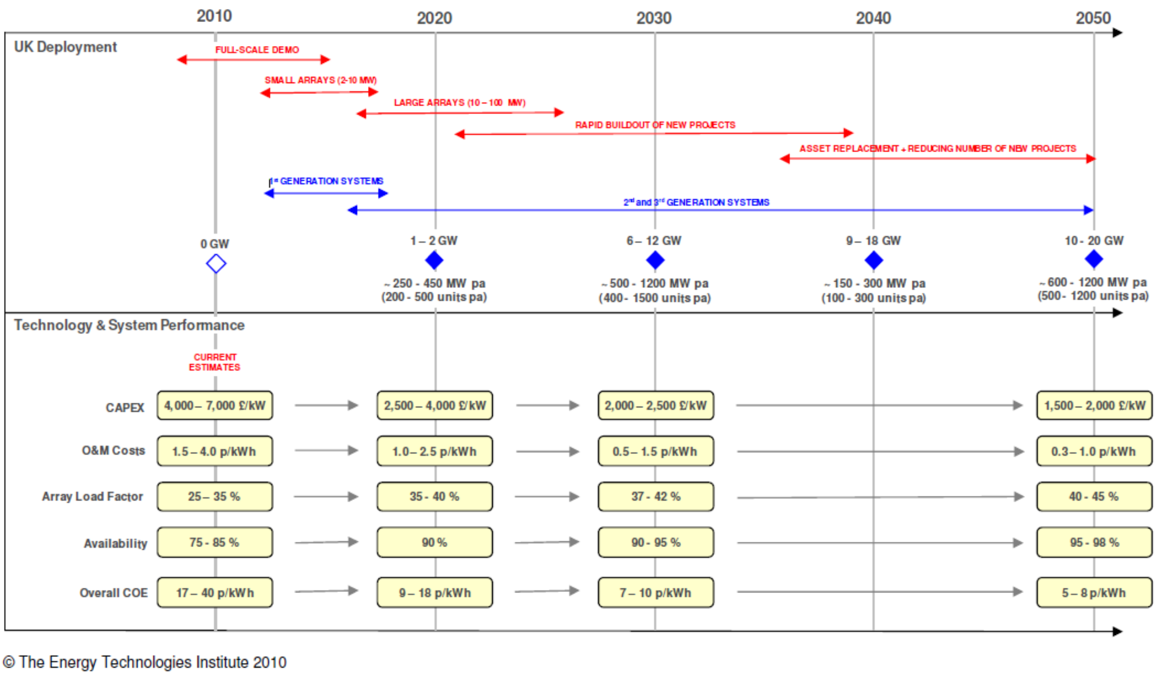

Figure 1 UK Deployment and costs as suggested by the ETI.

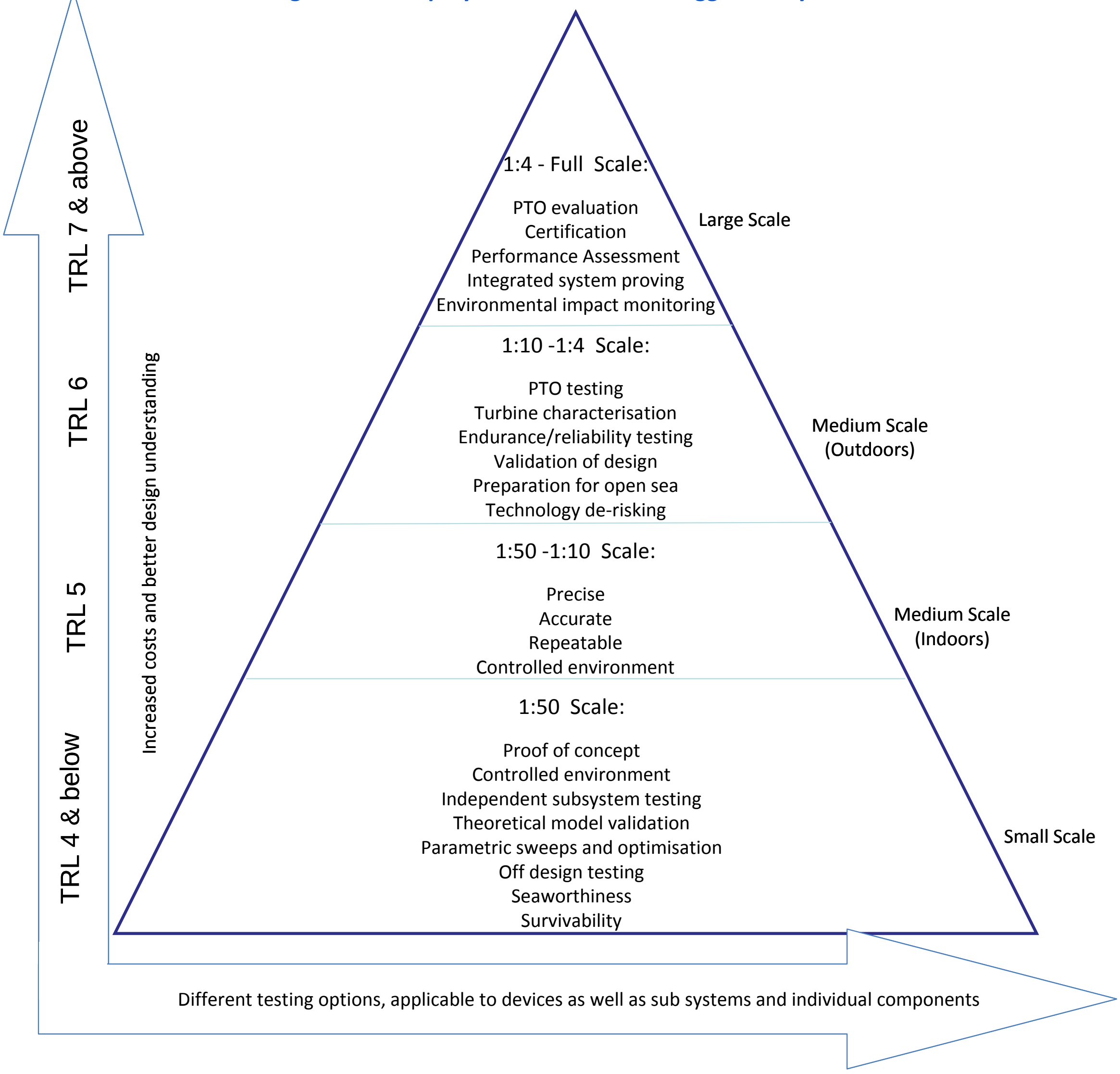

Figure 2 Testing options pyramid

1.1 Purpose and Rationale of Scale Testing for TECs

The purpose of initial testing can simply be to characterise essentials such as power and thrust, and to carry out parametric optimisations. Subsystems can also benefit from testing at this scale. However, the power-take off system is usually simplified as it may be difficult to replicate at small scale and accuracy may be lost due to poor results. One of the most important uses of small scale testing is 'validating' a computational or theoretical model of the energy converter and identifying if the concept works. The scope of the testing should be to strengthen the theoretical model and provide better insight into the working of the energy converter. Additional aspects such as off-design conditions, station-keeping and the effects of surface waves could perhaps be investigated.

Medium scale tests are particularly devoted to the comprehension of the phenomena that are likely to take place at full scale; in fact, modern experimental techniques are able to unveil the important flow features around complex geometry tidal energy converters which can have significant influence on the performance and the environmental impact. A representative power take off system can be thoroughly tested and evaluated. Component and reliability testing can also be conducted.

At the sea trial testing stage, the full TEC system is ready for evaluation and proving. At this stage the final power take off configuration may also be tested. Tests will provide operating experience, knowledge of environmental impacts, and verification of the complete system. This is the final proof of seaworthiness and long-term functionality.

Why test at small scale (Tank)?	Testing at Small scale can be quick and inexpensive. The controlled environment helps as experiments can be easily repeated for a range of parameters. An additional advantage of testing at small scales is that each individual subsystem can be independently tested.
Why test at medium scale (Tank)?	Testing at medium scale is an important step as it can reproduce some of the full scale physics, and this can eliminate some of the scaling issues while still maintaining the ability to be precise, accurate and repeatable in a controlled environment.
Why test at medium scale (Channel / Sea trial)?	Testing at an outdoor medium scale facility can be used to characterise the power take-off under realistic circumstances, This is the opportunity to validate the technology and the device design. At this scale, it is possible to test new designs and make improvements without excessive additional cost. There is also the chance to perform some endurance testing before going to full scale.
Why test at large scale (Sea trial)?	Sea trials are the last stage of testing and perform a vital role in terms of verification and the attraction of development funding.

1.2 Constraints in Scaled Tests of TECs

1.2.1 Tidal Flow Characterisation (Key Physics, Scaling Issues and Correction Factors at Small Scale)

Limitations of scale testing are outlined fully in a number of sources, listed in Sections 1.4 and 1.5. The following is thus a summary of scaling issues which, while self-contained, should only be considered a précis.

1.2.1.1 Scaling and Similarity

When performing experiments at scale denoted λ, there are three levels of *similitude* between a scale *model* and the full scale *prototype*:

1. **Geometric similitude: all length ratios are constant and equal to λ, e.g.:** $\lambda = \frac{L_{\text{Prototype}}}{L_{\text{Model}}}$

   In words, the model and flow shapes are a scale reproduction of the prototype, e.g. square components are still square and deformations are also scaled.

2. **Kinematic similitude: all velocity ratios are constant**
   The ratio of velocities of the model and the flow are constant in all directions, e.g. the ratio of model velocity to fluid inflow velocity is constant, reduced angular velocities (e.g. TSR) are constant, and circular motions of model (or fluid) are still circular.

3. **Dynamic similitude: all force ratios (or accelerations) are constant**
   The ratio of characteristic forces is constant, e.g. classically the ratio of inertial to viscous (Reynolds number) forces, or the ratio of inertial to gravitational (Froude number) forces is matched.

Observation 1: A kinematically similar model satisfies geometric similitude. Likewise, a dynamically similar model is kinematically similar (and thus geometrically similar).

Observation 2: Unless λ=1, it is not usually possible to obtain dynamic similitude and, in general hydrodynamic tests, only *one* force ratio can be matched.

When designing an experiment it is typical to select an appropriate force ratio as a *scaling law* to determine fluid properties, velocities etc.

1.2.1.2 Scaling Laws

The scaling problem is well understood, and there exist methods of analysis which allow an engineer to determine the most appropriate scaling law for a given problem, e.g. the Buckingham-∏ theorem. The most common scaling laws are discussed briefly here. Classic naval architecture and marine engineering tank tests are performed on ship hulls and propellers. In isolation these have differing requirements for scaling, which may be translated into the marine renewables world.

Since some parameters are effectively invariant (e.g. gravity etc.) it is possible to tabulate the scaling relationships according to the scaling laws for physical parameters. For the Reynolds and Froude number scaling they are presented in Table 1.

Froude number scaling: Ship hull drag tests consider viscous effects as secondary and focus on the wave drag and thus the Froude number is used as a scaling law. Froude number scaling is used to relate pressure coefficients on the model and prototypes. The Froude number is obtained by dividing a characteristic velocity *U* by the square root of the product of a characteristic length *L* and gravity *g*:

$$\mathrm{Fr} = \frac{U}{\sqrt{gL}}.$$

Physical Parameter	Unit	Multiplication Factor (Fr)	Multiplication Factor (Re)
Length	[m]	λ	λ
Angular Displacement	[1] (rad)	1	1
Time	[s]	$\lambda^{0.5}$	1
Frequency	[s^{-1}] (rad·s^{-1})	$\lambda^{-0.5}$	1
Period	[s]	$\lambda^{0.5}$	1
Wavenumber	[m^{-1}] (rad·m)	λ^{-1}	λ^{-1}
Mass	[kg]	$\lambda^3 \cdot \rho_p/\rho_m$	$\lambda^3 \cdot \rho_p/\rho_m$
Linear Velocity	[ms^{-1}]	$\lambda^{0.5}$	λ
Reduced Angular Rate	[1]	1	1
Angular Rate	[s^{-1}] (rad·s^{-1})	$\lambda^{-0.5}$	1
Linear Acceleration	[ms^{-2}]	1	λ
Reduced Angular Acceleration	[1]	1	1
Angular Acceleration	[s^{-2}] (rad·s^{-2})	λ^{-1}	1
Force	[N]	$\lambda^3 \cdot \rho_p/\rho_m$	$\lambda^4 \cdot \rho_p/\rho_m$
Torque	[N·m]	$\lambda^4 \cdot \rho_p/\rho_m$	$\lambda^5 \cdot \rho_p/\rho_m$
Power	[W]	$\lambda^{3.5} \cdot \rho_p/\rho_m$	$\lambda^5 \cdot \rho_p/\rho_m$
Pressure	[N·m^{-2}] (Pa)	$\lambda \cdot \rho_p/\rho_m$	$\lambda^2 \cdot \rho_p/\rho_m$
Turbulent Kinetic Energy	[m^2s^{-2}]	λ	λ^2
Reynolds Stresses	[m^2s^{-2}] (Pa)	λ	λ^2
Turbulence Dissipation Rate	[W·kg^{-1}]	$\lambda^{0.5} \cdot \rho_p/\rho_m$	$\lambda^2 \cdot \rho_p/\rho_m$

Table 1. Parameter multipliers for Froude and Reynolds scaling. Note that, in general, the further the exponent from unity, (except of course zero) the more difficult the parameter will be to scale.

Reynolds number scaling: Basic propeller tests are performed in isolation from the free surface and consider the drag due to viscosity and hydrodynamic loading due to surface pressure and thus the Reynolds number is used as a scaling law. The Reynolds number is obtained by dividing the product of a characteristic length scale *L* and velocity *U* by the kinematic viscosity, ν :

$$\mathrm{Re} = \frac{UL}{\nu}.$$

Cavitation number scaling: In experiments on flow about hydrofoils, propellers and turbines, the scaling parameter is the cavitation number. This is used to adjust the ambient pressure to maintain the ratio of fluid vapour and local pressures.

$$\sigma = \frac{P_{\mathrm{vapour}} - P_{\mathrm{ambient}}}{\frac{1}{2}\rho U^2}.$$

Strouhal number scaling: when dealing with oscillating or rotating mechanisms, a scaling number for the frequency is necessary; the Strouhal number is a frequency made non-dimensional by the free flow velocity and a characteristic size of the involved phenomenon:

$$\mathrm{St} = \frac{fL}{U}.$$

In a broader sense, the Strouhal number is a non-dimensional indicator of the unsteadiness of the phenomena under investigation.

Observation 3: The Reynolds scaling laws are especially stringent: consider a prototype 5m diameter turbine operating at TSR of 4 at 2.5ms^{-1}. A scale model is made with a diameter of 0.8m for testing. The only way to achieve dynamic similarity through Reynolds scaling is to use extremely high flow velocities (which is impractical) or by modifying the kinematic viscosity, using mercury as a working fluid! Reynolds number scaling is however achievable for component testing of a model, for example determining the lift/drag characteristics of an aerofoil.

Observation 4: Often, when tank testing tidal devices in water where the effects of a free-surface are not relevant (and also negligible), attaining any relevant dynamic similitude for the hydrodynamic subsystem is not possible. This is since Froude number scaling, which is achievable, is only relevant to gravity effect dominated free-surface flows (it is not a dimensional grouping generated during e.g. Buckingham-∏ analysis), and Reynolds scaling is impractical (see above). In situations such as these, at the smallest scales it is typical to resort to kinematic scaling using velocity ratios, e.g. the tip-speed-ratio for turbines.

Observation 5: An additional point to note is that the power scales very poorly using either the Froude or Reynolds scaling laws. For example, Froude scaling a 1MW rated plant to 1/50th scale (λ=0.02) tank test would result in a model PTO rating of 1.13W, with very accurate measurement of performance in order to meet e.g. ITTC or EquiMar experimental guidelines – permitted deviations of ±50mW maximum. A similar PTO scaled according to Reynolds number would be rated at 3.2mW – clearly unfeasible both in terms of energy flux through the rotor, and also manufacturing. Because of this, the PTO is generally simulated at small scale.

1.3 Tidal Test Parameters or Subsystems which can be effectively tested at small scale:

1.3.1 Hydrodynamic Subsystem

1.3.1.1 Individual components

The performance of components of the hydrodynamic subsystem can be characterised in a very straightforward manner in a towing tank or flume. Indications of the thrust and drag associated with nacelles, hubs and other components is of crucial concern to the developer. However, tests on some components, for example to obtain aerofoil section characteristics, are better performed using a wind tunnel, since the complexity and overheads are substantially reduced.

1.3.1.2 Primary interface

The obvious and most important use of facilities capable of testing at these scales is the characterisation of the primary interface of the hydrodynamic subsystem. The combination of reduced cost and complexity associated with small scale testing, along with the strong controllability, repeatability and fast turnaround capabilities of towing tanks and flumes is an obvious attraction when the requirement is a high quality dataset of performance characteristics.

1.3.1.3 Flow augmentation devices

Device components designed to alter the flow around the primary interface, for example ducting around a rotor system or a flow augmentation step below a rotor, can and should be tested in isolation of the rotor system for characterisation in order to adequately capture the hydrodynamic effects. A correct characterization of the performance of a ducted turbine should be thus performed in two steps. First, model testing of isolated rotor (operating in open water) and model testing of the isolated ducting. Preliminary optimization of the latter can be accomplished at this stage. Then, model testing of the complete assembly to analyse the mutual interactions among the rotary and fixed components. A similar process can be followed for other devices, e.g. a flow augmentation step.

1.4 SUBSYSTEMS WHICH CANNOT BE EFFECTIVELY TESTED AT SMALLEST SCALE

These subsystems are not suitable for testing in small scale tank facilities without considerable effort in the design of the test-pieces. More economical options include bench testing of individual components and testing at larger scales.

1.4.1 Power Take Off Subsystem

The ability to manufacture and test functional PTO systems for small scale tests is severely hampered by the inability to scale them correctly. In general they will be represented by some idealised mechanical or electronic system. The primary objective during early stage scale tests is to ensure that the effects of the PTO on the hydrodynamic subsystem are represented as accurately as possible. Later stage trials on PTO systems are typically conducted using “in-the-dry” bench-tests, or via a PTO simulator.

At large scale: This is the only opportunity to test fully the PTO sub-system. Different control strategies may be assessed, and a validation of PTO models should also be obtained. Endurance and reliability information about the PTO will also be obtained.

1.4.2 Control Subsystem

Closely related to and often buried within the PTO subsystem, the control system scales poorly, and is anyhow unlikely to be fully defined and capable of implementation at the stages where testing of these scales is conducted. Exceptions to this are when the control system is a crucial component without which the device would be unable to function – an example from the literature might be a Stingray type device. In these circumstances a proxy computer driven control system might be employed with appropriate actuators, or a purely mechanical solution might be sought. In either case, simplicity is of the essence.

1.4.3 Reaction Subsystem

The reaction subsystem is another which scales poorly, and is anyway unlikely to be included in tests, since the primary objective for the scale mooring system will be to adequately secure the test-piece to the facility. That being said, there are foreseeable tests where measurements of the interaction between a scale representation of the mooring system and the behaviour of the device are desired. These tests will likely be conducted at later design stages than those where the principal objective of experimental testing is proving the hydrodynamic performance of a device, as they admit an additional layer of complexity due in no small part to the difficulties in creating an accurate theoretical dynamic model.

1.4.4 Structural Components

As with the reaction subsystem, the structural components of an experimental device tested at small scale are such as to properly support and protect the prototype. Scaling of the load response is problematic, and it is often difficult to ensure that there is enough compliance in the structure that strain-gauges may be used effectively. If implemented, they will provide useful information about likely forces and moments (and might be essential to capture adequately the individual contributions of, for example, thrust due to the nacelle, rotor and mounting system. Another point is that the construction methods for the prototypes are, in general, substantially different to those proposed at full scale. Specific examples of this might be the use of all metal rotor-blades in place of a semi- or fully monocoque construction using carbon/glass fibre, or the use of components constructed through the use of rapid-prototyping technologies. In both these examples, the distribution of loads within the structure of the small-scale prototype will be substantially different to those at larger scale.

1.5 Considerations when Testing at Small Scale Facilities

1.5.1 Type of experiment and flow physics capability

Due to the nature of tow-tanks, in general and with respect to tidal power, the tests which can be performed are those in which a device is suspended from a carriage and drawn along the length of the tank. In flumes, the device is suspended or mounted directly to the facility structure. These facilities are useful for generating highly repeatable datasets on power and thrust characteristics at the range of scale flow speeds which the carriage can accommodate.

1.5.2 Appropriate device sizing

Due consideration should be given to the effects of blockage and proximity to any free-surface, even though correction factors exist.

1.5.3 Flow physics and scaling issues

In tow tanks, unless a disruptive mesh is placed up-carriage of the test piece, the only source of turbulence is that created during the test runs, and once a run is complete the turbulence begins to dissipate. Therefore the turbulence field varies in space and diminishes in time after a run. This can be considered both a benefit and a hindrance depending on the objectives of the experiment, since high turbulence can increase variability and it is not obvious how to scale for turbulence. Tow tanks also possess a free-surface which is disturbed during runs, and there are reflections from the sides of the tank (and also the ends if there is no wave absorption). Free surface effects can also impact on performance measurements of devices, since deformation of the surface can occur due to proximity to both the device and its wake. Finally, in tow-tanks and flumes, wave-makers can be used to simulate experimentally the effects of one-dimensional sea-states on tidal devices.

1.5.4 Relevant and possible measurements

Load cells can be used to calculate thrust during resistance tests. When using a towing tank, these measurements are typically taken “in-the-dry” on the supporting structure on the carriage. In flumes, the point of attachment to the facility structure may already be instrumented, or measurements must be taken from the device “in-the-wet.” In either case, strain gauges can be waterproofed or embedded and loads can be measured on structural members and for example at blade roots, to obtain forces and moments.

Due to PTO scaling issues, a proxy PTO is generally substituted, a particular example for a turbine being a disk braking system where a load cell is used to measure the braking force required. Other options include using a small electric generator-motor connected to a computer control system and a resistor bank.

Displacement and velocity measurements are obtained directly from the carriage, and optical or magnetic systems can be used to determine angular velocities. This being the case, it is possible to obtain all of the relevant measurements required to adequately characterise a small scale hydrodynamic subsystem.

1.5.5 Data capture, repeatability and uncertainty associated with measurement

Typically, computer driven data capture and storage is available at facilities. Even basic modern systems are capable of sample rates measured in kHz, with tens of channels, and due to the low cost of storage, entire datasets can be preserved.

Test programmes conducted in towing tanks are highly desirable due to their enhanced repeatability and precision. Due to the fact that many data samples can be taken over a single run, for “steady” experiments in general only a small number of runs are required to capture sufficient data for **95% CL ± 5%**. For “unsteady” experiments, such as measurements on yawed turbines, methods such as phase locking and time averaging are required; more runs may be required depending on the degree of unsteadiness.

1.5.6 Reaction subsystem and structural components

The response of the structure in terms of forces and motions will be assessed. The principal concern is to establish the stability, seaworthiness and station keeping ability of the device. Consideration of wind and wave loading will also be made, and observations of marine growth and corrosion may be made. There is also the opportunity to measure environmental interactions before moving onto full scale commercial deployment.

1.6 Further Information

Full descriptions of the processes and problems associated with small scale testing are available in the deliverables of the EC PF7 project EquiMar, specifically:

- EquiMar D3.2: **"Concept Appraisal and Tank Testing Practices for 1st Stage Prototype Devices;"**
- EquiMar D3.3: **"Assessment of current practice for tank testing of small marine energy devices;**"
- EquiMar D3.4: "**Best practice for tank testing of small marine energy devices.**"

2 COLLATION OF THE SCALE TIDAL TESTING OPTIONS IN THE MARINET PROJECT

There exist a number of lists of the scale model testing facilities available in Europe and worldwide, and as such this list is confined to those which are available under the Transnational Access objectives of the MaRINET project. Two examples of external lists are:

- The FP7 HydralabIV website project lists facilities available in Europe: http://www.hydralab.eu/N_facilities.asp;
- The US Department of Energy provides, in the website of the "Energy Efficiency and Renewable Energy Water Power Program," a list of facilities in the US: http://www1.eere.energy.gov/water/hydrodynamic/facilityList.aspx.

A large number of the available facilities in MaRINET are listed in the HydralabIV database.

2.1 Small Scale Indoor Facilities

These include towing tanks and flumes for testing complete configurations, as well as wind tunnel facilities for characterising individual components.

2.1.1 Kelvin Hydrodynamics Laboratory, Strathclyde University (UK)

2.1.1.1 Infrastructure Specification:

- Tank Dimensions:
    - 76m long, 4.6m wide and 2.5m deep.
    - Typical water depth: 0.5-2.3m.
- Carriage:
    - Computer-controlled digital drive.
    - Max speed 5ms^{-1}, max acceleration 1ms^{-2}.
    - Speed accuracy and regulation exceeding ITTC standards.
    - Equipped with digitally-controlled sub-carriage for unsteady forward speed testing.
- Wavemaker:
    - Variable-water-depth, computer-controlled for flap absorbing wavemaker.
    - Generates regular or irregular waves over 0.5m height (subject to water depth.)
- Beach:
    - High quality variable-water-depth sloping beach.
    - Reflection coefficient typically less than 5% over frequency range of interest.
- Data acquisition:
    - PC based modular data acquisition/control system.
    - Up to 64 input and 20 output channels, sample rate up to 60kHz.
- Key Instrumentation:
    - Qualisys optical 6 DOF real-time motion capture camera system.
    - Resistance dynamometers for different device types and model sizes.
    - 6 DOF dynamometers for force measurement.
    - 25 wave probes to determine water surface elevation.
    - 3-axos fluid velocity measurement systems.
    - Dantec PIV system.
    - Pressure distributions on model surfaces can be measured.
    - Above-water and underwater video systems are available.
- Strathclyde University Subsonic Wind Tunnel:
    - Recirculation, open jet type, with a 4m long by 1.6m diameter cylindrical working section.
    - Flow speeds of 0.2-25 ms^{-1} with flow straightening applied upwind.
    - Ultrasonic Doppler anemometry for velocity and dynamic fluctuation measurement.

- 3 DOF (L/D/M) balance table for static loads (dynamic loads by custom on structure instrumentation e.g. strain gauges).
- Modular PC based data acquisition with up to 64 input and 20 output channels and up to 60kHz sample rate.
- Recirculation Flume (to be commissioned):
  - 5m length with 1.5 x 1.5 m working section.
  - 1.5m flow speed with flow straighteners upstream of working section.

Services Offered:

Access to wave/ towing tank for device testing. Services will normally include:

- Advice & assistance with test planning (instrumentation choice, test matrix etc.)
- Wave generation to specified requirements.
- Model set-up, ballasting, installation, instrumentation and data acquisition.
- Mooring set-up and instrumentation.
- Measurements of motions, forces, etc.
- Power determination.

Support Offered:

- Support for model installation, instrumentation set-up and testing is normally supplied by experienced KHL staff.
- Support for calibration and basic data processing are normally supplied.
- Desk space and internet can be provided (internet required advance notice).
- Advice on travel and accommodation etc.
- Ready access for vehicles.
- Craneage up to 1 tonne into building and 500kg into tank.

Optional support includes:

- Model making and fit out services are available, but not supplied as standard;
  - Complex shapes can be manufactured using a 5m CNC router suitable for lightweight materials.
  - Full mechanical workshop for manufacture of mechanical parts.
- Customised mechanical systems and transducers can be manufactured.
- Customised supports, mooring systems etc. can be manufactured.

Typical Projects/ examples:

- Resistance and sea-keeping tests for ships and floating structures.
- Wave energy device and component performance evaluation.
- Tidal Energy device and component performance evaluation.
- Dynamics and survivability of floating structures in waves including wave and tidal devices.
- Wave impact on fixed and floating bodies - including wave and tidal devices, ships and oil and gas structures.
- Hydrodynamics of towed bodies, including tidal devices.
- Steady/unsteady loading on surface and underwater structures.
- Vortex-induced vibration studies.

2.1.2 Current Flume with a Carriage, Danmarks Tekniske Universitet (DK)

2.1.2.1 Infrastructure Specification:

The infrastructure is a medium-scale open current flume with dimensions 35 m (length), 3.0 m (width) and 1.0 m (depth). Water currents can be run with a maximum velocity of 1.5 ms^{-1}. The facility has a carriage which facilitates to tow model structures with a maximum velocity of 2.1 ms^{-1}, enabling the flume to be used as a towing tank. The carriage has dimensions of 3 m by 3 m (plan view). The same carriage (with a model structure mounted onto the carriage) can be used to generate an oscillatory motion around the structure model, with a maximum velocity of about 1.2-1.3 ms^{-1}, depending on the stroke of the motion. In this way, wave-induced oscillatory flow around structures is simulated by moving the carriage back and forth in otherwise still water. This proves extremely useful to generate large-amplitude oscillatory motions which cannot be achieved in small- and medium-scale wave flumes. With this facility, flow around and forces on cylindrical structures of dimensions of up to 0.5 m (in some instances, even larger) and subjected to steady current and/or waves can be studied, e.g. offshore wind turbine foundations/towers, bridge piers, marine pipelines, etc. The flume has been in constant use ever since it became operational, particularly after the installation of the carriage in early 80s. As a result of this intense research activity, a substantial amount of knowledge has been gained on flow around and forces on offshore structures such as marine pipelines, marine risers, piles, etc., highlighted in many papers that the staff have published in scientific journals and conference proceedings as well as in a monograph by Sumer & Fredsøe: Hydrodynamics Around Cylindrical Structures, 2006, World Scientific. The facility has also been used quite extensively by industrial research organizations and consulting firms, among others, Danish Hydraulic Institute (DHI). The flume is currently being used by DHI, to study problems in connection with Femern Bridge that will link Denmark to Germany.

Services Offered:

- “Towing-tank” experiments of structure models such as offshore wind turbine towers / foundations
- Calibration of measuring instruments using the carriage facility up to 2.1 ms^{-1} velocity
- Current experiments with velocities up to 1.5 ms^{-1}, or using the carriage facility up to 2.1 ms^{-1}
- Wave-induced oscillatory flow experiments with velocities of up to 1.2-1.3 ms^{-1}
- Experiments on flow around structures including flow visualization and flow velocity measurements
- Pressure and force measurements on structure models

Support Offered:

The user will be provided by scientific/ technical support as it is deemed appropriate. The user will be in a scientific environment with more than 10 PhD and Master’s students as well as Postdoctoral fellows working in a broad range of marine civil engineering disciplines covering from coastal engineering to offshore engineering, to hydraulic engineering, and to physical modelling studies and CFD applications. The group is truly international, with three foreign permanent faculty staff and one foreign postdoctoral fellow, and a substantial number of international Master’s students.

2.1.3 Institut für Aerodynamik und Gasdynamik Laminar Wind Tunnel, Universität Stuttgart (DE)

2.1.3.1 Infrastructure Specification:

The Laminar Wind Tunnel (LWT) of the IAG is an open return tunnel of the Eiffel design for dedicated aerodynamic and aeroacoustic 2D aerofoil measurements. The high contraction ratio of 100:1 and 5 screens and filters result in a very low turbulence level below $I = 2x10^{-4}$. Typical model chords range from 0.4m to 1m and enable a Reynolds number range from $Re = 5x10^{5}$ up to $5x10^{6}$. Beside standard measurements such as lift, drag and moment as well as aerofoil pressure distributions, dedicated boundary-layer experiments can be performed by means of hot-wire probes. Experiments in a wind-tunnel enable highly accurate drag measurements of aerofoils for tidal current turbines. As a unique feature important for wind turbine blade developers the LWT enables to measure the emitted aerofoil trailing-edge noise. The LWT is a widely used workhorse for basic research and industry investigations.

Services Offered:

IAG provides measurement services to researchers and developers in profile and turbine blade design for tidal current turbines and wind turbines. Due to the long experimental experience in profile testing and development efficient and accurate measurements can be offered. Profile data for blade development and validation of numerical predictions will be a main service.

2.2 Medium Scale Indoor Facilities

2.2.1 Flume of Boulogne-sur-mer, IFREMER (FR)

2.2.1.1 Infrastructure Specification:

- 18m long, 4m wide, 2.1m deep.
- Flow velocity range: 0.1 to 2.2 ms^{-1}.
- Turbulence intensity range: 5 to 25%.
- Regular and irregular waves: peak period 0.5 to 2s and maximum peak-trough height of 0.3m (waves with or against the current).
- Mobile floor of 6 x 4m2 to adjust the depth form 0 to 2.1m.
- 2D Laser Doppler and Particle Image Velocimeter systems.
- Optical Tracking system and Multiple sensors.
- National Instruments/Labview Data Acquisition System.

Services Offered:

- Hydrodynamic force and moments measurements on fixed and moving devices.
- Hydrodynamic behaviour and performance in a range of wave-current conditions.
- Non-intrusive velocimetry measurements and time resolved flow analysis.
- Data acquisition and analysis through bespoke software.

Support Offered:

- Support for users set up projects and instrumentation.
- Teamwork with motivated researchers and technicians having long-term experience in model testing in the IFREMER facilities and in the use of state-of- the-art measurement and processing techniques.
- In-house workshops: realisation, maintenance and repair of mechanical, electrical, electronic devices.
- CAD and CFD experts.
- Desk space and internet access provided.

Typical Projects/ examples:

- Tidal energy devices testing from 1/30 to 1/2 scale in multiple sea conditions.
- Hydrodynamics characterisation of surface and submarine vessels and structures.
- Wake characterisation.
- Turbulence intensity effects.
- Wave/Current/Structure interaction studies.

2.2.2 CNR-INSEAN Circulating Water Channel (IT)

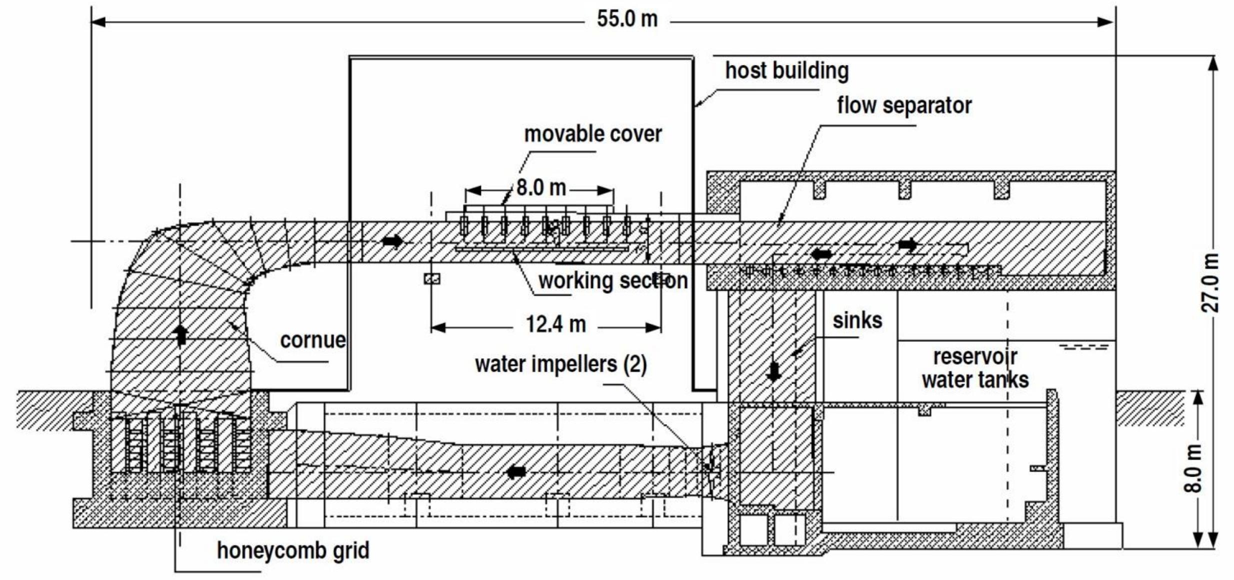

Figure 3 Diagram of the circulating water channel at CNR-INSEAN.

2.2.2.1 Infrastructure Specification:

- Free water surface circulating channel
- Vertical plane circuit, 4 million litres capacity
- Working section dimensions: 10m (length), 3.6m (width), 2.25m (maximum water depth)
- Two operating modes: (i) fully wet section, and (ii) partially wet section, free surface flow
- Water speed in the test section: 0.3 5 ms^{-1}
- Control of absolute pressure in the test section: 3 - 101 KPa
- Type of drive system: two 4-bladed axial flow impellers, Ward-Leonard controlled, operating in two parallel trunks
- Total impeller motor power: 2 x 435 kW at 1500rpm
- Typical model size range: 0.15 0.30 m (marine propeller), 0.1 6.0 m (vessel or marine structure model)
- Instrumentation: velocimetry (LDV, 2D-PIV, Stereo PIV, DDPIV), pressure sensors, force measuring dynamometers, hydrophones and noise measuring equipment, data collection and system control, time resolved visualization systems

Services Offered:

- Cavitation and ventilation tests with and without free surface effects
- Hydrodynamic loads measurements on marine vessels and structures
- Non-intrusive velocimetry measurements (pointwise, planar and volumetric techniques by LDA, PIV)
- Hydroacoustic measurements
- Time resolved flow visualizations using high-speed camera and digital image techniques
- Waterborne structural excitation tests

Support Offered:

- Operation of the facility in collaboration with CNR-INSEAN staff
- Support of CNR-INSEAN experienced staff during set up and testing activities
- Teamwork with motivated researchers and technicians having long-term experience in model testing in the CNR-INSEAN large facilities and in the use of state-of-the-art measurement and processing techniques.
- In-house workshops: realization, maintenance and repair of mechanical, electrical, electronic devices
- CAD-CAM experts
- CFD experts
- Desk space and internet access, library.

Typical Projects/ examples:

- Hydrodynamics characterization of surface and submarine vessels and structures
- Analysis of marine propulsor performance
- Analysis of marine current turbine performance
- Cavitation and ventilation studies on floating and submerged devices
- Hydroacoustics characterization of marine devices (noise emission and radiation)
- Characterization of complex flow field structures through correlated velocimetry, pressure, and flow visualization analyses.

2.2.3 CNR-INSEAN Towing Tank No. 2 (IT)

Figure 4 Picture of the towing tank number 2 at CNR-INSEAN.

2.2.3.1 Infrastructure Specification:

The main characteristic of CNR-INSEAN towing tank No. 2 are listed below:

- Dimensions: 220m (length), 9m (width), 3.5m (water depth)
- Maximum carriage speed: 10 ms^{-1} (accuracy better than 0.15%)
- Motor driven, manual and automatic control, manned carriage
- Electric drive system with 8 drive-wheels, each coupled to a DC main motor via a reduction gear and 2 pairs of horizontal guide wheels (only on one rail). Electric main motors (57kW x 8)
- Wavemaker type: one-side flap-type wavemaker, 9 m wide, electro-hydraulically powered with 3 pumps of 38.5 kW total power, controlled by 100 harmonic component electronic programming device (each harmonic can be modulated both in amplitude and frequency)
- Wave generation capability: regular waves from 1 to 10m in length with corresponding height of 100 to 450 mm (slope 1°- 9°); irregular waves according to any desired sea spectrum condition in appropriate scale
- Beach type and extent: 2 crossed layers of square tubular 70x70 mm equally spaced with movable central part for model transit
- for mooring tests an additional structure, carrying wind generators, can be added on the beach of the carriage and oriented on the horizontal plane; air blowing generation system, of 2 rows with 6 fans each, capable of a continuous variation of speed (from 0 to 20 ms^{-1}), direction (0°±20°) and vertical gradient.
- Model size range: 1.5 to 8m
- Instrumentation: force balance dynamometers, model propeller transmission dynamometers, 5-holes Pitot tube, 1 to 6 component balance for rudders and ship model tests, fully submerged propeller dynamometer (thrust range= 400N, torque range= 15Nm, speed range= 60 to 3000 rpm, left and right hand rotation, inclined operation up to ± 15° in the vertical plane), 3D optical system and inertial platform for measuring surface model motion in waves

2.2.3.2 Type of experiment, appropriate device sizing and measurements

Any kind of device for power generation from tides, as well as any other object tested in a towing tank, is tested being attached through some additional element to the carriage running over the tank itself; so, with quiet water or in waves generated by the action of the wavemaker, the effect of the tide is simulated by the movement of the carriage. In Figure 5, a picture of a tested Kobold turbine is presented as example with 600 mm in radius, 800 mm in span and chord 80 mm .

Figure 5 Kobold turbine tested at CNR-INSEAN.

Depending on the desired test matrix under investigation, different velocities, depths and wave trains, if necessary, can be tested. As a matter of fact, to reproduce as stricter as possible the operative points of the device, a proper scaling of the device itself has to be done carefully considering the characteristics of the tank, mainly in relation to the blockage problem also considering that reducing the scale means increasing the carriage velocity to get a constant Reynolds number. As reported in Literature, when the ratio of the cross-section area of the device over the analogous of the tank is equal or less than 0.05, the blockage effect can be neglected; anyhow, larger values of this ratio can be used applying the appropriate correction.

Nowadays, to fully characterize energy generator devices, a multi-techniques approach is needed; for this reason a large number of services are available for customers at CNR-INSEAN. The main ones are:

- Station-keeping of marine structures (floating and submerged) in waves
- Flow velocimetry and acoustic field measurements
- Hydrodynamic force and moments measurements on fixed and moving bodies
- Mooring tests
- Body-to-body interaction
- Structural response to hydrodynamic loads.

On this basis, as a natural consequence, the following list of activities/projects are suitable to be performed in the tank:

- Analysis of tidal turbines and design
- Analysis of tidal energy conversion systems and design
- Assessment of tidal energy devices power output capability
- Analysis of mutual interactions among energy generation devices (wake effects)
- Hydrodynamic and hydroelastic response of marine structures (floating and submerged)
- Simulation of ship-structure interaction in calm water and in a sea-state
- Hydroacoustics characterization of marine devices (noise emission and radiation to near and to far-field)

- Characterization of complex flow field structures through correlated velocimetry, pressure, and flow visualization analyses
- Hydrodynamics characterization of surface and submarine vessels and structures
- Analysis of marine propulsor impact on surrounding field

On customer request, any other test can be designed and supported by in-house staff.

2.2.3.3 Flow quality and Repeatability

It is generally accepted the high level of repeatability of the observations performed in a towing tank; in fact, being the repeatability linked to the flow quality, if a sufficient amount of time is allocated between a run and successive one, any flow disturbance, due to the passage of the carriage, will decay and the quality of the flow will be restored – no small scale turbulence in the basin, no coherent structures of large dimension, no waves due to their absorption on the tank sides.

2.3 Medium Scale Outdoor Facilities

2.3.1 Portaferry Tidal Test Centre, QUB (UK)

2.3.1.1 Infrastructure Specification:

Type of experiment and flow physics capability

The facility at Portaferry is located on the eastern shore of Strangford Lough which is a large (150km²) shallow sea Lough situated on the east coast of County Down, Northern Ireland. About a third of the Lough is intertidal - the southern entrance to the Lough is a deep channel about 8km long, called the Narrows. The width from Portaferry across the Narrows to Strangford is just 0.5km with an associated current regime that is extremely strong and fast. At spring tides around 30,000m^3/s leave or enter the Lough resulting in strong currents of up to 9 knots (≈4 ms^{-1}) at spring tide. QUB has a Marine Science laboratory facility at Portaferry (Queens University Marine Laboratory - QML) that provides logistical backup and office space during testing. The facility is unique in Europe due to: Range of scaled tidal conditions to suit a large range of device configurations Location and ease of access (1 hour from Belfast International Airport). QUB are currently licensed to undertake a range of experimental activities in relation to tidal stream power in a site area stretching from the Portaferry Quay (opposite the RNLI lifeboat station) to Walter Rock in the north. Testing of different devices requires permission from NIEA, which involves in general at least an environmental screening and stakeholder consultation prior to deployment. Potential users therefore need to contact the site manager well in advance of the proposed test to assess the requirements for licensing.

2.3.1.2 Device sizing

The bathymetric profile of the Lough and the variation in current profiles at various locations permits scaled (approx. 1/10th) tests of full-scale tidal devices (either floating or fixed) that are designed for specific operating conditions (depth, current, wave interaction, tidal range etc). The water depth in the licensed area ranges from 0 - 12m Chart Datum (c. Lowest Astronomic Tide) with a tidal range in the order of 3.2m at spring tides. Thus the sizing is primarily limited by other parameter than the flow and is more so restricted by the size of the support vessels/support structures required.

2.3.1.3 Flow physics and scaling issues

The flow varies following the typical semidiurnal pattern with flow velocities up to 1.5 ms^{-} in places in the licensed area. Ebb and flood flow are not exactly symmetric and the strength varies from location to location. In particular in the ebb flow large eddying takes place shedding from Walter Rock. The turbulence intensity is similar to a large number of full scale tidal stream sites, with being slightly higher compared at the shallower inshore locations. The water is normal salinity seawater.

2.3.1.4 Data, instrumentation & equipment

There is detailed numerical modelling available for this site giving a range of different flow speeds and water depths. Specialist equipment available includes a comprehensive inventory of Oceanographic instrumentation (ADCP, ADV, Underwater Data Transmission & Power Cable, Underwater Video, WIFI radio link). Specialised software is available for data analysis. Standard services include warehouse building, slipway, moorings, boats (1 ton lift capacity on boat), barge and manufacturing/fabrication facilities. A dedicated catamaran to mount turbines in between can also be made available.

2.3.1.5 Additional information

Extensive supporting facilities on hand Experienced staff with expert knowledge of Strangford Lough and operating procedures therein. Research activities in the infrastructure to date have concentrated on resource assessment, environmental impact assessments, turbulence-related monitoring techniques and marine biology research related to the benthos of the Lough. A concurrent project involving the installation of a 1.2MW full-scale tidal turbine

(Marine Current Turbines™, www.marineturbines.com) has provided a unique opportunity for research in this area and a direct link to desired research at model-scale. The Lough has been in use since 2004 for the full-scale tidal energy research. The scaled test sites are available from April 2008 with the 1st 1.5m diameter floating device being tested in April 2008.

2.4 Medium Scale Testing in Channel Facilities

2.4.1 Facility: TTC nl.

In the channels in the Tidal Testing Centre (TTC) in The Netherlands, water speeds are going up to 4.3 ms^{-1}. Turbines with a diameter up to around 3m diameter create huge thrust in these water speeds and should therefore be professionally designed and documented to withstand the resulting forces. It is therefore needed that thorough calculations and design evaluation (and if possible small scale testing) is done before going to these sites. In open waters one has to realise that there is no "valve" to switch the flow off. The flow starts when both basins are at equal level and the tide at the sea side makes the water level going down. The period during which this happens is around 3 hours (twice a day).

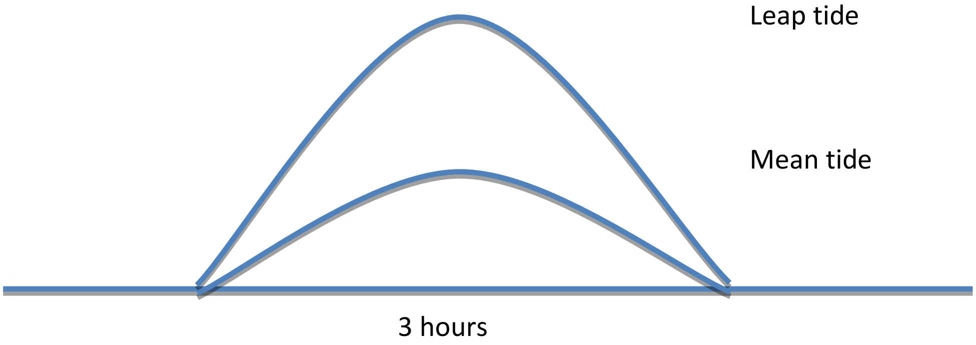

Figure 6 Tidal velocity profiles at TTC.

At the Tidal Testing Centre, the channel is 4.5 m deep and about 12 m wide. The main function of the channel is to exhaust water through the dike, from the lake on one side to the sea on the other side. The dike itself is a water defence system. This main function may never be challenged. As the channel is quite old (1930), no changes to the channel by drilling etc. are allowed. As a consequence, building and construction of devices into the channels needs approval from the local government. At the moment permits for one channel are given and the permits for a second channel are under preparation. The scale of testing is related to the final size of the system, developers want to build. The turbines tested until now were tested at a 1:1 scale, with rotor diameter close to 3m.

During testing, the generated electrical energy can be fed into the grid, via a central connection box ca. 60m from the test location. The developer should provide all equipment to do so. The TTC can assist with this, but the developer should have their own organisation skills to make this happen. All installations and connections should be done under the approval of the TTC. This also includes monitoring and controls. The TTC has good connection with local specialised companies that can assist.

To get an idea of the test circumstances at the TTC, please look at http://www.youtube.com/user/TocardoBV at which one of the developers that tested their turbine at the TTC has presented some videos. As described above the forces are substantial, during operation several tons of loading on the turbine and the structure can be expected. The flow at the entrance of the flume is laminar.

For data logging, a cabin can be provided next to the flume. There is a Wi-Fi connection to the office building. At the building there is plenty of space to work with larger teams. Near the flume safety should be taken seriously. Work can only be done with two or more people at the location.

The flow speed for each run is predicted from level measurements. Sometimes there is no flow at all, because sea-level is too high.

2.4.1.1 Type of experiment and flow physics capability

Medium size testing facilities are more focussed on validation of the expected performance or behaviour of tidal devices. As the scale is substantial, all individual components are at the same time tested for usability as well, like seals, electrical connections and installation ability and repeatability. At such sites, the operations are becoming more complex already than in small scale test facilities. However, operations are still far more easy than at the open sea. The testing of systems in medium size facilities is therefore highly recommended before going offshore.

2.4.1.2 Device sizing

Same as with small scale testing, consideration should be given to the effects of blockage and proximity to the free-surface.

2.4.1.3 Flow physics and scaling issues

Depending on the scale of testing, which can be either at full scale for small devices or up to 1:10 for future large offshore devices, results of testing have to be interpreted and scaled to larger designs. The advantage of the medium size testing facilities compared to small scale is that full designs of Power take off system can be tested.

As described before, the flow in such natural environments is dependent on the actual situation. Flow speed at the Tidal Testing Centre in The Netherlands can only be anticipated as the actual tide predicts the water level difference, leading to the maximum flow speed. The increase and decrease of the flow speed during the exhaust period of approx. 3 hours however gives a good opportunity to test a setup with different flow speeds. The testing protocols should anticipate on such variations.

2.4.1.4 Blockage

Placing a test device in a channel will affect the actual flow. To be able to compare the performance of devices for measured flows to performance at open sea locations, corrections have to be made which take into account the blockage and local circumstances of the channel. With the experience that has been built up at TTC, for different test configurations these effects can be evaluated.

2.4.1.5 Relevant and possible measurements

Measurement of the water flow at different locations in the channel can be done and test devices can be equipped with all kind of relevant sensors. Via cable connection (or wireless) data can be transferred to data collection systems that gather the data for further analysis. Since medium scale tests are used to evaluate designs, the sensors and relevant measurements are very much determined by the aspects that need to be evaluated, which can vary per device and per experiment.

2.4.1.6 Reaction Subsystem

On medium scale test sites like TTC and full scale test sites (EMEC) measurements of the interaction between the mooring system and the behaviour of the device can be measured and monitored, to prove the hydrodynamic performance of a device.

2.4.2 Facility: CNR-INSEAN Circulating Water Channel

The following paragraphs present the main features of the circulating water channel experiments, with specific reference to CNR-INSEAN apparatus located in Rome, which is available to access through the MaRINET project.

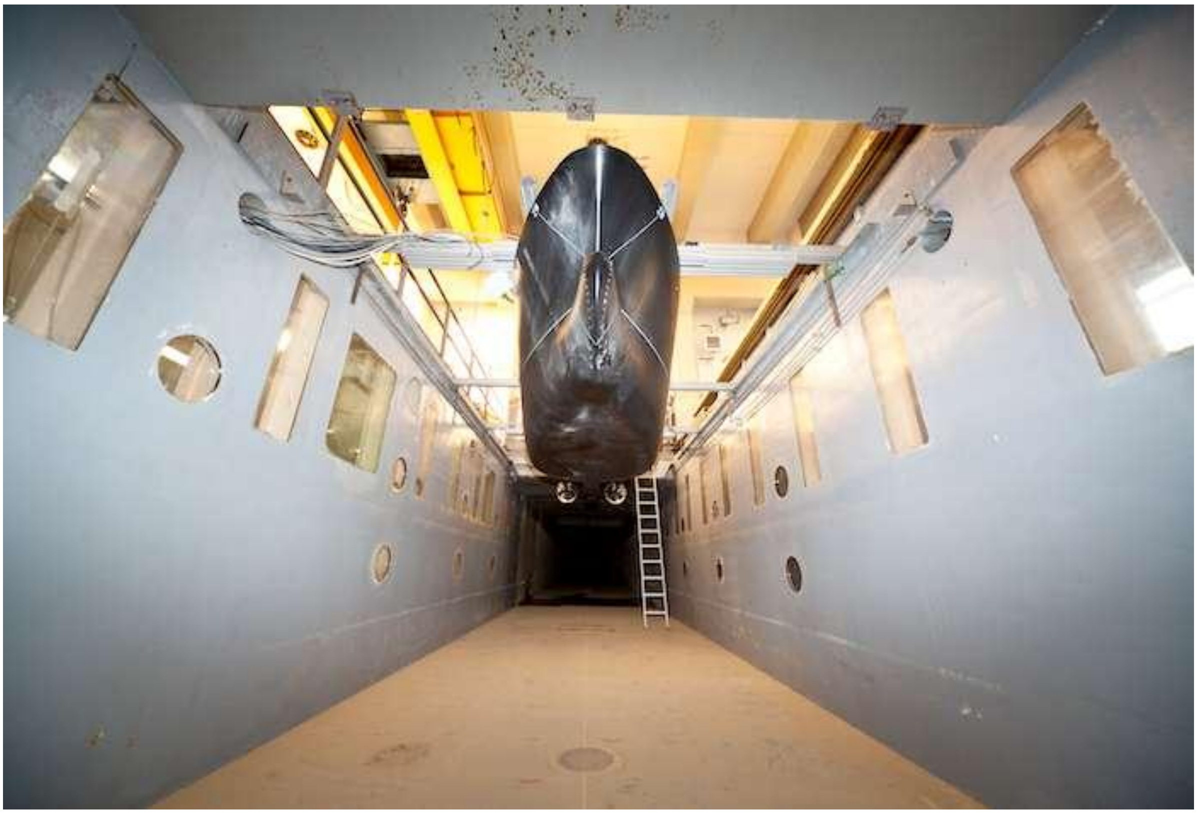

Figure 7 Picture of the Circulating Water Channel at CNR-INSEAN.

2.4.2.1 Facility Specification – Circulating Water Channel:

The main characteristic of CNR-INSEAN circulating water channel are listed below:

- Free water surface circulating channel
- Vertical plane circuit, 4 million litres capacity
- Working section dimensions: 10m (length), 3.6m (width), 2.25m (maximum water depth)
- Two operating modes: (i) fully wet section, and (ii) partially wet section, free surface flow
- Water speed in the test section: 0.3 - 5 ms^{-1}
- Control of absolute pressure in the test section: 3 - 101 KPa
- Type of drive system: two 4-bladed axial flow impellers, Ward-Leonard controlled, operating in two parallel trunks.
- Total impeller motor power: 2 x 435 kW at 1500rpm
- Typical model size range: 0.15 - 0.30 m (marine propeller), 0.1 - 6.0 m (vessel or marine structure model)
- Instrumentation: velocimetry (LDV, 2D-PIV, Stereo PIV, DDPIV), pressure sensors, force measuring dynamometers, hydrophones and noise measuring equipment, data collection and system control, time resolved visualization systems

2.4.2.2 Type of experiment and flow physics capability

Any kind of device for power generation from tides, as well as any other object tested in a channel, is tested being attached through some additional element or struts to the channel structure; the effect of the tide is simulated by the water flowing in the hydraulic circuit driven by the flow impellers. Depending on the desired test matrix under investigation, different velocities and positioning of the device to be tested can be studied.

As a matter of fact, to reproduce as strictly as possible the operative points of the device, a proper scaling of the device itself has to be done carefully considering the characteristics of the tank, mainly in relation to the blockage problem also considering that reducing the scale means increasing the free stream velocity to get a constant Reynolds number. As reported in Literature, when the ratio of the cross-section area of the device over the analogous of the tank is equal or less than 0.05, the blockage effect can be neglected; anyhow, larger values of this ratio can be used applying the appropriate correction.
Nowadays, to fully characterize energy generator devices, a multi-techniques approach is needed; for this reason a large number of services are available for customers at CNR-INSEAN. The main ones available at CNR-INSEAN are:

- Cavitation and ventilation measurements with and or without free surface effects
- Hydrodynamic loads measurements on marine vessels and structures
- Non-intrusive velocimetry measurements (pointwise, planar and volumetric techniques by LDA, PIV)
- Hydroacoustic measurements
- Time resolved flow visualizations using high-speed camera and digital image techniques
- Waterborne structural excitation tests

On this basis, as a natural consequence, the following list of activities/projects are suitable to be performed in the tank:

- Hydrodynamics characterization of surface and submarine vessels and structures
- Analysis of marine propulsor performance
- Analysis of marine current turbine performance
- Cavitation and ventilation studies on floating and submerged devices
- Hydroacoustics characterization of marine devices (noise emission and radiation)
- Characterization of complex flow field structures through correlated velocimetry, pressure, and flow visualization analyses.

On customer request, any other test can be designed and supported by in-house staff.

2.4.2.3 Flow quality and Repeatability

The flow quality is a crucial characteristic of a circulating water channel; due to the way of generation of the flow, a lot disturbances, such as swirling motions, free surface instabilities, large coherent structures, boundary layer effects and so on, can affect the flow quality in the test section. To get a high flow quality, classical devices are used avoid the formation of all these disturbances: screen, grids, turning vanes are placed in crucial locations of the apparatus to get a free stream velocity in the test section as constant and stable as possible. At CNR-INSEAN circulating water channel, all these devices are used and typically a high flow quality is obtained with free stream turbulence levels lesser than 0.1% over the three velocity components.

As a consequence, the repeatability of the observations performed in a channel is attained and this permits also to perform endurance tests; in fact, once the facility has reached its operating point, it can work continuously for hours – 8 hours as reference.

2.5 Large Scale Outdoor Testing

2.5.1 Full scale prototype testing

EMEC's tidal operations are located in the Fall of Warness, a tidal strait at the island of Eday, with office and data facilities in Stromness, and service accommodation available at Hatston Pier. The main tidal stream at Fall of Warness is approximately 4 ms^{-1} (7.8 knots) at spring tides, in a channel approximately 2km wide and 4km long. Water depths vary from 20m to 50m. Testing requires environmental consent from the Scottish Government, through Marine Scotland. EMEC operates within a UKAS accredited integrated management system, which incorporates Quality Health & Safety standards.

Service accommodation is available at Hatston Pier, the principal marine operations base. Full office and data facilities are situated in Stromness some 35km distant.

Figure 8 Scotland's first tidal turbine

2.5.1.1 Device sizing

Subject to consenting, including a navigational risk assessment, devices up to 3MW may be installed. All berths are connected to the UK grid at 11kV via the Eday substation. Devices may installed as sea-bed mounted or floating devices.

2.5.1.2 Infrastructure

A total of 8 berths are presently available at the test site. All berths are covered by EMEC's supply agreement to the UK grid. All berths are individually metered for revenue purposes and to allow accredited performance testing. Each berth has a bespoke SCADA system installed, with fibre optic connection from the sub-station to the TEC under test, enabling realtime technology, environmental and resource monitoring.

- Coastal 11kV control and switching stations
- All berths UK grid connected
- Metered power output from test devices
- Comprehensive SCADA system (system control and data acquisition)

- Data transfer by fibre optic cables to allow remote access
- Wave, tidal and environmental baseline data collection
- MET stations calibrated to national standards
- Full confidentiality of data
- CCTV monitoring

2.5.1.3 Fall of Warness Tidal Test Site

- Full tidal regime with 8 test berths in 12m-50m water in an area 2km across and approximately 4km in length

The tidal test site at the Fall of Warness, to the west of the island of Eday, was chosen for its high velocity marine currents which reach almost 4 ms^{-1} (7.8 knots) at spring tides. The flow is a typical, non-symmetric semi-diurnal tide. Flood and ebb axes differ by c. 20 degrees. The sea-water is of normal salinity.

2.5.1.4 Services

Base line wave, tidal and environmental data are provided. All berths are characterised by ADCP deployment before device installation. A detailed numerical flow model of the test site is also available, which may provide forecast information at the site.

A meteorological station is maintained next to the sub-station, for wind, barometric, and temperature measurements.

EMEC provide full-scale tidal device performance testing, accredited by UKAS, allowing an independent assessment of devices' energy conversion capabilities.

EMEC provides assistance with Grid connection, Power Purchase Agreement and ROCs accreditation, and gives extensive assistance with consent & regulatory issues. EMEC also has extensive local research and engineering support, with nearby access to workshops and sheltered water and harbours

Provision of full-scale tidal device testing (UKAS Accredited (ISO 17025))

- Independent assessment of devices' energy conversion capabilities
- Realtime technology, resource and environmental monitoring
- Assistance with Grid connection, Power Purchase Agreement and ROCs accreditation
- Extensive assistance with consent & regulatory issues
- Extensive local research and engineering support
- Nearby access to sheltered water and harbours
- Office and data centre support

2.5.1.5 Accreditation

EMEC operates within a UKAS accredited integrated management system, which incorporates Quality Health & Safety standards. UKAS accreditation - a world first - means we can offer independent, internationally recognised verification of the performance of devices which come to test at EMEC.

3 CHOICE OF FACILITY

The following flow chart is designed as a decision tree to aid in identifying an appropriate institution from the MaRINET partners for testing a scale model tidal device.

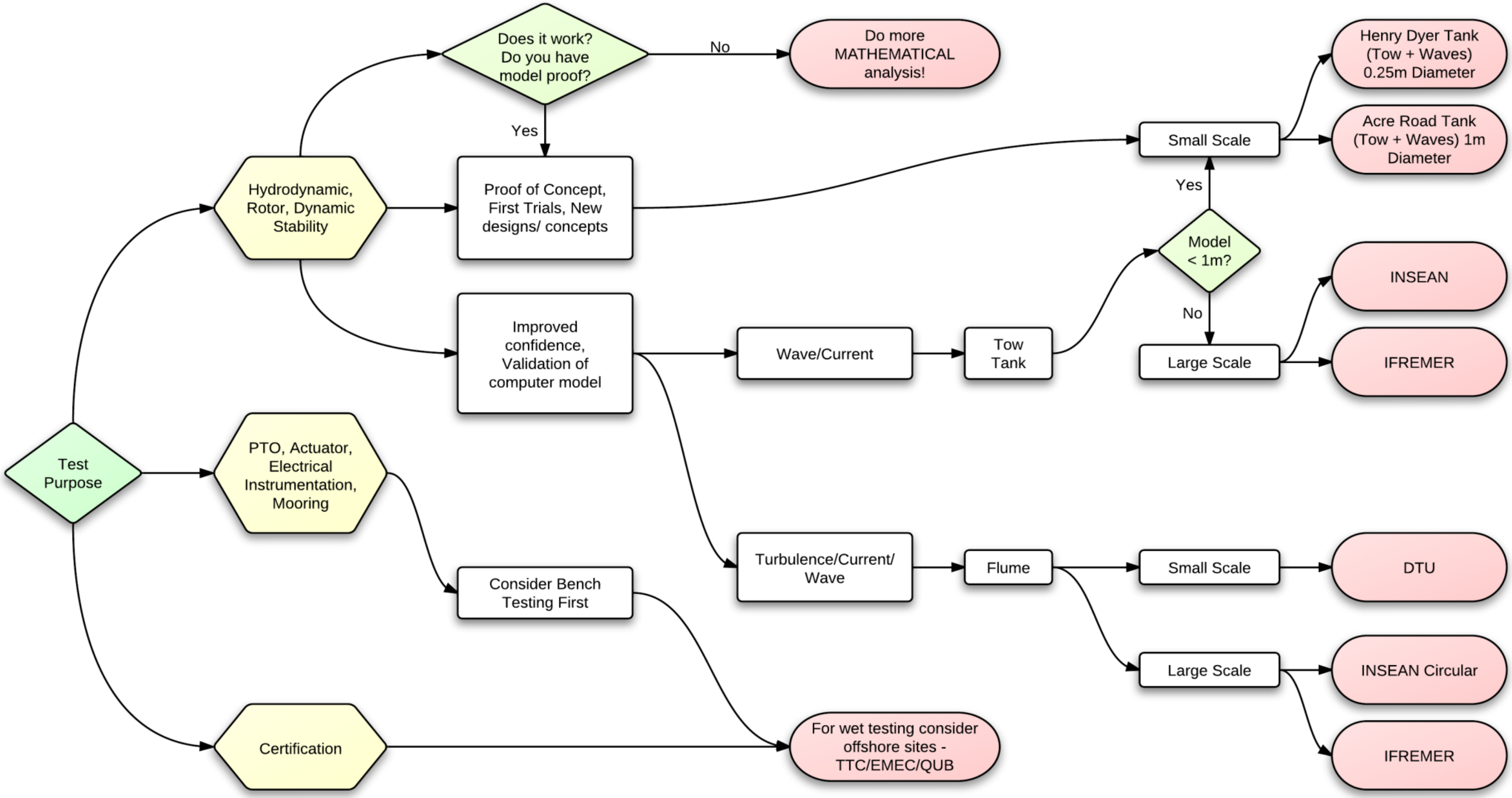

Figure 9 Decision tree for facility choice

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