Institution: Edinburgh Research partnership in Engineering – ERPE (Heriot Watt/Edinburgh)

Unit of Assessment: B15: General Engineering

Title of case study: Advanced Wavemaker Designs

1. Summary of the impact (indicative maximum 100 words)

Edinburgh Designs Ltd., (EDL) was spun-out to exploit ERPE research from the original Wave Power Group. With six staff and an annual turnover approaching £2M EDL has supplied the equipment and control systems for wave tanks in 19 countries including the world's largest computer-controlled wave test facility, the US Navy Manoeuvring and Station Keeping Tank. They are currently completing the world's first circular tank, combining waves with currents in any relative direction, which is operated by the 6 person company, "FloWave"
EDL, still run by the founding staff, it is the world-leading supplier of wave-making technology for scientific and recreational facilities.

2. Underpinning research (indicative maximum 500 words)

The ERPE research team comprises Salter (Emeritus Professor), Professors: Bryden; Ingram; and Wallace, Senior Lecturer Bruce, PDRAs: Davey; and Richon, and PhD Robinson (all here throughout the period). PhD Maguire (to 2011) and former RA Taylor were previous team members.

The important research contribution underpinning this case are:

- Design of absorbing wavemaker paddles [2] for the accurate, controlled generation of waves in test tanks.
- Implementation of a curved tank, with associated computer drive, to make more effective use of small facilities [1].
- Design (and construction) with EDL of the worlds first wave and current test tank facility [3] with ducted impeller designs [4, 5].

Waves are reflected off the surfaces of device models on test and from the sides of tanks in which they are being tested to degrade the predictability and repeatability of the waves in the test area. To maximise the useful test area, the original Wave Energy Group in ERPE built the wide tank with wave-makers along the long side, phase controlled to propagate at up to ±20° to its perpendicular centre line. Paddles were driven individually with signals embodying differing frequencies, amplitudes, angles and phases to define individual wave fronts, which summed to generate long-crested multi-spectral or mixed seas. They developed in 2000 impedance-matched beaches at the down-wave end to dissipate residual waves together with absorbing wave-makers that measured the forces on the paddles and fed them back to the control systems to modulate velocity to absorb reflected waves. However, the short sides continued to reflect cross-waves into the test area.

This led to the construction of the Edinburgh Curved Tank in 2002 with EPSRC support (GR/R64438/01 £143k) with 48 absorbing wave-makers in a 90° arc, one side of matched beaches and a single glass wall. It propagates the full palate of 1/100th scale seas, steerable through ±45° about a radial centre line [1].

Edinburgh Designs Ltd (EDL) staff, all originally members of the ERPE Wave Power Group, continue to test developments in their control software in this tank in collaboration with ERPE staff and researchers. ERPE researchers have continued to underpin developments in absorbing wavemakers through numerical and physical modelling to quantify the dependence of absorption characteristics on geometry and control coefficients. They also established and validated in 2011 computational fluid dynamic (CFD) techniques to numerically model wave tanks, in the absence of flow [2].

Experience in the early deployment of another wave energy power extraction technology, Pelamis – also developed within ERPE, identified the need to be able to conduct scale-test models of wave

devices under the influence of tidal currents. This stimulated interest in tidal test machines, not only for flowing water with controllable levels of turbulence, but in generating flow patterns which more closely resemble the tidal ellipses which are encountered [3] in practical seas.

The underpinning research has extended, beyond earlier ERPE research on tidal current energy extraction techniques [6], and evolved into the EPSRC-funded project (EP/H012745/1 £990k 2010-14) to prove numerically and physically the omni-directional combination of waves and currents in a predictable and stable manner, with prescribed levels of turbulence. The final wave plus current tank design adopted phased absorbing wavemakers with force feedback control to enable, for the first time, the practical combination of waves and currents in a stable manner.

This led to the awards of support from EPSRC (EP/102932C/1, £6M) to construct the fully circular FloWave tank, 30m in diameter and 5m deep, in ERPE at Edinburgh. With 168 force-feedback absorbing wave-makers in a 25m circle it can propagate and absorb 1m waves in any direction relative to an array of devices mounted on an elevating floor. Simultaneously 28 1.7m diameter ducted flow drives will circulate water in any relative direction at up to 1 m/s through a test area 18m wide and 2m deep. It will be used to emulate sea conditions at the European Marine Energy Centre (EMEC) and at other coastal sites in European waters at up to 1/20th scale. Stable combination of flow patterns with the wave field, at programmable levels of turbulence, is a highly demanding challenge that has been addressed in the flow conditioning and wave-maker control. Current is generated across the tank by using groups of impellers arranged around its perimeter.

EPRE staff performed both computer simulations and experiments [4] to provide a new method for conditioning flow from ducted impellers to remove swirl and reduce large-scale turbulence with minimum energy loss. Each impeller produces a single flow velocity, which may be different to its neighbours. These differences can lead to a stepped or curved plan view velocity profile in the test section of the tank where a plug profile is required. EPRE staff have recently characterised the maximum allowable velocity difference for a stable plug profile to be generated [5]. The same work allows a shear layer to be used to control force feedback wave makers in the presence of current.

3. References to the research (indicative maximum of six references)

References identified with * are those which best indicate the quality of the underpinning research.

[1] Taylor, J.R.M., Rea, M. and Rogers, D.J., "The Edinburgh Curved Tank", Proceedings 5th European Wave Energy Conference, Cork, Ireland, 2003.
www.mech.ed.ac.uk/research/wavepower/0-Archive/EWPP%20archive/2003%20The%20Edinburgh%20curved%20tank.pdf
This paper described the construction of the curved tank and suggested the first designs of a fully round tank that was the inspiration for FloWave.

[2]* Maguire, A.E. and Ingram, D.M.,"On Geometric Design Considerations and Control Methodologies for Absorbing Wavemakers", Coastal Engineering, Vol. 58, no. 2, 135-142, 2011. DOI:10.1016/j.coastaleng.2010.09.002.
This investigated the effects that geometry and control have on the absorption characteristics of wavemakers and presented the hydrodynamic coefficients bottom hinged flap wavemakers, as applied in reactive and complex conjugate control to achieve increased absorption over a broader band of frequencies.

[3] Davey, T., Bryden, I., Ingram, D.M., Robinson, A., Sinfield, J.L. and Wallace, A.R., "The All-Waters Test Facility – a new resource for the marine energy sector", Proc 4th International Conference on Ocean Energy 2012. Available on request.
This paper described the design and construction of the fully round FloWave, combining waves and currents in any relative direction.

[4] Robinson, A., Bryden, I., Ingram, D.M. and Bruce, T., "The Use of Conditioned Axial flow Impellers to Generate a Current in a Test Tank", Working paper accepted for publication in the

Journal of Ocean Engineering 2013. Available on request.
This paper describes the initial and intermediate propulsion and flow conditioning of currents in the round tank to achieve the required bulk flow-speeds with acceptably low levels of turbulence above the test area for tidal currents.

[5]* Robinson, A., Richon, J-B., Bryden, I., Bruce, T. and Ingram, D.M., "Vertical mixing layer development", European Journal of Mechanics – B Fluids, 2013. DOI:10.1016/j.euromechflu.2013.07.001.
This developed and described the final flow conditioning that creates a shear layer between the plug of flowing water directed ahead of the wave-makers in the round tank, to avoid interference with the force-feedback of the absorbing wave-makers and improve stability of combination.

[6]* Salter, S.H. and Taylor, J.R.M., "Vertical-axis tidal-current generators and the Pentland Firth", Proceedings Institution of Mechanical Engineers, Part A: Journal of Power and Energy, Vol. 221, No. 2, pp. 181-199, 2007. DOI:10.1243/09576509JPE295. 18 GS citations.
This describes an early design of tidal current energy extraction technique based on a vertical-axis approach. It extends 2 ideas introduced in papers from the 2005 World Renewable Energy Conference.

4. Details of the impact (indicative maximum 750 words)

Edinburgh Designs Ltd., the staff spin-out from the ERPE wave energy group (http://www.edesign.co.uk/) specialises in the design, manufacture and installation of a wide range of wave and tidal generators. Since 1987 EDL has established itself as a world leader in the provision of hydrodynamic test equipment, including:

- flap-type ocean wave generators;
- piston-type coastal wave generators;
- wave generating software and measuring equipment;
- beaches and movable floors;
- scientific tidal, wind and flow tanks and recreational tank equipment.

EDL directly employs 6 full-time staff with a turnover exceeding £2M per annum [S1]. They sub-contract manufacture and installation to local and UK companies, depending on the location of each installation, creating significant indirect employment and onward turnover.

They have supplied over 1000 wave-makers to 50 installations in 19 countries into academic, governmental, defence and recreational facilities (http://www.edesign.co.uk/list-of-contracts/) including every academic installation in the UK. Examples of recreational wave makers are surf wave pools, rapid river rides, theme park waves and flow rides. www.edesign.co.uk/product/leisure/ shows the current range of leisure designs.

Since 2008 EDL has:

- supplied the CoAST laboratory at Plymouth University with a coastal basin, ocean tank, sediment flume and tilting tank. All four rectangular tanks are equipped with wave-makers and straight-flow current generators and the ocean tank has a hydraulic moving floor [S3].

- Installed in 2011 wave-making equipment in the 260 m Marin Depressurised Wave Basin at Waginengen in the Netherlands to generate bow-on and beam waves during ship-towing tests. For the first time this enabled the investigation into cavitation in a wave environment and the study of air entrapment under reduced ambient air pressure.

- Created the giant wave and flood scenes for 2012 film *The Impossible* on the 2004 Indian Ocean tsunami, www.edesign.co.uk/2012/12/edinburgh-designs-creates-the-impossible-wave/

- Commissioned on completion, in 2013, the Manoeuvring and Sea Keeping Basin for the US Navy David Taylor Facility in Maryland [S4], with 216 flap generators producing over 1 MW of wave energy, to become the largest computer-controlled wave tanks in the world for testing ship models.

The detailed technical collaboration between ERPE and EDL in wave-maker design and testing was recognised by the 2011 joint award of (EP/H012745/1, £2.1 Million with EDL) to further explore the design of several new wave and current generators for stable wave generation in multi-directional combined tanks and prove that this concept could be applied to a round tank. This led to the subsequent award of EP/102932C/1, £6 Million, to construct the All-UK Waters Combined Wave and Current Test Facility [4] and subsequent formation of the subsidiary company FloWave TT Ltd (http://www.flowavett.co.uk.) with 6 full-time staff. Complementing these investments and subscription by the University of Edinburgh, Scottish Enterprise awarded a further £1 Million to enhance the scientific and staff provision increasing the total investment to £11.2 Million.

"As Managing Director I can verify that Edinburgh Designs continues to have strong technical collaborations with the Wave Power Group at ERPE. In particular we have adopted, into our design portfolio, ERPE research on new methods for integrating waves with current flow generated by an array of impellers. The new Flowave tank has 28 computer controlled impellers arranged in a circle. Each can be programmed so that the direction and velocity of the combined flow within the basin can be controlled in real time. This was a unique opportunity to combine our experience of constructing previous project with new research work conducted within the University. We are very pleased to have been selected to design the new Flowave facility as it further extends our capability from wave makers into full 3D marine current test tank design", Managing Director, Edinburgh Designs [S1].

"Stephen Salter and his colleagues have provided many technical advances in the design of wavemakers and their associated drivers for wave tanks, which have been installed worldwide through the spin-out company Edinburgh Designs. This world-leading technical capability has enabled recent funding for the construction of the new FloWave facility, which gives the UK a world-wide lead in simulating ocean conditions for testing tidal and wave energy devices." Chief Scientific Advisor, Department for Energy and Climate Change [S2].

This world-unique facility, which combines recent ERPE research [4, 5] with EDL's commercial expertise, http://www.edesign.co.uk/portfolio/edinburgh-university/, has had already significant impact on the marine energy and other sectors, with a pipeline of device developers and academic researchers already established. It emulates at up to 1/20th scale the combination of wave and tidal conditions anywhere around European coastlines. The facility simulates conditions at EMEC as a pre-proving ground for technology developers and investors as part of the UK commercial test capability, which ranges from 1:100 scale testing in laboratories to full scale at EMEC and at WaveHub in Cornwall.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[S1] Managing Director, Edinburgh Designs Ltd., see comments included in Section 4.

[S2] Chief Scientific Advisor, Department of Energy and Climate Change, see comments included in Section 4.

[S3] www.edesign.co.uk/portfolio/plymouth/shows the Plymouth Marine facility.

[S4] www.edesign.co.uk/portfolio/nswcdd-mask-basin-usa/%20%20 shows, the US Navy, Maryland facility.