Brí Toinne Teoranta

User Project: Testing a scaled prototype of the Brí Toinne Teoranta tidal turbine

Project Acronym: BTT-TT

Project Reference Number: 1080

Infrastructure Accessed: Ifremer-Basin of Boulogne sur Mer

Infrastructure Access Reports

Status: Final

Version: XX

Date: 21/Jun/2018

MaRINET2

ABOUT MARINET

The MaRINET2 project is the second iteration of the successful EU funded MaRINET Infrastructures Network, both of which are coordinated and managed by Irish research centre MaREI in University College Cork and avail of the Lir National Ocean Test Facilities.

MaRINET2 is a €10.5 million project which includes **39 organisations** representing some of the top offshore renewable energy testing facilities in Europe and globally. The project depends on strong international ties across Europe and draws on the expertise and participation of **13 countries**. Over 80 experts from these distinguished centres across Europe will be descending on Dublin for the launch and kick-off meeting on the 2nd of February.

The original MaRINET project has been described as a *"model of success that demonstrates what the EU can achieve in terms of collaboration and sharing knowledge transnationally".* Máire Geoghegan-Quinn, European Commissioner for Research, Innovation and Science, November 2013

MARINET2 expands on the success of its predecessor with an even greater number and variety of testing facilities across offshore wind, wave, tidal current, electrical and environmental/cross-cutting sectors. The project not only aims to provide greater access to testing infrastructures across Europe, but also is driven to improve the quality of testing internationally through standardisation of testing and staff exchange programmes.

The MaRINET2 project will run in parallel to the MaREI, UCC coordinated EU marinerg-i project which aims to develop a business plan to put this international network of infrastructures on the European Strategy Forum for Research Infrastructures (ESFRI) roadmap.

The project will include at least 5 trans-national access calls where applicants can submit proposals for testing in the online portal. Details of and links to the call submission system are available on the project website www.marinet2.eu

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 731084.

Document Details	
Grant Agreement Number	731084
Project Acronym	MaRINET2
Title	Testing a scaled prototype of the Brí Toinne Teoranta tidal turbine
Distribution	**Public**
Document Reference	MARINET-TA1-BTT-TT-1080
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Document Approval Record		
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Document Changes Record			
Revision Number	**Date**	**Sections Changed**	**Reason for Change**

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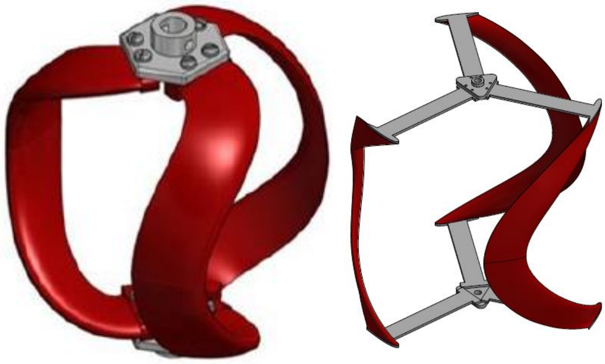
1 Introduction & Background

1.1 Introduction

This MaRINET 2 project is to test scaled prototypes of a novel vertical axis tidal turbine. The patented turbine concept has been developed by Brí Toinne Teoranta (McGuire, 2014). The novelty of the turbine design arises from its swept spiral blades, shown in Figure 1.1. Work has been carried out on the optimisation of the design within Marine and Renewable Energy Ireland (MaREI) through collaboration with a PhD student at NUI Galway. Research to date has focused on numerical modelling which has shown the increased mechanical power efficiency of the novel design over existing vertical axis turbines (Heavey, McGarry and Leen, 2016) (Heavey, Leen and McGarry, 2017). The numerical models have also been implemented to optimise the turbine design parameters. A towing tank test facility has been set up at NUI Galway with plans to test a scaled prototype (1/100th scale), shown in Figure 1.2.



(a) **(b)**

Figure 1.1 Inventor drawings of the two prototypes tested. (a) Spherical turbine blades (Turbine A); and (b) Cylindrical turbine blades (Turbine B).

Brí Toinne Teoranta has received funding through the MaRINET program to conduct model tests in the recirculation tank of IFREMER in Boulogne (France) for 1 week. The funding received covers 5 days access to the recirculation tank at the IFREMER facilities plus travelling and accommodation expenses. These tests were carried out from 14^{th} – 18^{th} May 2018.

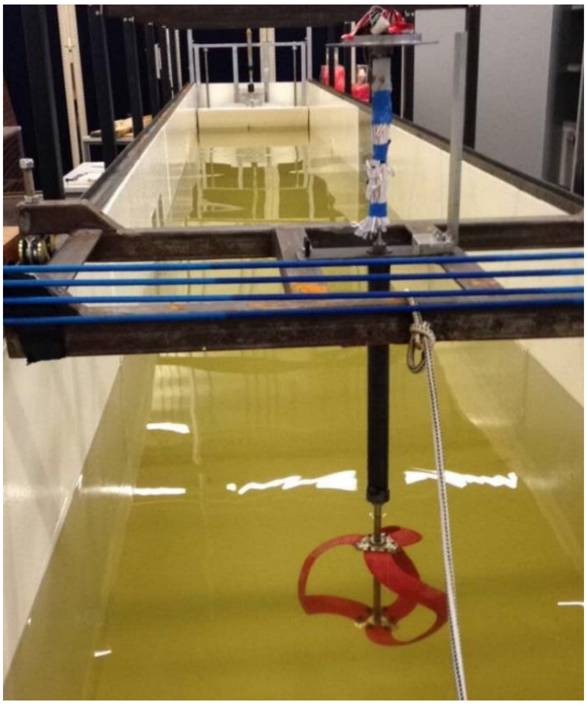


Figure 1.2 Previous experimental tow tank setup at NUI Galway

1.2 Development So Far

1.2.1 Stage Gate Progress

Previously completed: ✓

Planned for this project: ➲

STAGE GATE CRITERIA	Status
Stage 1 – Concept Validation	
• Linear monochromatic waves to validate or calibrate numerical models of the system (25 – 100 waves)	
• Finite monochromatic waves to include higher order effects (25 –100 waves)	
• Hull(s) sea worthiness in real seas (scaled duration at 3 hours)	
• Restricted degrees of freedom (DofF) if required by the early mathematical models	✓
• Provide the empirical hydrodynamic co-efficient associated with the device (for mathematical modelling tuning)	➲
• Investigate physical process governing device response. May not be well defined theoretically or numerically solvable	➲
• Real seaway productivity (scaled duration at 20-30 minutes)	➲
• Initially 2-D (flume) test programme	➲
• Short crested seas need only be run at this early stage if the devices anticipated performance would be significantly affected by them	
• Evidence of the device seaworthiness	➲
• Initial indication of the full system load regimes	➲
Stage 2 – Design Validation	
• Accurately simulated PTO characteristics	
• Performance in real seaways (long and short crested)	
• Survival loading and extreme motion behaviour.	
• Active damping control (may be deferred to Stage 3)	
• Device design changes and modifications	
• Mooring arrangements and effects on motion	
• Data for proposed PTO design and bench testing (Stage 3)	
• Engineering Design (Prototype), feasibility and costing	
• Site Review for Stage 3 and Stage 4 deployments	
• Over topping rates	
Stage 3 – Sub-Systems Validation	
• To investigate physical properties not well scaled & validate performance figures	
• To employ a realistic/actual PTO and generating system & develop control strategies	
• To qualify environmental factors (i.e. the device on the environment and vice versa) e.g. marine growth, corrosion, windage and current drag	
• To validate electrical supply quality and power electronic requirements.	
• To quantify survival conditions, mooring behaviour and hull seaworthiness	
• Manufacturing, deployment, recovery and O&M (component reliability)	
• Project planning and management, including licensing, certification, insurance etc.	
Stage 4 – Solo Device Validation	
• Hull seaworthiness and survival strategies	
• Mooring and cable connection issues, including failure modes	
• PTO performance and reliability	
• Component and assembly longevity	
• Electricity supply quality (absorbed/pneumatic power-converted/electrical power)	

STAGE GATE CRITERIA	Status
• Application in local wave climate conditions	
• Project management, manufacturing, deployment, recovery, etc	
• Service, maintenance and operational experience [O&M]	
• Accepted EIA	
Stage 5 – Multi-Device Demonstration	
• Economic Feasibility/Profitability	
• Multiple units performance	
• Device array interactions	
• Power supply interaction & quality	
• Environmental impact issues	
• Full technical and economic due diligence	
• Compliance of all operations with existing legal requirements	

1.2.2 Plan For This Access

The objectives of this project are (i) to achieve technology readiness level *(TRL)* 3 for the novel turbine design, thereby completing the concept development and (ii) to experimentally validate computational fluid dynamics *(CFD)* and blade element momentum *(BEM)* models of the turbine and (iii) compare the power performance of the two turbine prototype designs.

To achieve these objectives the following specific aims were set:

- Characterise the power performance of the scaled prototypes by determining their power coefficient as a function of tip-speed-ratio *(TSR).*
- Determine the flow field in the wake of the turbine using the laser Doppler velocimeter *(LDV)* available at the IFREMER facility.

2 Outline of Work Carried Out

2.1 Setup

The test layout is shown in Figure 2.1. The turbine's rotational speed was controlled for the purpose of finding the optimum tip speed ratio for peak power performance. This was achieved by using a variable speed drive *(VSD)* to control the speed of the AC motor and gearbox. A braking resistor is used to burn off any power generated by the motor acting in reverse.

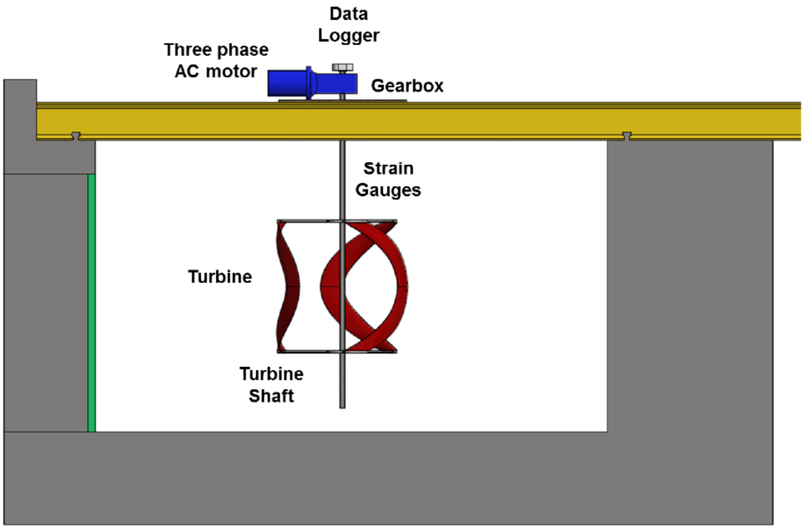


Figure 2.1 Layout of test setup showing various components

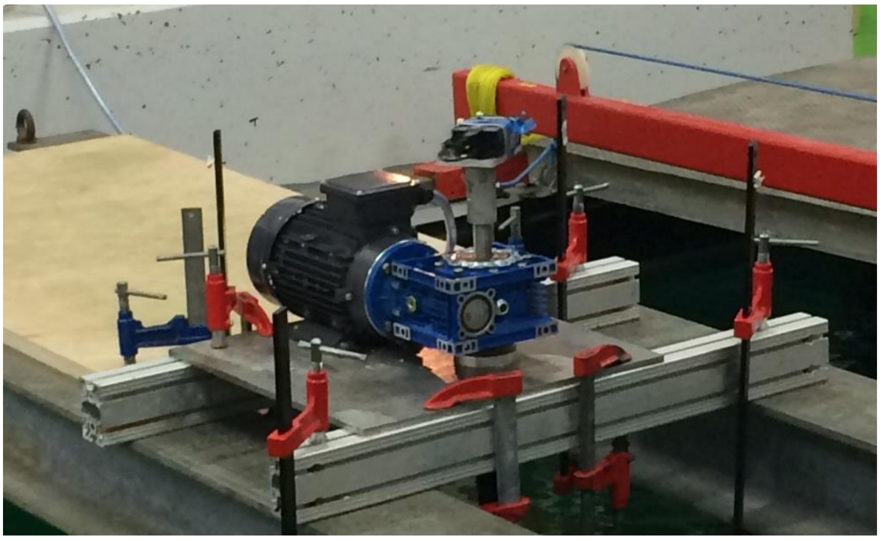


Figure 2.2 Test setup installed at the IFREMER facility showing AC motor, right-angle hollow bore gearbox and VersaLog data logger for recording the strain values.

Two turbine prototypes were tested during this series of testing. The turbine parameters for both prototypes, shown in Figure 1.1, are listed in Table 2.1.

Table 2.1 Turbine parameters

Parameter	Turbine A	Turbine B
Radius [m]	0.25	0.5
Height [m]	0.5	1
Chord length [m]	0.07	0.15
Blade profile	NACA 0015	NACA 0015
Number of Blades	3	3
Blade Shape	Spherical	Cylindrical

2.2 Tests

2.2.1 Test Plan

Turbine A was initially placed in the flume. The rotational speed of the turbine was controlled and varied using the VSD for a series of freestream velocities. Values of strain for each rotational velocity were recorded for time intervals of 90 s, with a 30 s changeover period between each rotational velocity. The averaged values of stain for each rotational velocity were calculated and convert to torque values.

Once testing for Turbine A was completed a similar procedure was applied for testing Turbine B. Table 2.2 and Table 2.3 summarise the freestream velocity and tip-speed ratio for each test carried out.

Table 2.2 List of experimental test carried out for Turbine A

Freestream velocity (m s^{-1})	Range of TSR (-)
0.5	0 - 6
0.75	0 - 5
1	0 - 4.5
1.25	0 - 4.5
1.5	0 - 4.5

Table 2.3 List of experimental test carried out for Turbine B

Freestream velocity (m s^{-1})	Range of TSR (-)
0.5	0 - 5
0.75	0 - 4.5
1	0 - 4.25

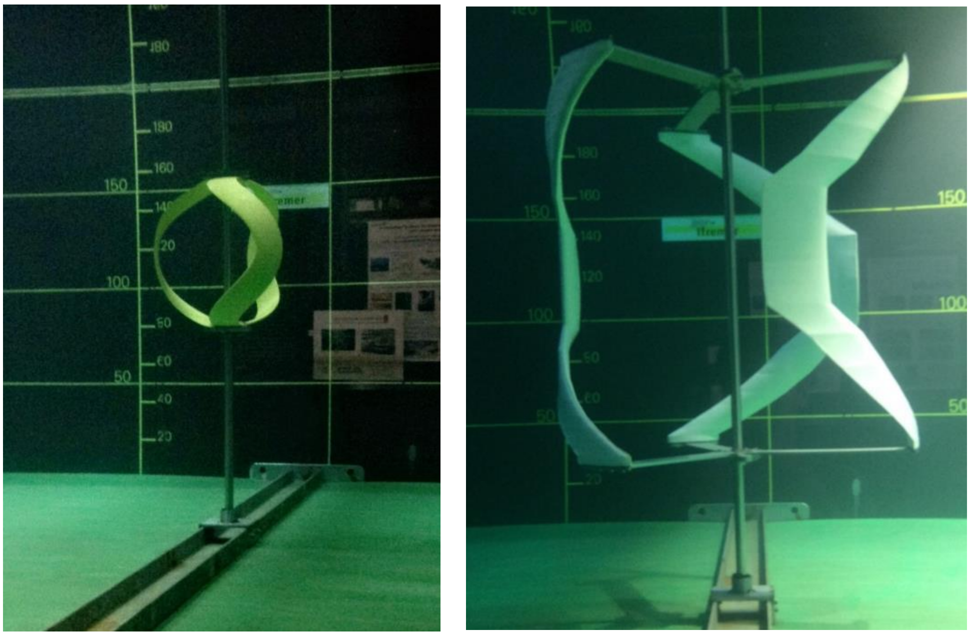


Figure 2.3 Physical prototypes installed in the recirculation tank at IFREMER

The two key measurements to determine the power output from a turbine shaft are the torque and rotational velocity. These two key measurements facilitate the calculation of the power coefficient (C_P) and tip-speed ratio (TSR). These two dimensionless parameters, C_P and TSR, are key indicators of the power performance of the turbine and allow for the comparison of similar scaled turbine designs. For the purpose of these tests the rotational velocity is fixed, i.e. the TSR is fixed, and the torque is measured using calibrated strain gauges.

The TSR is defined as:

$$TSR = \frac{\omega R}{U_\infty} \quad (2.1)$$

where ω is the turbine rotational velocity (rad s^{-1}), R is the turbine radius (m) and U_∞ is the freestream velocity of the fluid (m s^{-1}).

The power coefficient is defined as the total power output from the turbine divided by the total power of the fluid passing through the turbine area. It is calculated as:

$$C_P = \frac{P}{P_\infty} = \frac{Q\omega}{0.5\rho A U_\infty^3} \quad (2.2)$$

where P is the power from the turbine, P_∞ is the total power available from the fluid, Q is the measured torque (N m), ρ is the density of the fluid (kg/m^3) and A is the total turbine frontal area (m^2).

Once the optimum TSR, for maximum C_P, was determined, a laser Doppler velocimeter *(LDV)* was used to define the flow measurement in the wake of the turbine, as shown in Figure 2.4.

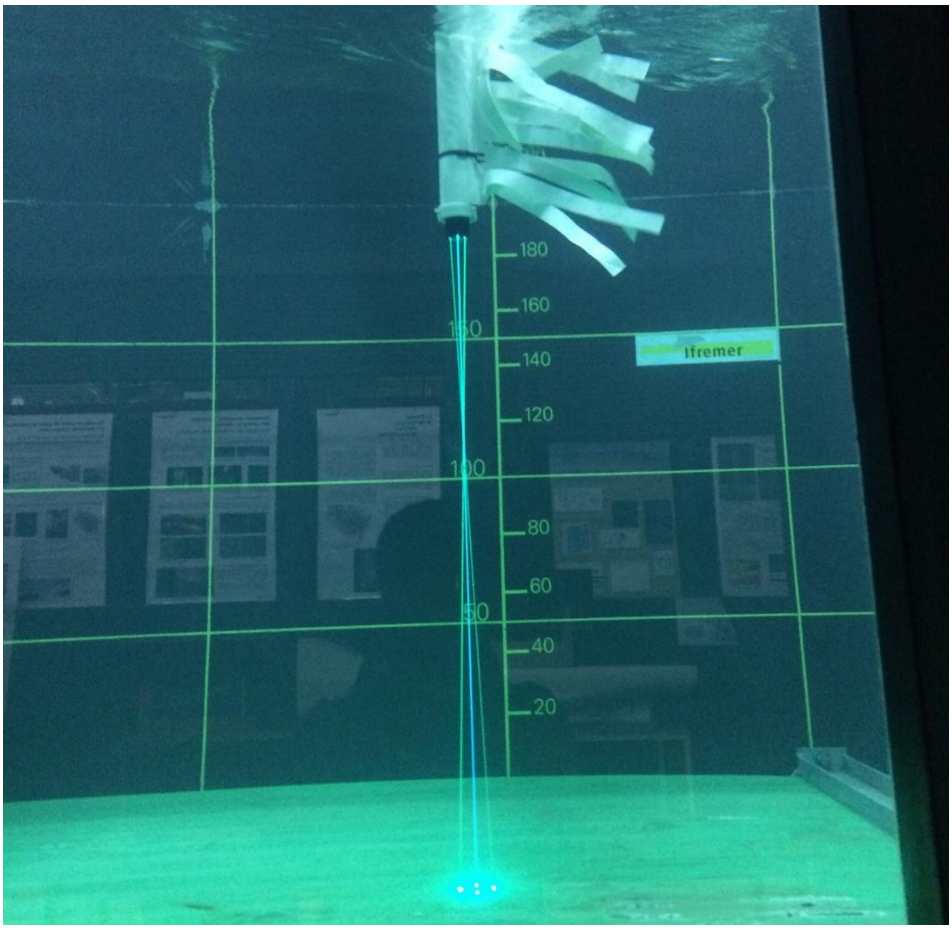


Figure 2.4 LDV characterising the flow field in the wake of the turbine for the tests at IFREMER.

2.3 Results

The calibration of the strain gauges was carried out prior to arrival at the test facility. For the calibration, the shaft was fixed on one end and simply supported at the other. Known torques were applied using a lever arm and weights, located between the strain gauges and the simply supported end. Four known torques were applied to the shaft and values of strain were recorded for 60 seconds each. The strain values variation with time for each of the torque values are shown in Figure 2.5 (a). The results presented in Figure 2.5 (a) were averaged over each time period for each applied torque with the final results of the strain-torque calibration, along with the equation to convert strain to torque ($y = 2.1\,x + 0.38$), shown in Figure 2.5 (b).

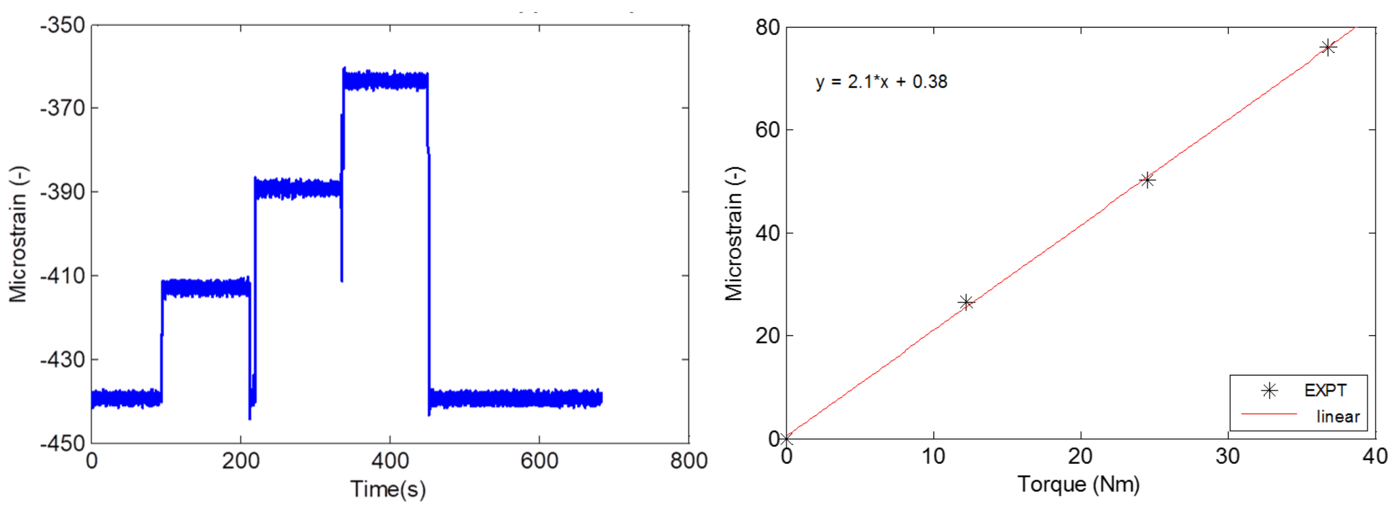


Figure 2.5 (a) Variation of Micro strain measurements with time for known applied torques. (b) Relationship between the measured micro strain and applied torque. The linear equation relating strain to torque is also included.

The strain-torque calibration curve was used to convert strains to torques for the tests at the IFREMER facility. Figure 2.6 and Figure 2.7 show the dimensionless power curves for Turbine A and Turbine B respectively. Figure 2.8 shows the velocity measurements taken using the LDV in the wake of the turbine.

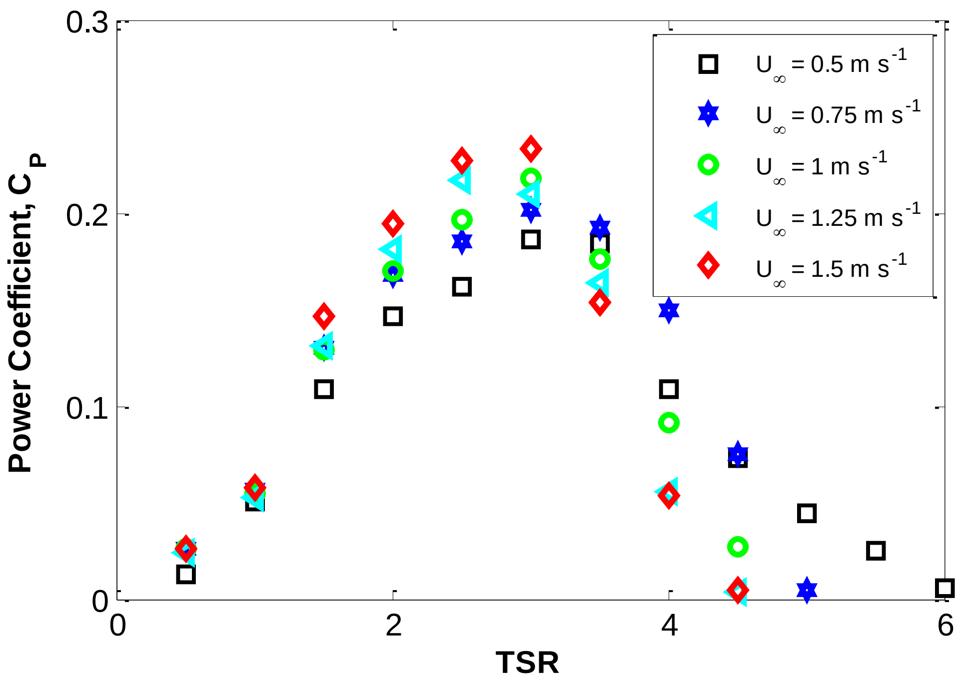


Figure 2.6 Power coefficient variation with flow velocity for a range of tip-speed ratios for Turbine A.

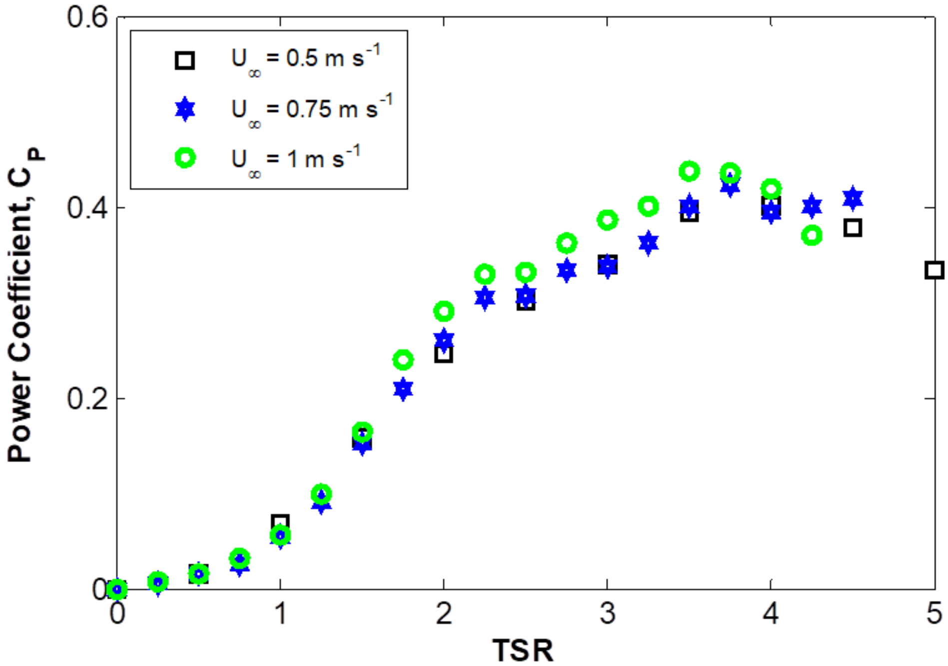


Figure 2.7 Power coefficient variation with flow velocity for a range of tip-speed ratios for Turbine B.

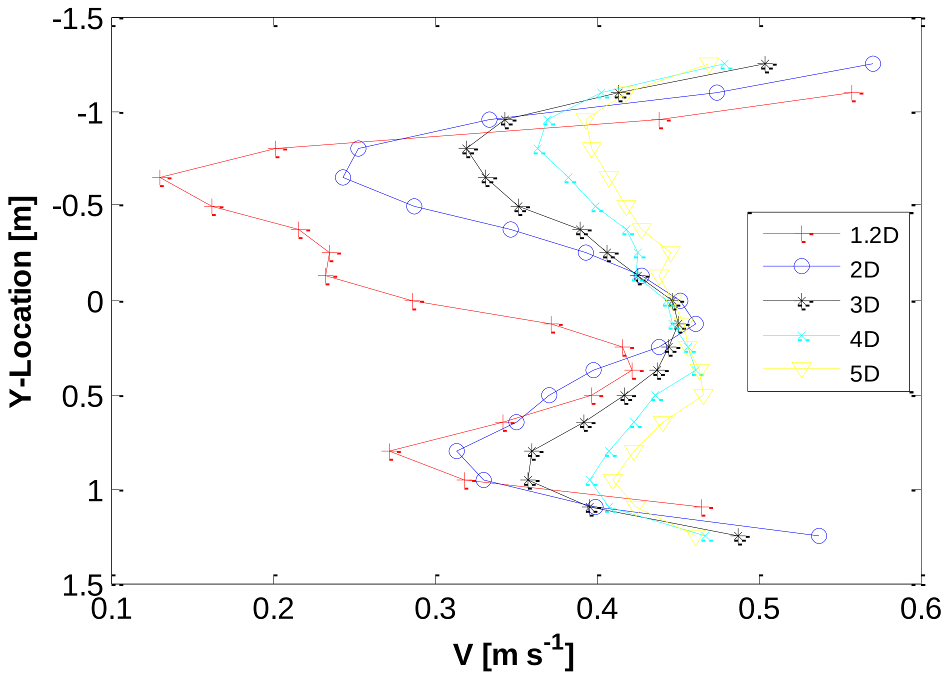


Figure 2.8 Flow velocity measurements variation with distance downstream of the turbine for Turbine B (U_∞= 0.5 m s^{-1}, TSR = 3.75).

2.4 Analysis & Conclusions

Comparing both results for a freestream velocity of 1 m s^{-1}, the results in Figure 2.6 and 2.7 show a peak C_P of 0.22 at TSR = 3 for Turbine A, and 0.43 at TSR = 3.5 for Turbine B. There are a number of contributing factors to the increased power performance of Turbine B over Turbine A, namely:

- **Blockage effects:** The blockage ratio is the ratio of the total frontal turbine area to the overall width of the tank. It is recommended that test results where the blockage ratio is greater than 10% be corrected. For the tests concerning Turbine B, the blockage ratio was roughly 13 %, while the blockage ratio for the Turbine A tests was 3.5 %. An increased blockage ratio leads to increased power performance. Empirical-based models have been developed to assess these blockage effects and they will be implemented to correct the results of Turbine B.

- **Reynolds number scaling:** Reynolds number scaling is often an issue when testing tidal turbines. The Reynolds number (Re) is defined as:

$$Re = \frac{\rho U_{\infty} L}{\mu} \qquad (2.3)$$

where L is a device related length, typically turbine diameter, and μ is the viscosity of the fluid. The hydrodynamic forces, i.e. lift and drag forces, are influenced by Reynolds number, especially at low Reynolds number. Turbine A is a smaller turbine and therefore experiences lower Reynolds number. It can be noted from Figure 2.6 that with increasing Reynolds number, i.e. increasing freestream velocity, the maximum power coefficient is increasing. As the Reynolds number increases, the hydrodynamic forces become in independent of Reynolds number. This is evident in Figure 2.7, as the difference between the peak power coefficients does not differ as much for each freestream velocity.
- **Blade design:** Another contributing factor is the blade design. The torque generated by a turbine is directly related to the turbine radius. Turbine B has a uniform radius for its entire length. In comparison, Turbine A has a maximum radius at the mid-height of the blade and the radius approaches zero at both the top and bottom of the blades. This may also be a contributing factor to the decreased power performance of Turbine A.
- **Turbine shaft diameter:** The same turbine shaft was used for both turbines. The shaft was designed to handle the loads for Turbine B and therefore it was oversized for Turbine A. This had a significant effect on the performance blades in the downstream portion of the Turbine A.

Analysis of the results is still ongoing at the time of writing this report. Additional work will look at addressing the error for each of the test runs. Blockage effects will also be accounted for in the results for Turbine B. Once this has been carried out the results will be compared to CFD and BEM models. The flow wake measurements shown in Figure 2.8 will be used as further validation of CFD models.

3 Main Learning Outcomes

3.1 Progress Made

Technology readiness level 3 has been achieved from this round of the testing. The design concept has been proven and the technology is ready to move on towards higher TRLs. Preliminary validations of numerical models using the experimental data have been analysed. A comparison between two turbine designs (Turbine A & Turbine B) has been completed. Turbine B has been identified as the optimum design for peak power performance. This will be the turbine design adopted for further analysis which will look aspects of the turbine design including blade fatigue, power-take-off, site location, etc.

3.2 Key Lessons Learned

- A successful methodology has been developed for testing a vertical-axis tidal turbine,
- A cost-effective method of measuring torque using calibrated strain gauge and self-powered data logger has been developed.
- The rotational speed of the turbine was controlled using a VSD to control the speed of the motor and gearbox.
- Results (C_P vs. TSR) were successfully recorded and will be used to validate mathematical models,
- Possible shortcomings have been identified and will be addressed in future analyses. i.e. Reynolds scaling, Blockage effects.

4 Further Information

4.1 Scientific Publications

Results are still being analysed and a publication is planned using the experimental results to validate mathematical models, both CFD and BEM based.

4.2 Website & Social Media

n/a

5 References

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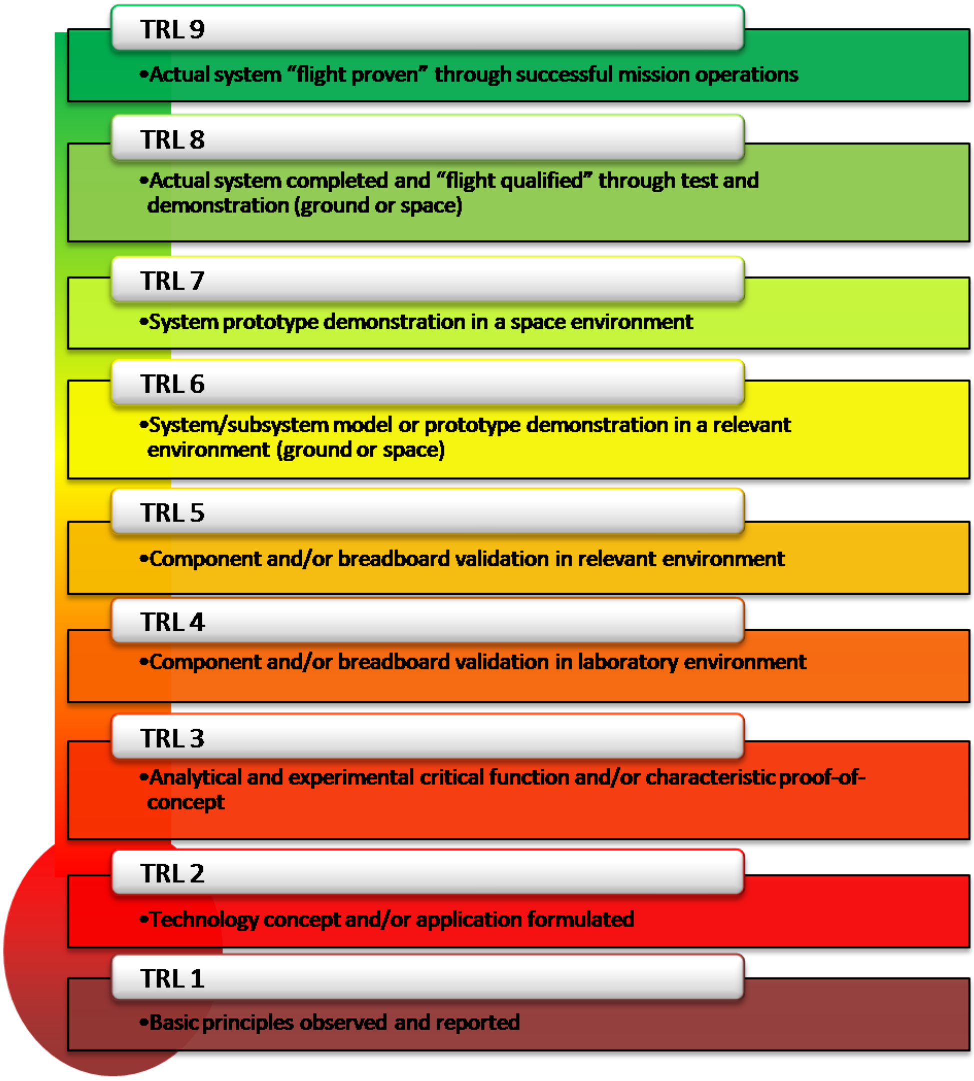
Heavey, S., Leen, S. and McGarry, P. (2017) 'An efficient and accurate methodology for hydrofoil characterisation and tidal turbine design', in *Proceedings of the 12th European Wave and Tidal Energy Conference*. Cork, Ireland, pp. 1–10.

McGuire, B. (2014) 'Turbine and a rotor for a turbine'. Ireland: United States.

6 Appendices

6.1 Stage Development Summary Table

The table following offers an overview of the test programmes recommended by IEA-OES for each Technology Readiness Level. This is only offered as a guide and is in no way extensive of the full test programme that should be committed to at each TRL.



NASA Technology Readiness Levels[1]

NASA TRL Definition Hardware Description Software Description Exit Criteria

TRL	Definition	Hardware Description	Software Description	Exit Criteria
1	Basic principles observed and reported.	Scientific knowledge generated underpinning hardware technology concepts/applications.	Scientific knowledge generated underpinning basic properties of software architecture and mathematical formulation.	Peer reviewed publication of research underlying the proposed concept/application.
2	Technology concept and/or application formulated.	Invention begins, practical application is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture.	Practical application is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture. Basic properties of algorithms, representations and concepts defined. Basic principles coded. Experiments performed with synthetic data.	Documented description of the application/concept that addresses feasibility and benefit.
3	Analytical and experimental critical function and/or	Analytical studies place the technology in an appropriate context and laboratory demonstrations, modelling and simulation validate analytical prediction.	Development of limited functionality to validate critical properties and predictions using non-integrated software components.	Documented analytical/experimental

[1] https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html

	characteristic proof of concept.			results validating predictions of key parameters.
4	Component and/or breadboard validation in laboratory environment.	A low fidelity system/component breadboard is built and operated to demonstrate basic functionality and critical test environments, and associated performance predictions are defined relative to the final operating environment.	Key, functionally critical, software components are integrated, and functionally validated, to establish interoperability and begin architecture development. Relevant Environments defined and performance in this environment predicted.	Documented test Performance demonstrating agreement with analytical predictions. Documented definition of relevant environment.
5	Component and/or breadboard validation in relevant environment.	A medium fidelity system/component brassboard is built and operated to demonstrate overall performance in a simulated operational environment with realistic support elements that demonstrates overall performance in critical areas. Performance predictions are made for subsequent development phases.	End-to-end software elements implemented and interfaced with existing systems/simulations conforming to target environment. End-to-end software system, tested in relevant environment, meeting predicted performance. Operational environment performance predicted. Prototype implementations developed.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements.
6	System/sub-system model or prototype demonstration in an operational environment.	A high fidelity system/component prototype that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate operations under critical environmental conditions.	Prototype implementations of the software demonstrated on full-scale realistic problems. Partially integrate with existing hardware/software systems. Limited documentation available. Engineering feasibility fully demonstrated.	Documented test performance demonstrating agreement with analytical predictions.
7	System prototype demonstration in an operational environment.	A high fidelity engineering unit that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate performance in the actual operational environment and platform (ground, airborne, or space).	Prototype software exists having all key functionality available for demonstration and test. Well integrated with operational hardware/software systems demonstrating operational feasibility. Most software bugs removed. Limited documentation available.	Documented test Performance demonstrating agreement with analytical predictions.
8	Actual system completed and "flight qualified" through test and demonstration.	The final product in its final configuration is successfully demonstrated through test and analysis for its intended operational environment and platform (ground, airborne, or space).	All software has been thoroughly debugged and fully integrated with all operational hardware and software systems. All user documentation, training documentation, and maintenance documentation completed. All functionality successfully demonstrated in simulated operational scenarios. Verification and Validation (V&V) completed.	Documented test performance verifying analytical predictions.
9	Actual system flight proven through successful mission operations.	The final product is successfully operated in an actual mission.	All software has been thoroughly debugged and fully integrated with all operational hardware/software systems. All documentation has been completed. Sustaining software engineering support is in place. System has been successfully operated in the operational environment.	Documented mission operational results

DEVELOPMENT PROTOCOL	STAGE 1 CONCEPT VALIDATION			STAGE 2 DESIGN VALIDATION	STAGE 3 SYSTEMS VALIDATION		STAGE 4 DEVICE VALIDATION		STAGE 5 ECONOMICS VALIDATION
	TRL 1: Confirmation of Operation	**TRL 2: Performance Convergence**	**TRL 3: Device Optimisation**	**TRL 4: Sub-Systems Assessment**	**TRL5: Sub-Assembly Bench Tests**	**TRL 6: Full System Sea Trials**	**TRL 7: Solo, Sheltered, Grid Emulator**	**TRL 8: Solo, Exposed, Grid Connected**	**TRL 9: Multi-device Array (3-5)**
Objectives/ Investigations	Op. Verification Design Variables Physical Process Validate/Calibrate Maths Model Damping Effect Signal Phase	Real Generic Seas Design variables Damping PTO Natural Periods Power Absorption Wave to Devise Response Phase	Hull Geometry Components Configurations Power Take-Off Characteristics Design Eng. (Naval Architects)	Final Design Accurate PTO [Active Control] Mooring system Survival Options Power Production Added mass	PTO Method Options & Control Inst. Power Absorption Electricity Production & Quality	Scale effects of Overall Performance Characteristics Mooring & Anchorage Security Environmental Influences & Factors	Oper & Mains Procedures Electrical Output Quality Grid Supply, Stability & Security PTO Performance at all phases Control Strategy Seaworthiness, Survival & Lifecycle Analysis Device Array Interaction (Stages 1 & 2)		Grid Connection Array Interaction Maintenance Service Schedules Component Life Economics
Output/ Measurement	Vessel Motion Response Amplitude Operators & Stability Pressure / Force, Velocity RAOs with Phase Diagrams Power Conversion Characteristic Time Histories Hull Seaworthiness; Excessive Rotations or Submergence Water Surface Elevation Abeam of Devices			Motion RAOs Phase Diagrams Power v Time Wave Climates @ *head, beam, follow*	PTO Forces & Power Conversion Control Strategies	Incident Wave Field 6 D of F Body Motion & Phase Seaworthiness of Hull & Mooring [Survival Strategies]	Full On-Board Monitoring Kit for Extended Physical Parameters Power Matrix Supply forecasting	Array Interaction Annual Power Prod. Elec. Power Perfm. Failure Rates Grid EIA reviews	Service, Maintenance & Production Monitor, Telemetry for Periodic checks & Evaluation
Primary Scale (λ)	λ = 1 : 25 - 100 (∴ λ_t = 1 : 5 - 10)			λ = 1 : 10 - 25	λ = 1 : 2 - 10		λ = 1 : 1 - 2		λ = 1:1, Full size
Facility	2D Flume or 3D Basin			3D Basin	Power Electronics Lab	Benign Site	Sheltered Full Scale Site	Exposed Full Scale Site	Open Location
Duration *–inc Analysis*	1-3months	1-3months	1 3 months	6 – 12 months	6 – 18 months		12 – 36 months		1 – 5 years
Typical No. Tests	250 - 750	250 - 500	100 - 250	100 - 250	50 - 250		Continuous		Statistical Sample
Budget (€,000)	1 – 5	25-75	25-50	50 - 250	1,000 – 2,500		10,000 – 20,000		2,500 – 7,500
Device	Idealised with Quick Change Options Simulated PTO (0-∞ Damping Range) Std Mooring & Mass Distribution		Distributed Mass Minimal Drag Design Dynamics	Final design (internal view) Mooring Layout	Advanced PTO Simulation Special Materials	Full Fabrication True PTO & Elec Generator	Grid Control Electronics or Emulator Emergency Response Strategies Pre-Production	Pre-Commercial	Operational Multi-Device
Excitation / Waves	Monochromatic Linear (10-25Δ*f*) (25-100 waves)	Panchromatic Waves (20min scale) +ve 15 Classical Seaways Spectra Long crested Head Seas		Deployment -Pilot Site Sea Spectra Long, Short Crested Classical Seas Select Mean wave Approach Angle		Extended Test Period to Ensure all Seaways inc.	Full Scatter Diagram for initial Evaluation Continuous Thereafter Time & Frequency Domain Analysis		
Specials	DofF (heave only) 2-Dimentional Solo & Multi Hull	Short Crest Seas Angled Waves As Required	Storm Seas (3hr) Finite Regular As required	Power Take-Off Bench Test PTO & Generator	Device Output Repeatability Survival Forces	Salt Corrosion Marine Growth Permissions	Grid Emulator Quick Release Cable Service Ops	Stakeholder Consult. Health & Safety Issues	Small Array (Up-grade to Generating Station)?
Maths Methods (Computer)	Hydrodynamic, Numerical Frequency Domain to Solve the Model Undamped Linear Equations of Motion		Finite Waves Applied Damping Multi Freq Inputs	Time Domain Response Model & Control Strategy Naval Architects Design Codes for Hull, Mooring & Anchorage System. Economic & Business Plan			Economic Model Electrical Stab. Array Interaction	Grid Simulation Wave forecasting	Array Interaction Market Projection for Devise Sales
	EVALUATION [Stage Gates]								
Absorbed Power									
Converted [kW]									
Weight, [tonnes]									
Manufacturing Cost [€]									
Capture [kW/tonne] or [kW/m^3]	[200-50 m^3]								
Production [c/kW]	< 25 €c / kW			≤ 15 €c / kW			≤ 10 €c / kW		≤ 5 €c / kW