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Programme Area: Marine

Project: PerAWAT

Title: Test Schedule and Test System Design of 1:10th Scale Tidal Turbines in Strangford Lough, Northern Ireland

Abstract:

This deliverable describes the experimental activities being undertaken to assess the nature of interactions between neighbouring 1:10th scale horizontal axis tidal turbines, as part of WG4 WP5. This includes details of the experimental programme and design specifications being followed by EDF at their flume facilities. A series of tests will be conducted with one turbine located in a fixed position whilst the second turbine is moved longitudinally and laterally throughout the frame of the test platform. The tidal turbines fabricated for this project are 1.2 metre diameter (1:10th scale) and are being assembled by Ocean Flow Energy. A test platform is being constructed by Wave Barrier Ltd and this will provide the frame to which the turbines and survey instruments will be attached to. Following this deliverable, the test rig will be constructed and assembled with rotors, then installed in the EDF flume and calibrated.

Context:

The Performance Assessment of Wave and Tidal Array Systems (PerAWaT) project, launched in October 2009 with £8m of ETI investment. The project delivered validated, commercial software tools capable of significantly reducing the levels of uncertainty associated with predicting the energy yield of major wave and tidal stream energy arrays. It also produced information that will help reduce commercial risk of future large scale wave and tidal array developments.

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Energy Technologies Institute

PerAWaT (MA1003)

WG4 WP5 D2: TEST SCHEDULE AND TEST SYSTEM DESIGN OF 1:10TH SCALE TIDAL TURBINES IN STRANGFORD LOUGH, NORTHERN IRELAND

Lead Participant:	**Ian G. Bryden**
Other Participants Involved:	**Laura Finlay**
Version:	**1.0**
Date of submission:	**3rd May 2011**

Executive Summary

This report details the test specifications of Work Group 4 Work Package 5 in order to assess the nature of interactions between neighbouring 1:10th scale horizontal axis tidal turbines. This includes details of the experimental programme and design specifications. This forms the second deliverable for WG4 WP5.

A guide test programme has been established in order to detail experimental work to be conducted in Strangford Lough. This programme ensures that a series of tests has been conducted with one turbine located in a fixed position whilst the second turbine is moved longitudinally and laterally throughout the frame of the test platform.

The tidal turbines fabricated for this project are 1.2 metre diameter 1:10th scale and are being assembled by Ocean Flow Energy. The surveying instrumentation includes one Accoustic Doppler Velocimeter and two Aquadopps in order to provide measurements of flow and wake interactions. A test platform is being constructed by Wave Barrier Ltd and this will provide the frame to which the turbines and survey instruments will be attached to.

Table of Contents

1.0 Introduction

1.1 Project overview

A series of field tests with two 1:10th scale horizontal axis tidal turbines is to be conducted in Strangford Lough, Northern Ireland in order to support the verification of numerical models and to provide experimental support for the planning of tidal current arrays. Experimental tests will be conducted to ascertain the effects of torque and thrust on tidal turbines within a simulated array formation and the interactions and wake effects of this formation.

This work is being conducted as part of the PerAWaT Work Group 4, Work Package 5. This work package aims to ascertain the optimum position of tidal turbines when placed in an array configuration and how the placement and positions of the turbines affect torque, thrust and wake interactions. The second deliverable of this work package is the confirmation of the test schedule and test system designs, including the design of the platform and rotor, and definition and agreement of test schedule.

A buoyant twin-hulled test platform will be moored in Strangford Lough with four anchors. Two turbines will be fitted to the platform and will be held with their central axis 2 metres below the free surface. The relative position of the rotor centre will be mechanically altered to provide longitudinal and lateral separations. One turbine will remain in a fixed position whilst the second turbine will be moved to a maximum of 8 longitudinal and 3 lateral separations. Testing will take place on the flood tide with turbines in altered positions over the full neap – spring tidal cycle. Installation and decommissioning of the test platform and turbines will take place in accordance with the terms set out by the FEPA consent licence (see WG4 WP5 D1 Report).

Calibration and set up of the test platform, turbines and associated surveying equipment will take place at the privately owned Montgomery Lough, Ballynahinch (permission has been granted by the owner). All experimental sea trial work will be conducted at the entrance to Strangford Lough in Strangford Narrows (a deep channel approximately 8km long between the towns of Strangford and Portaferry) and the test platform will be moored close to the east coast of the Lough offshore of Portaferry. Strangford Lough has been selected as the ideal site for these tests due to its relatively sheltered position from the conditions of the Irish Sea by the Ards Peninsula and has tidal flows that reach up to 4 m/s on a spring tide.

The test platform and turbines will be moored in an area located adjacent to the Evopod tidal device [1]. A full environmental assessment for Evopod has been carried out and concluded that the mooring and activity of this tidal energy device will have no significant impact to the environment. Due to this factor, including the close proximity to the Evopod site and the temporary time scale of the PerAWaT test platform mooring (May – August) no significant environmental impacts are envisaged. In addition all equipment associated with the tests will be removed and decommissioned at the end of the test schedule.

2.0 Deliverables

The second deliverable of Work Group 4 Work Package 5 requires details of the test schedule and test system design. Specifically:

Test specification of sufficient detail and scope to:

- Assess the nature of interactions between neighbouring 1/10th scale horizontal axis tidal rotors,

- Specification contains details of the detailed experimental programme,

- Design meets the stated test purpose (i.e. range of lateral and longitudinal spacing, simultaneous flow speed measurement and controllable rotor tip speeds),

- Design specification report including a clear definition of reasons for design selection, method for manufacture and assembly of all key components; instrumentation system and support structure.

3.0 Test Specifications

3.1 Experimental Programme

All field test schedules are adaptive and are subject to change as a result of weather conditions and, crucially, to the implications of ongoing findings. Below is a brief test schedule of work to be conducted on Montgomery Lough (set up and calibration of equipment) and Strangford Lough (full range of field tests):

Table 1: Schedule of work.

Task	Location	Duration
Preliminary tests and installation	Montgomery Lough, Ballynahinch	Approx 2-4 weeks
Installation of test platform	Strangford Lough, Portaferry	Approx 1 week
Completion of test schedule	Strangford Lough, Portaferry	Approx 8-10 weeks
Retrieval of test platform	Strangford Lough, Portaferry	Approx 1 week

3.1.1 Preliminary Tests and Installation

Lake experimental work:

- Turbine 1 set up:
    - attach to test rig (to be conducted by Wave Barrier Ltd)
    - Install load cell arrangement (to be conducted by QUB technician)
    - Install torque gauge (to be conducted by QUB technician)
    - carry out downstream measurements (to be conducted by Wave Barrier Ltd and Laura Finlay)

- Uninstall Turbine 1 (to be conducted by Wave Barrier Ltd)

- Turbine 2 set up:
    - attach to test rig (to be conducted by Wave Barrier Ltd)
    - Install load cell arrangement (to be conducted by QUB technician)
    - Install torque gauge (to be conducted by QUB technician)

- carry out downstream measurements (to be conducted by Wave Barrier ltd and Laura Finlay)

- Reinstall Turbine 1 (to be conducted by Wave Barrier Ltd)
- Install and calibrate surveying equipment (Aquadopps and ADV) (to be conducted by Wave Barrier ltd, QUB technician and Laura Finlay)
- Conduct towing tests with both turbines with Turbine 2 in positions 1- 24 (3 lateral and 8 longitudinal positions) (to be conducted by Wave Barrier ltd, QUB technician and Laura Finlay)

3.1.2 Installation of Test Platform

The test platform, turbines, surveying and all associated equipment will be installed by being towed out to the test site from Ringhaddy Marina and anchored in place to the pre-fitted moorings. The anchorings will allow the test platform to follow the rise and fall of the tide.

3.1.3 Completion of Test Schedule

Strangford Lough experimental work:

- Turbine 1 set up:
    - attach to test rig (to be conducted by Wave Barrier Ltd)
    - Install load cell arrangement (to be conducted by QUB technician)
    - Install torque gauge (to be conducted by QUB technician)

    carry out downstream measurements (to be conducted by Wave Barrier Ltd and Laura Finlay)

- Turbine 2 set up:
    - attach to test rig (to be conducted by Wave Barrier Ltd)
    - Install load cell arrangement (to be conducted by QUB technician)
    - Install torque gauge (to be conducted by QUB technician)
    - carry out downstream measurements (to be conducted by Wave Barrier Ltd and Laura Finlay)

- Install and set up surveying equipment (Aquadopps and ADV) (to be conducted by Wave Barrier ltd, QUB technician and Laura Finlay)
- Conduct tests with both turbines with Turbine 1 in its fixed position at the front of the test platform and Turbine 2 in positions 1- 24 (3 lateral and 8 longitudinal positions). Tests will be conducted at 8 longitudinal separations (ranging up to 8 diameters) and 3 lateral separations (ranging up to 3 diameters). This will entail a total of 30 tests for a full cycle. A full test cycle will require 6 flood tides as it is anticipated that the range of lateral tests will be conducted for each longitudinal separation and will be conducted at each flood tide. Consecutive daily tests will ensure coverage over a wide range of tidal conditions. As the tidal state will change between successive flood tides on an approximately 14 day cycle, the tests will need to be conducted over a 6 week period. This will allow repetition of over a wide range of conditions to give confidence in the spread of input conditions. Tests will concentrate on operation at or near to the peak in the CP̃ lambda curve but at least one series of tests will be conducted away from the peak. (Prediction of the form and peak of the CP̃ lambda curve will be carried out by Ian Bryden using appropriate University of Edinburgh software prior to field tests and calibration of this will take place during experimental tests in Montgomery Lough). (to be conducted by Wave Barrier ltd, QUB technician and Laura Finlay)

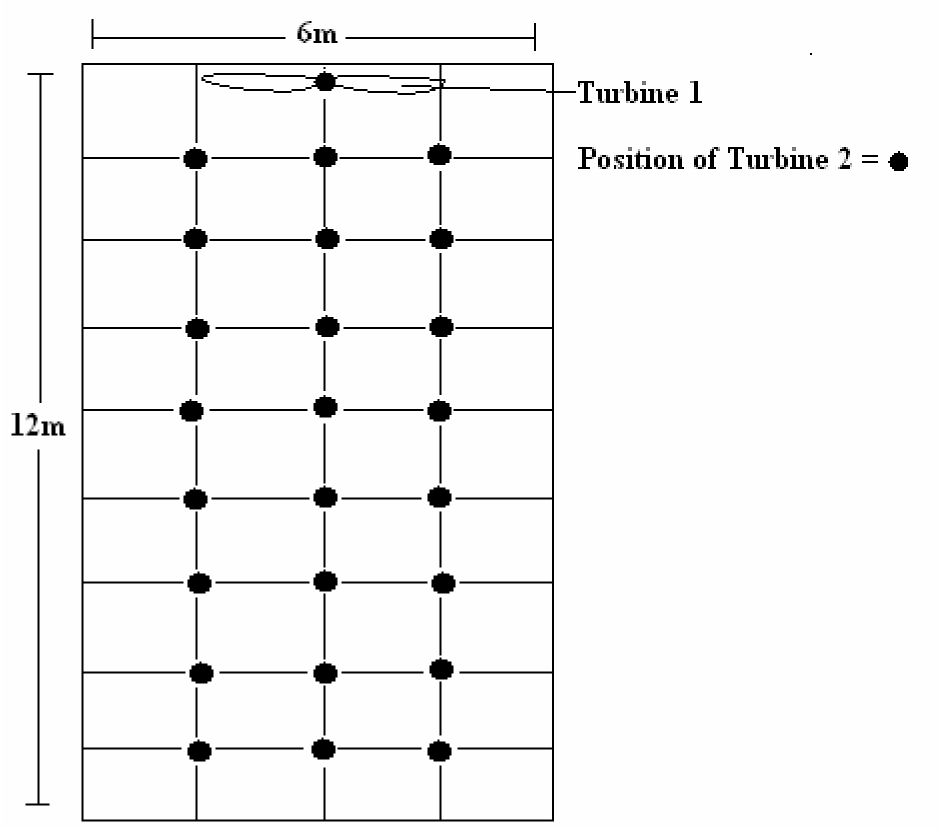


Figure 1: Sketch of test platform and turbine positions.

3.1.4 Retrieval of Test Platform

Upon completion of the test cycle, it will be necessary to retrieve the test rig and associated equipment. This will be done by reversing the installation operation and will be carried out by Wave Barrier Ltd.

3.1.5 Completion of Data Analysis

It will be necessary to determine the degree of interference between devices. The impact of the lead device on thrust and torque of the trailing devices will be mapped over the tested range of longitudinal and lateral separations.

3.2 Design Specification

3.2.1 Turbines

Two 1:10th scale 1.2m diameter, fixed pitch, three blade turbines will be fitted to the platform and their central axis will be suspended 2m below the free surface. The steel monostrut nacelle has a fixed mounting flange for connection to the test platform. The generator is 3-Phase Permanent Magnet AC Generator with a nominal output of 1kW and operating over a voltage range of 30V to 80V. Both turbines can be deployed in flow speeds up to 1.8m/s. However, 1.8m/s is well beyond the anticipated flow rate within the test zone. If the flow rate exceeds this level turbines will be immobilised for their own protection. A torque sensor (rated for up to 250Nm) from Sensor Technology Ltd and a thrust (drag) measurement load cell are mounted on a hinged frame arrangement on the top flange.

Figure 2. Turbine nacelle structures during manufacturing.

3.2.2 Thrust / Drag Measurement

The thrust of the turbines will be measured with the attachment of a load cell (which is mounted on a hinged frame arrangement on the top of the flange hinge) and measurement of the moment the device generates (see Figure 2). The friction in the pivot bearing may lead to some small amount of errors but these are expected to be negligible. In order to resist yawing forces on the strut, a solid bearing is used.

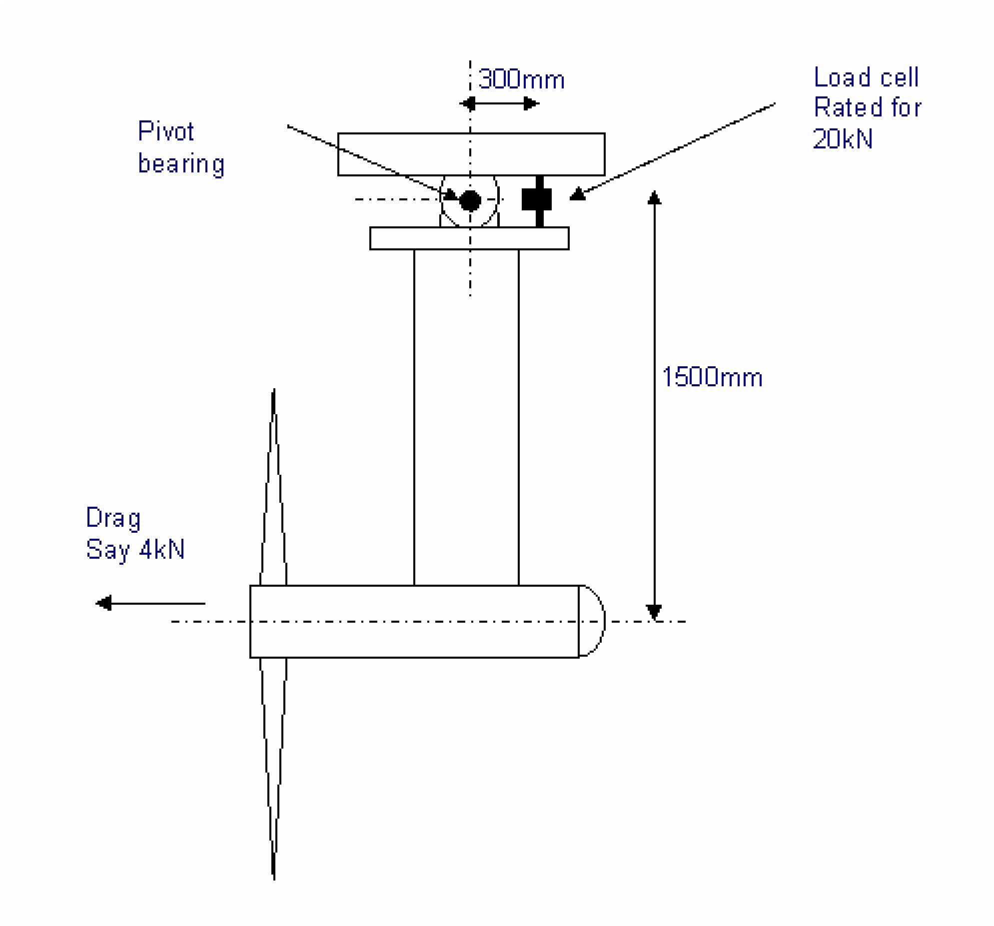


Figure 3. Measurement of thrust (drag) forces on the turbine.

The drag force will cause the device to pivot about the top hinges which will be restrained by a tie bar. One end of the tie bar is fitted with a shear pin load cell. The tie bar can be disconnected to allow the complete turbine unit to be swung up into the horizontal position (see Figure 3).

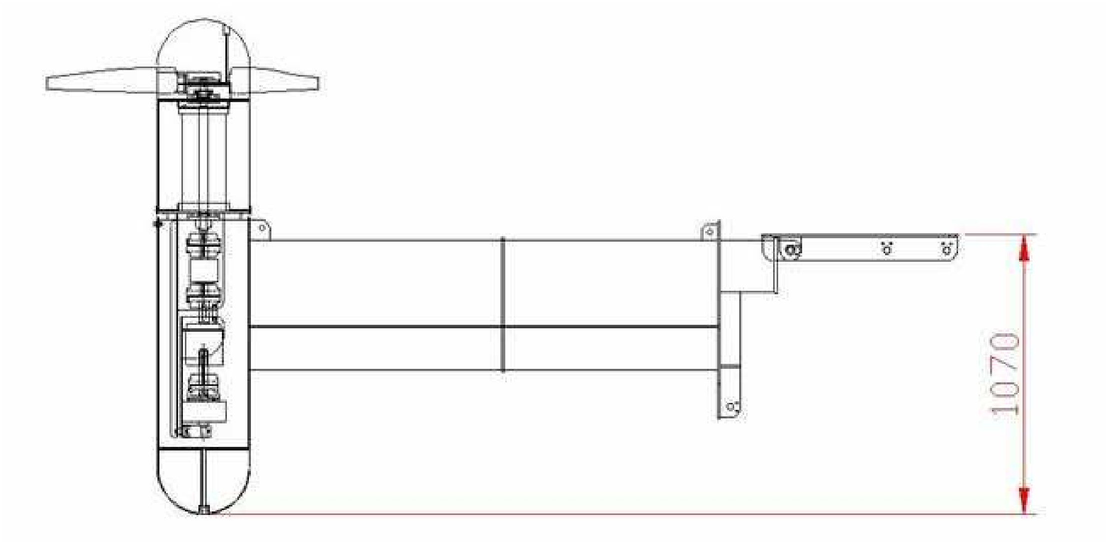


Figure 4. Pivot system for strut attached to test platform (this diagram shows how high the unit can be lifted on the proposed pivot bearings).

3.2.3 Turbine Output

Signal output given from turbine instrumentation is as follows:

- Generator AC - electrical output,
- Torque Gauge - digital output providing shaft torque and speed of rotation,
- Load cell - providing force measurement for determining drag.

3.2.4 Isolation Switch

The cable from the turbines will be directly connected to the generators. There is no means of isolating this cable while the turbine is rotating. An isolation box is fitted to the cable to allow for safe use. The isolation switch must be locked in the off position whenever disconnected.

3.2.5 Load Bank

A Load Bank is required on each turbine to allow a resistive load to be applied to the generator in each tidal turbine.

The Load Bank consists of two components, the resistor bank and the Control box. These are permanently connected to each other by 5m of cable. The resistor bank is sealed between two aluminium plates and has a mounting hole so it can be fixed underwater to prevent over heating. The Control box has 5 switches to switch in the required combination of resistors in a binary manner. A look up table shows total resistance being connected. The Control box has a water proof connector to connect the power lead from the Generators. Inside the Control box the generator power is rectified to DC and an overload protection fuse has been fitted. Analogue Voltage and Current gauges are mounted on top of the box to provide a visual guide to the generators performance. Appropriate shunts and dividers have been installed inside the Control box. In addition to the gauges mounted on the box isolations transducers have been included so the Voltage and Current can be safely logged by external equipment. This requires a continuous 24v supply. A DC converter has been installed in the box to provide a 24v supply from the generated power. Due to design limitation 24v can only be supplied when the generator produces between 19 and 72 volts DC. The 24v supply above generator voltage of 72v can not be guaranteed and below 19v is not possible. To maintain the 24v power supply above 72v the current may be limited to 2 amps. Water proof connectors on the side of the box include 24v DC output, and signal out and continuous 24v supply.

3.2.6 Turbine Contractors

Ocean Flow Energy have been contracted to assemble and supply the two turbines. Ocean Flow Energy were commissioned for this project due to their established experience with scaled tidal turbines. Their 1:10th scale Evopod is a semi-submerged, floating, tethered tidal current energy capture device. It uses a mooring and power export solution that allows the free floating device to maintain optimum heading into the direction of flow of the tidal stream or ocean current.

3.3 Instrumentation System

The experimental work will consist of measuring the impact of thrust, torque and wake effects of tidal turbines. (Measurement of thrust and torque is detailed in Section 3.2.2). Wake and flow interaction measurement will be conducted using 2x 2MHz Aquadopp current meters (an acoustic Doppler current profiler (ADCP) produced by Nortek which uses sonar to produce a profile of water current velocities at a range of depths) and 1x 10MHz acoustic Doppler velocimeters (ADV) (produced by Sontek, records instantaneous velocity components at a single point with a relatively high frequency). Both ADCPs and ADVs operate by measuring the velocity of particles in a remote sampling volume based on the Doppler shift. These devices are cost effective and user friendly. One AquaDopp will be positioned 1 diameter in front of the first fixed position turbine within the undisturbed flow, the second AquaDopp will be positioned 1 diameter in front of the second moveable turbine (its relative position will be between the two turbines). The ADV will be positioned at hub depth 2 diameters behind the second turbine. A strain gauge base mounted torque transducer will measure torque and a load cell device will be mounted on the supporting strut upper flange to measure thrust.

The ADV will primarily be used for point verification of the Aquadopps. The ADV position will be altered manually by unattaching, changing its position and reattaching it to the test platform by hand. The Aquadopps will be attached to an instrumentation support strut which is attached to the test platform structure, similar to that shown in Figure 6.

In order to optimise health and safety considerations and reduce risk associated with climbing onboard and disembarking from the test platform, a telemetry system has been developed in order to remotely transfer and transmit data and results from surveying equipment to the shore and support vessel.

3.3.1 Accoustic Doppler Velocimeter Specifications

The ADV system is a self contained processor fitted within an underwater housing and has a 25cm stem, the readings from which are given as analogue and serial outputs. The user interface for the ADV is the Windows–based HorizonADV software package which allows visualisation of data collection and data review.

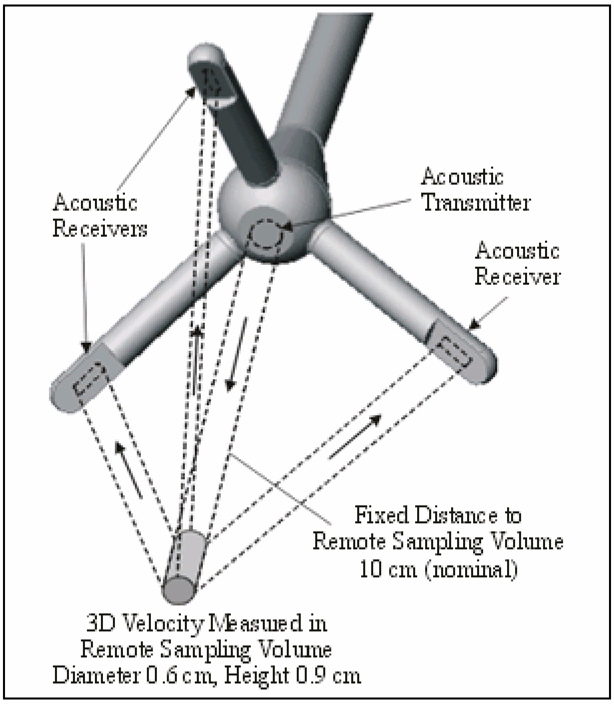


Figure 5: Sontek ADV features

Table 2: ADV Specifications

Sampling Rate	0.1 to 25 Hz
Sampling Volume	0.25 cc
Distance to Sampling Volume	10 cm
Resolution	0.01 cm/s
Programmed Velocity Range	3, 10, 30, 100, 250 cm/s
Accuracy	1% of measured velocity, 0.25 cm/s
Maximum Depth	60 m
Temperature Sensor	0.1°C
Compass/Tilt Sensor	Resolution — Heading, Pitch, Roll 0.1° Accuracy — Heading ±2° Accuracy — Pitch, Roll ±1°
Power	Input Power 12-24 VDC Typical Power Consumption 2.5 to 4.0 W Operating | <1mW Sleep

3.3.2 Aquadopp Profiler Specifications

The user interface for the Aquadopp Profiler is the Windows–based AquaPro software package which allows deployment planning, data retrieval, ASCII conversion, online data collection and graph display.

Table 3: Aquadopp Specifications

Maximum Profile Range	4-10m
Cell Size	0.1-2m
Beam Width	1.7°
Number of Beams	3
Velocity Range	± 10m/s
Accuracy	1% of measured value ± 0.5cm/s
Voltage Input	0.5 v
Power	Input power 9-15VDC

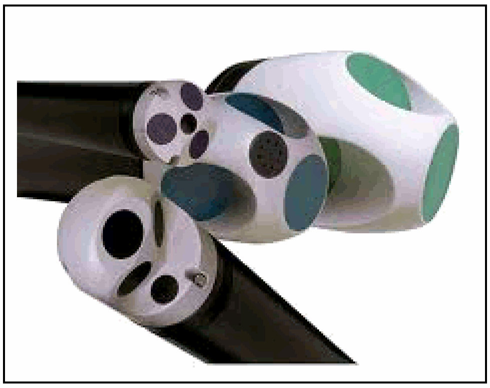


Figure 6: Nortek Aquadopp

3.4 Test Platform

Design plans of the test platform have been developed by Ian Bryden. However, due to the existing Allycat test platform towing rig (see Figures 6 & 7) already being built and operated by Wave Barrier Ltd as part of the EPSRC funded SuperGen Marine project, significant input on the specifics of the test rig design and structure have come from David Kidd at Wave Barrier Ltd.

Figure 7: Twin hulls, surveying instrumentation support structure (stretching between and supported by both hulls) and wheel house of existing SuperGen Marine Allycat structure

Figure 8: Allycat Test Platform

3.4.1 Test Platform Contractor

Wave Barrier Ltd Limited was founded by David Kidd to carry out research into wave attenuation and to develop a floating breakwater system for use in water sports events. Wave Barrier Ltd collaborated with the Queens University Belfast (QUB) Department of Coastal Engineering for three years in order to produce a full scale prototype of a floating breakwater system.

Aluminium catamarans (known as Allycats) have been constructed by Wave Barrier Ltd for various purposes including the SuperGen Marine project at QUB running towing trials of tidal turbine devices in Montgomery Lough Ballynahinch, Northern Ireland. Wave Barrier Ltd has re-designed the Allycat towing system for the PerAWaT trials and incorporated improvements which evolved during the conduct of SuperGEN Marine QUB trials during 2009 and 2010/11.

For the duration of this project, Wave Barrier Ltd's involvement with this project is to undertake the following tasks:

- Build a test rig platform in accordance with designs from Ian Bryden and the University of Edinburgh and develop the design from an already established rig structure through SuperGen Marine project.
- Fit turbines to the test rig.
- Transport test platform to and from Montgomery Lough and Strangford Lough.
- Secure and anchor test rig platform to the sea bed.
- Operate test platform and any associated vessels.
- Supply and employ any required technical staff for the field work and construction and operation of the test platform.
- Reconstruction and fitting of surveying equipment to test platform during installation.
- Carrying out a two – four week period (approximately) of preliminary tests and calibration of equipment in Montgomery Lough and conducting initial trials.
- Carry out two - three month period (approximately) of calibration of equipment in Strangford Lough and conducting all proposed tests.
- Assist in the carrying out of all field tests and data acquisition.
- Decommissioning of test platform.

4.0 Acceptance Criteria

Test specification of sufficient detail and scope to:

- Assess the nature of interactions between neighbouring 1/10th scale horizontal axis tidal rotors: this assessment will be undertaken with completion of fieldwork,

- Specification contains details of the detailed experimental programme: This report contains details of the experimental programme, how it will be conducted, what specific surveying equipment will be used and in what manner,

- Design meets the stated test purpose (i.e. range of lateral and longitudinal spacing, simultaneous flow speed measurement and controllable rotor tip speeds): The design of test platform and turbines meet the stated purpose of the project, as detailed within this report,

- Design specification report including a clear definition of reasons for design selection, method for manufacture and assembly of all key components; instrumentation system and support structure: Reasons for the design selection, manufacturing and assembly method of all key components, instrumentation system and support structure are all outlined within this report.

5.0 Future Tasks and Deliverables

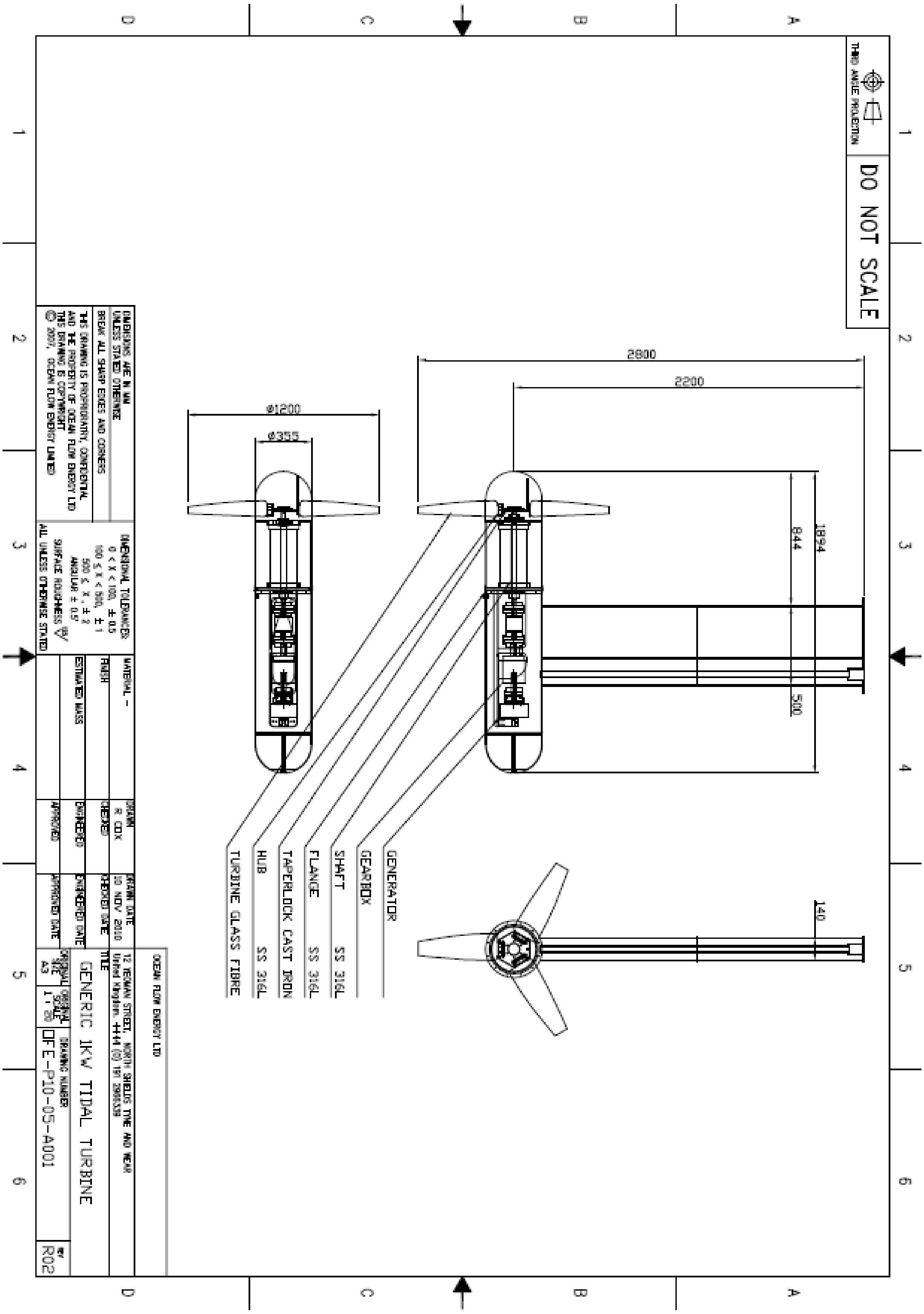
The next deliverables within the work package are as follows:

- Deliverable 3: Completed test rig equipment constructed and assembled with rotors installed,
- Deliverable 4: a) Correctly located test system, b) Test system calibrated: report and calibration database,
- Deliverable 5: a) Data sets over the prescribed range of longitudinal and lateral separations, b) Test report,
- Deliverable 6: System removed from site,
- Deliverable 7: Report on turbine interference parameters.

References

[1] (2011) Ocean Flow Energy, Evopod device. [Online]. Available: http://www.oceanflowenergy.com/

Appendix 1 – Turbine Diagrams



Appendix 2 – Turbine Specifications

oceanflowenergy

Specification for 1/10th Scale Mono-Strut Tidal Stream Turbine
(R03-16 Dec 2010)

Device	1/10th scale tidal stream turbine mono-strut trials unit.
Structure	Steel nacelle and mono-strut with mounting flange for connection to a support structure.
Turbine	1.2m diameter 3-bladed fixed pitch turbine. Hub – stainless steel 316. Taperlock - hub connection to shaft in carbon steel. Blades - black PAG with adjustable root pitch angle.
Shafting	Stainless steel 316.
Gearbox	ZF 1:10 epicyclic gearbox.
Generator	3-Phase Permanent Magnet AC Generator with a nominal output of 1kW and operating over a voltage range of 30V to 80V.
Maximum operating condition	The device can be safely deployed in flow speeds up to 1.8m/s
Turbine diameter	The unit can support a turbine of up to 1.5m diameter
Instrumentation	Torque sensor (rated for up to 250Nm) from Sensor Technology Ltd. Thrust (drag) measurement load cell mounted on a hinged fame arrangement on the top flange.
Anodes	Two zinc anodes fixed to the nacelle. One zinc anode fixed to the hub taperlock.
Corrosion Protection and Finish	Mild steel hull elements grit blasted to SA 2.5 and painted with International 2 pot epoxy primer (2 coats) and one coat of a compatible gloss top coat in yellow.

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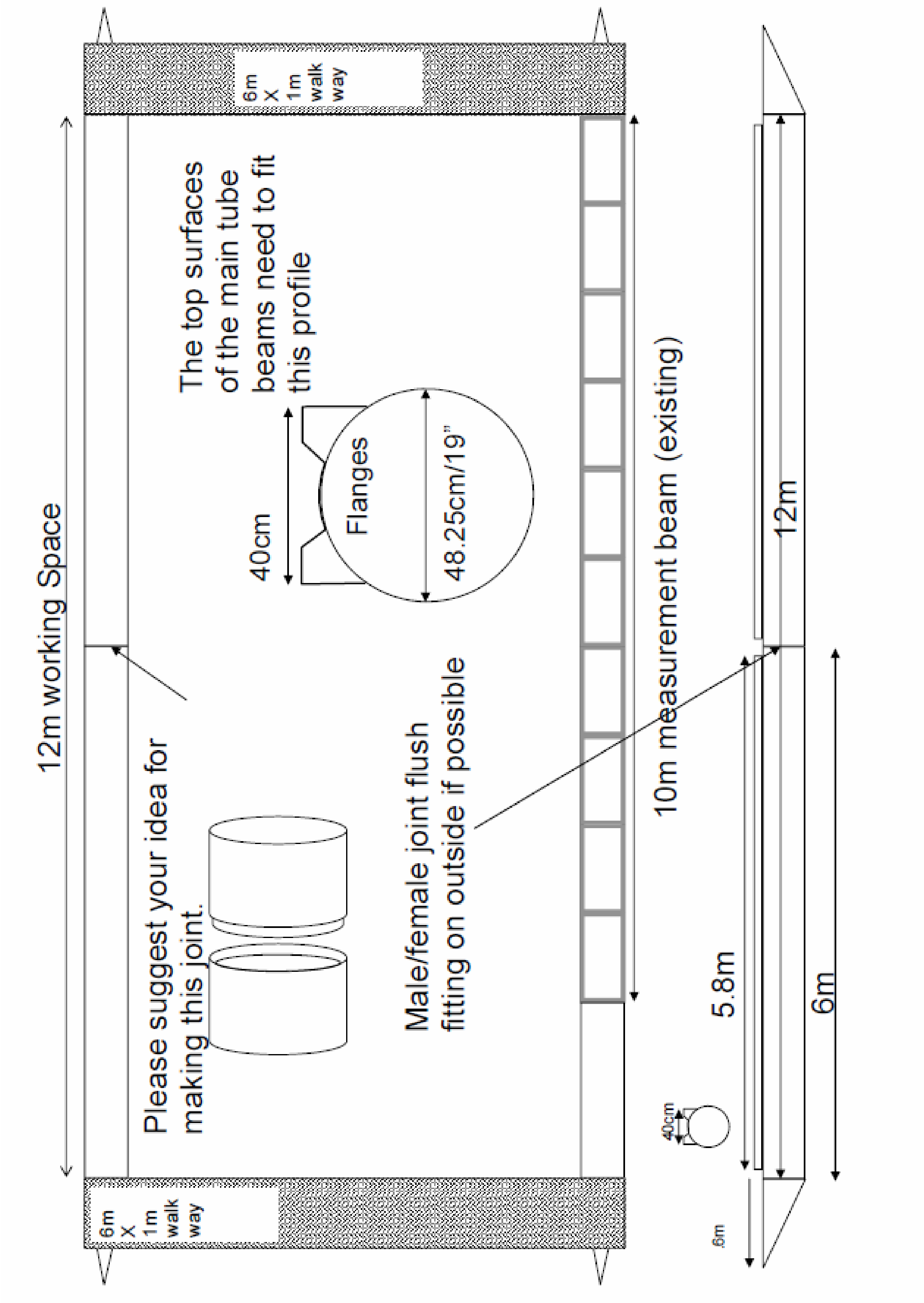
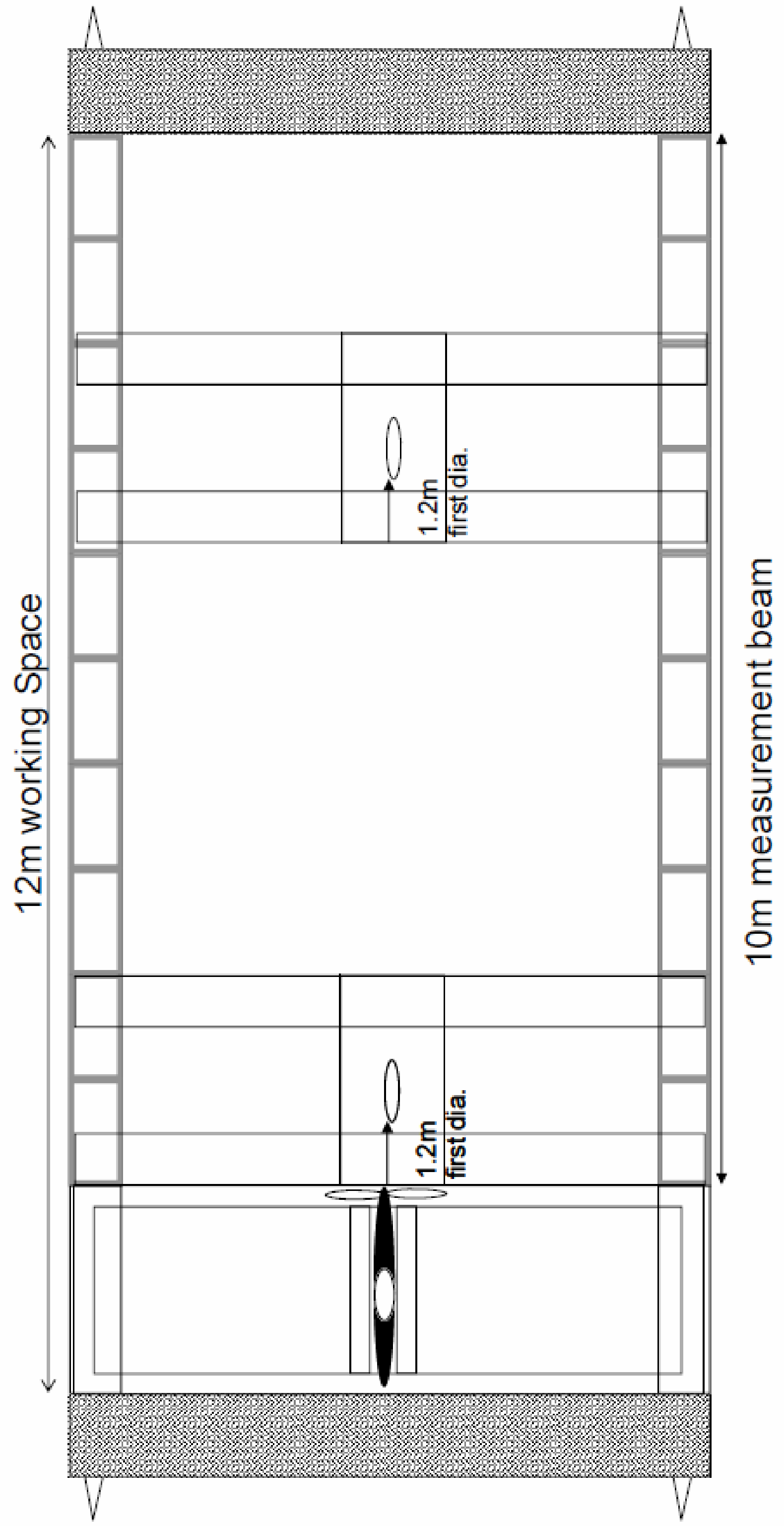
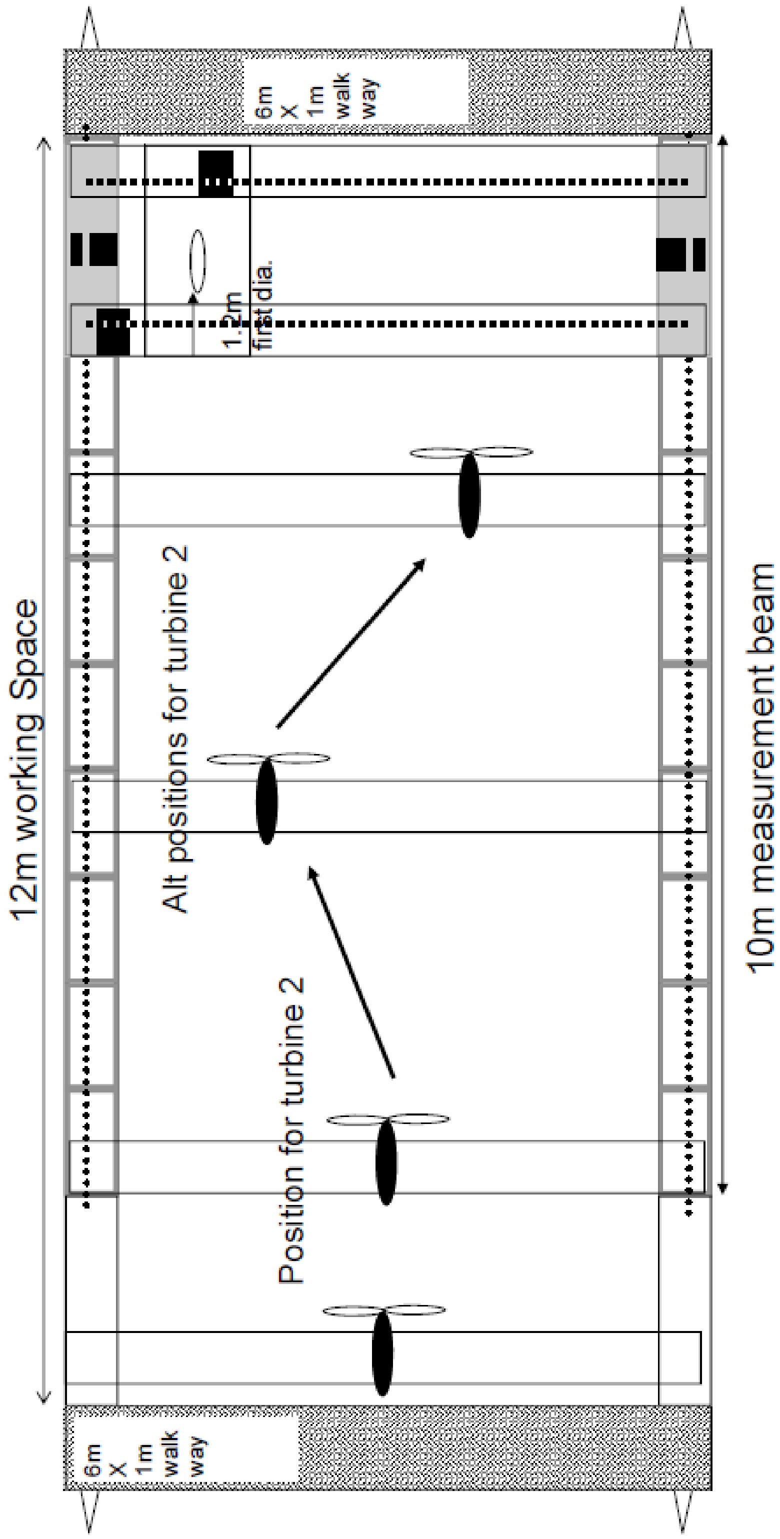
Appendix 3 – Test Platform Hull Joints Diagram



Appendix 4 – Turbine Positions within Test Platform




6m X 1m walk way
12m working Space
1.2m first dia.
Alt positions for turbine 2
Position for turbine 2
10m measurement beam
6m X 1m walk way