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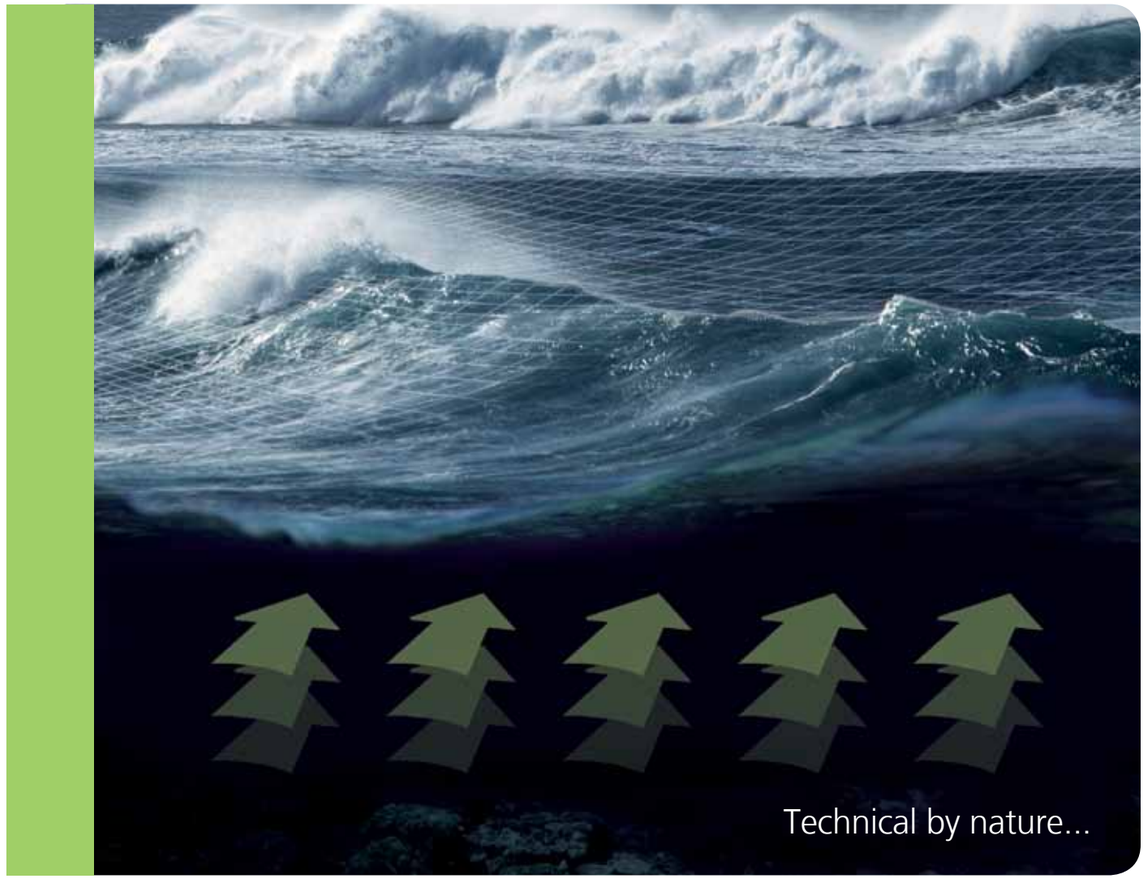
Renewable energy consultants

GL Garrad Hassan



WAVE AND TIDAL SERVICES

www.gl-garradhassan.com

Contents

THE TECHNICAL AUTHORITY ON RENEWABLE ENERGY

GL Garrad Hassan is the world's largest renewable energy consultancy. Dedicated to serving the renewables industry it offers independent technical and engineering services, products, and training to the wind, wave, tidal and solar sectors.

Although the **GL Garrad Hassan** name is new, the company has a rich heritage. It was created through the integration of specialist companies that, united under a single brand, form the renewable energy consulting division of the GL Group and deliver unrivalled depth and breadth of service to clients at all stages of the renewable energy project lifecycle.

GL Garrad Hassan is a consulting company and a recognised technical authority on renewable energy. It has no equity stake in any device or project. This rule of operation is central to its philosophy and sets it apart from many competitors, as well as underlining its independence.

Delivering outstanding marine services and world-leading products

GL Garrad Hassan's focus on the wave and tidal energy sectors began in 2005 with the founding of a Marine Renewables Group. **GL Garrad Hassan**'s engineers are working alongside key wave and tidal device and project developers to help spearhead the development of prototypes and demonstration projects. The company has worked on many projects, for all types of stakeholders, and has developed the world's first integrated tidal turbine design software – Tidal Bladed.

As well as working with key commercial organisations and the public sector, **GL Garrad Hassan**'s wave and tidal experts have secured significant funding for ongoing R&D efforts and are leading the £8 million ETI-funded PerAWaT (Performance Assessment of Wave and Tidal Array Systems) project. While the core of the team operates from **GL Garrad Hassan**'s Bristol headquarters, they are increasingly involved with projects across the globe as the sector evolves. Recent marine developments in Portugal have also led to the opening of an office in Lisbon in 2009.

"Wave and tidal energy will be a vital part of the future energy mix and, with the market evolving so rapidly, it's an extremely exciting place to be. It is reminiscent of the wind sector 20 years ago and, with the knowledge we have gained in wind from our involvement since its infancy, we are comparatively much better placed for marine energy developments. There are many elements of technology and engineering know-how that can be applied across multiple energies and, when combined with the technology-specific knowledge of experts recruited from within the wave and tidal sectors, this puts **GL Garrad Hassan** in a unique position to deliver outstanding services and world-leading products."

Dr. Andrew Garrad, President

Leading a team of dedicated wave and tidal experts

Wave energy

Joao Cruz
Head of Wave Energy Group,
GL Garrad Hassan
PhD, Dip.-Ing.

Prior to joining **GL Garrad Hassan**, Joao worked with the IST-Technical University of Lisbon, the University of Edinburgh, Teamwork Technology (Archimedes Wave Swing) and more recently Pelamis Wave Power Ltd, where he was an active member of the Cost Reduction and Performance Enhancement Department. Joao's expertise encompasses resource assessment, numerical and experimental modelling of wave energy converters and development of tools in an operational environment. He has a unique combination of R&D and field experience obtained in Portugal and in the UK, at the European Marine Energy Centre (EMEC).

Joao co-authored the book 'Wave Energy' (in Portuguese), commissioned by the Portuguese Institute for the Environment (2004), and was the editor of a book entitled 'Ocean Wave Energy' (Springer-Verlag) – one of the first textbooks in the field. He is also a reviewer for 'Ocean Engineering', 'Journal of Power and Energy', and 'Journal of Engineering for the Maritime Environment'.

Joao is the author of almost 20 journal papers and peer-reviewed international conference papers, including:

Cruz, J., Sykes, R., Siddorn, P., Eatock Taylor, R. (2010); **Estimating the Loads and Energy Yield of Arrays of Wave Energy Converters under Realistic Seas**, IET Journal of Renewable Power Generation, Vol 4, Issue 6, pp. 488-498 [a reduced version was originally presented at the 8th European Wave and Tidal Energy Conference (EWTEC 2009)]

Rhinefrank, K., Schacher, A., Prudell, J., Cruz, J., Jorge, N., Stillinger, C., Naviaux, D., Brekken, T., von Jouanne, A., Newborn, D., Yim, S., Cox, D. (2010); **Numerical and experimental analysis of a novel wave energy converter**; Proceedings of the 29th International Conference on Offshore Mechanics and Arctic Engineering (OMAE2010)

Philips, J., Cruz, J., Holbrow, R., Rawlinson-Smith, R.I., Parks, J. (2008); **Defining the Long-Term Wave Resource at Wave Hub: The Role of Measurements and Models**; Proceedings of the 27th International Conference on Offshore Mechanics and Artic Engineering (OMAE2008)

Cruz, J., Mackay, E., Martins, T.J. (2007); **Advances in Wave Resource Estimation: Measurements and Data Processing**; Proceedings of the 7th European Wave and Tidal Energy Conference (EWTEC 2007)

Cruz, J., Salter, S. (2006); **Numerical Modelling of a Modified Version of the Edinburgh Duck Wave Energy Converter**; Journal of Engineering for the Maritime Environment (Proc. Inst. Mech. Engineers Part M), Vol. 220 (3), pp. 129-147 [Awarded 'Professional Engineering Publishing Paper of the Year']

"At **GL Garrad Hassan** we are privileged to have unique conditions to develop tools that bridge the gap between project and device developers. Not only do we have a team of young, bright and highly motivated individuals who have specialised in wave energy but we can also take advantage of the extensive experience that the company has in the wind energy sector, where it has pioneered from the outset and has already addressed similar issues by developing software tools. We have two technical bases in two of the most active countries in the world in this field (UK and Portugal), and such local knowledge further enhances the services and support we can offer to our clients".

Tidal energy

Mat Thomson
Head of Tidal Energy Group,
GL Garrad Hassan
MEng, MSc, CEng IMechE

Prior to joining **GL Garrad Hassan**, Mat worked within the tidal industry for Swan Turbines, where he developed the concept design for an axial-flow tidal stream turbine. His work established technical specifications which allowed the design to be fully costed. He also conducted detailed research into the flow around axial-flow tidal stream turbines as part of a fully-funded National Environmental Research Council Masters Degree. His experience is wide-ranging, from conducting device assessments, loading and performance analyses, to leading the development of Tidal Farmer, a software design tool to predict and optimise the energy capture of tidal turbine arrays.

Mat is the author of a number of peer-reviewed international conference papers, including:

Smith, S., Thomson, M.D., Whelan, J. (2010); **Planning and optimising the construction and O&M strategy of tidal stream turbine arrays**; Paper accepted for 3rd International Conference on Ocean Energy (ICOE 2010)

McCann, G., Thomson, M.D., Hitchcock, S. (2008); **Implications of site-specific conditions on the prediction of loading and power performance of a tidal stream device**; Proceedings of the 2nd International Conference on Ocean Energy (ICOE 2008)

Bahaj, A.S., Myers, L.E., Thomson, M.D., Rawlinson-Smith, R.I. (2008); **The effect of boundary proximity upon the wake structure of horizontal axis marine current turbines**; Proceedings of the 27th International Conference on Offshore Mechanics and Arctic Engineering (OMAE2008)

Whelan, J., Thomson, M.D., Graham, J.M.R., Peiró, J. (2007); **Modelling of free surface proximity and wave induced velocities around a horizontal axis tidal stream turbine**; Proceedings of the 7th European Wave and Tidal Energy Conference (EWTEC 2007)

Bahaj, A.S., Myers, L.E., Thomson, M.D., Jorge, N. (2007); **Characterising the wake of horizontal axis marine current turbines**; Proceedings of the 7th European Wave and Tidal Energy Conference (EWTEC 2007)

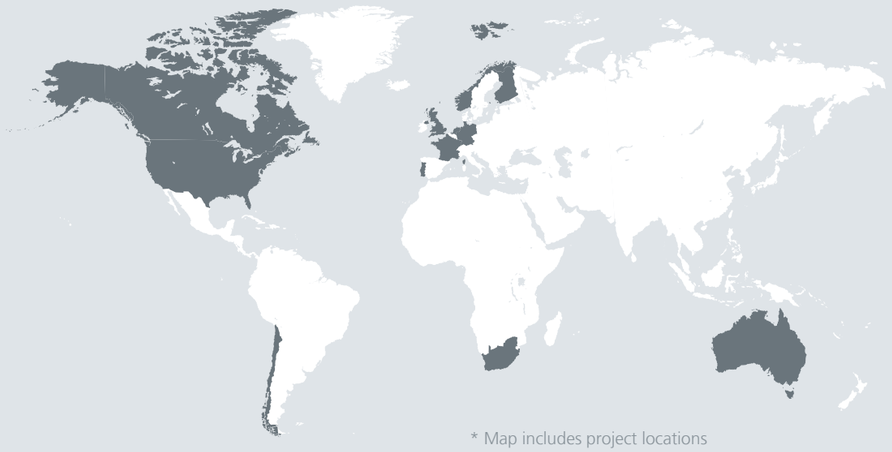
"The nature of tidal energy is such that it offers a predictable source of renewable energy which could provide GWs of useful power to both the UK and to the rest of the world. However, to transform this emerging industry into an operational business, multi-disciplinary technical expertise is required. The engineering challenge is to provide a cost-effective solution within a complex operating environment; that is why initial efforts at **GL Garrad Hassan** were focused on the development of Tidal Bladed – a sophisticated design tool which can predict device performance and loading, given representative combinations of current, wave and wind conditions.

Installation and access are clearly major issues that the industry needs to conquer, but equally, the ability to predict lifetime energy yield is also of key importance. **GL Garrad Hassan** is leading the industry in R&D activities to define the energy yield of wave and tidal arrays through the PerAWaT (Performance Assessment of Wave and Tidal Array Systems) project. This is a highly complex area, and it requires a rigorous approach to the investigation with cross-validation at each step. We are also developing tools for the optimisation of construction and operations, and maintenance methodologies for marine energy arrays.

The combination of in-house R&D and the existing diverse wealth of experience at **GL Garrad Hassan** in the field of renewable energy offers advantageous technology transfer opportunities to this sector".

Services and tools that bridge the gap between project and device developers

Device developers/ manufacturers	Project developers	Investors/lenders	Owners/operators	Government/NGOs
Device design	Project development support	Due diligence services	Owner's engineering support and FEED studies	Market intelligence
Control system development	Site feasibility studies	Marine warranty services	Due diligence	Policy and regulatory studies
Innovative technology evaluation	Environmental and permitting services	Strategic and policy advice	Asset management and optimisation services	Specialist strategic studies
Measurement services	Resource and energy analysis	Performance assessment	Energy assessment	
Device type approval and certification support	Site suitability studies	Training courses	Measurement services	
Marine warranty services	Device consulting		Marine warranty services	
Strategic and policy advice	Due diligence		Supply of SCADA systems	
Performance assessment	Interconnection		Strategic and policy advice	
Training courses	Construction phase modelling and operations and maintenance modelling		Performance assessment	
	Construction / installation services		Training courses	
	Strategic and policy advice			
	Performance assessment			
	Training courses			



* Map includes project locations

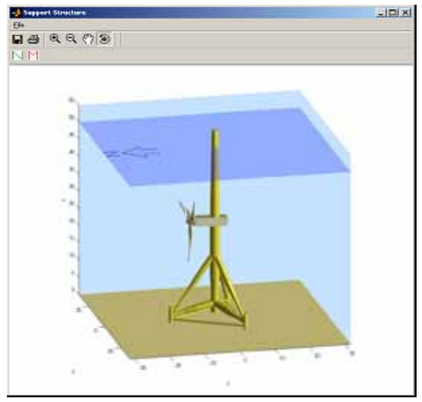
	Device developers/ manufacturers	Project developers	Investors/ lenders	Owners/ operators	Government/ NGOs
GL Garrad Hassan tools					
Tidal Bladed (Tidal energy converter design software)	*	*			
WaveDyn (Wave energy converter dynamic solver)	*	*			
Tidal site data analysis toolbox	*	*			
Wave site data analysis toolbox	*	*			
Tidal array design tools	*	*	*	*	
Wave array design tools	*	*	*	*	
O2C (Construction modelling tool)	*	*		*	
O2M (operation and maintenance tool)	*	*		*	
Cost of energy modelling tool	*	*	*	*	*
Developer database and investment tool		*	*	*	*
Commercial software					
Mooring analysis tools	*	*		*	
Boundary element methods for free surface interactions	*	*			
3-d RANSE solvers	*	*			
Shallow water solvers	*	*			
FEM (Finite Element Method) tools	*				
CAD	*				
Electrical system design tools	*	*		*	
GL Group Capabilities					
CFD tools	*	*			
FRIENDSHIP Systems CAE tools	*	*			

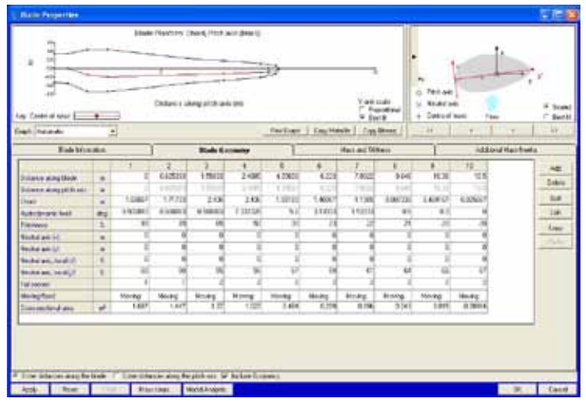
Clients

- AES Corporation (USA)
- Alstom Ocean Energy (France)
- Anderson Solutions (Consulting) Ltd (UK)
- Atkins (UK)
- AW-Energy Oy (Finland)
- AWS Ocean Energy Ltd (UK)
- Centre for Renewable and Sustainable Energy Studies (South Africa)
- Columbia Power Technologies LLC (USA)
- Dehlsen Associates LLC (USA)
- DTI / BERR / DECC (UK)
- Edinburgh University (UK)
- Energy Technologies Institute (ETI) (UK)
- European Marine Energy Centre (EMEC) (UK)
- Hammerfest Strøm A/S (Norway and UK)
- Inter-American Development Bank (USA)
- ITI Energy (UK)
- Lunar Energy / Rotech Engineering Ltd (UK)
- Marine Power Systems (UK)
- Natural Resources Canada (NRCan) (Canada)
- Npower Juice (UK)
- Oregon Wave Energy Trust (OWET) (USA)
- Oscilla Power Inc (USA)
- REN / ENONDAS (Portugal)
- ScotRenewables Ltd (UK)
- ScottishPower Renewables (UK)
- Set Venture Partners (Netherlands)
- South West Regional Development Agency (SWRDA) (UK)
- Technology Strategy Board (TSB) (UK)
- The Carbon Trust (UK)
- The Highlands and Islands Enterprise (UK)
- The Scottish Government (Scottish Executive) (UK)
- Tidal Generation Ltd (UK)
- TidalStream Ltd (UK)
- Turner Hunt Ocean Renewables (THOR) (USA)
- Voith Hydro Ocean Current Technologies (Germany)
- Wave Energy Centre (WavEC) (Portugal)
- WAVEenergy AS (Norway)

GL Garrad Hassan has a range of in-house tools and commercial software designed specifically for tidal and wave devices and arrays

Tidal Bladed: The world's first tidal turbine design software



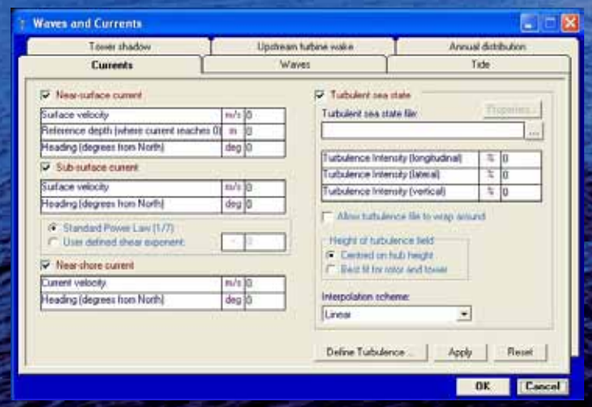


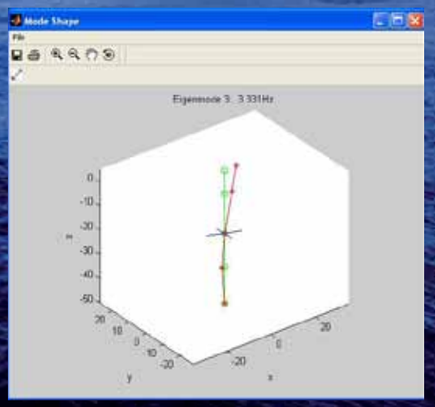
The development of tidal current turbine technology has progressed rapidly, with prototype systems installed and operational. These developments represent the dawn of a new industry that is focused on exploitation of the vast, clean energy resource available from tidal stream currents.

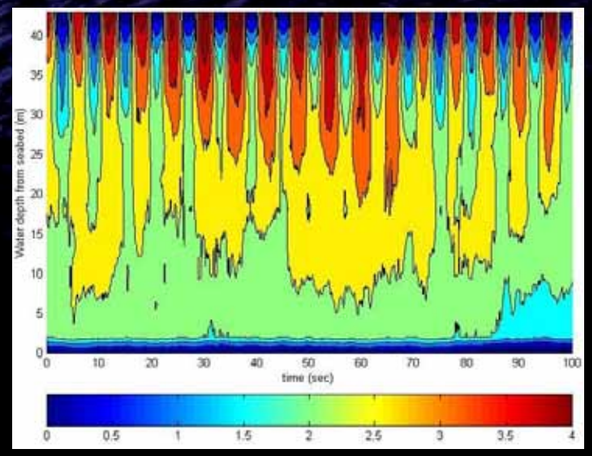
Tidal Bladed is based on the industry standard software for wind turbine design – Bladed, which is certified by Germanischer Lloyd and used all over the world. Many of the wind turbine-related features and engineering models can be directly applied to, or have been adapted for, tidal turbines. This means that, while Tidal Bladed is the first software of its kind, users can be confident of a robust package with high quality modelling capabilities and, while it will obviously be further developed as the market grows, it is already being utilised by tidal turbine device developers.

Tidal Bladed currently features:

- Time-domain simulations of combined current, wave and wind loading with full hydroelastic modelling and seismic excitation, plus a range of supporting steady-state calculations
- A range of wave and current models to define the hydrodynamic forces acting on the device
- Models to describe 'added mass' effects on both the rotor and support structure
- An accurate representation of the buoyancy forces acting on the device
- An extensive suite of post-processing functions, covering statistical and spectral analysis of simulation time-histories, through to calculation and presentation of extreme and fatigue loads, and automatic reporting
- A Windows-based graphical user interface and on-line help facility for ease of use







The image above visualises outputs from a Tidal Bladed simulation of extreme waves in a turbulent flow

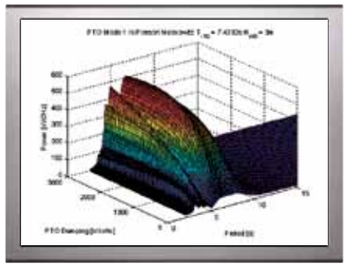
GL Garrad Hassan has published a number of papers on Tidal Bladed:

McCann, G. N., Thomson, M., Hitchcock, S.; **Implications of site-specific conditions on the prediction of loading and power performance of a tidal stream device**; 2nd International Conference on Ocean Energy (ICOE 2008), Brest, France, October 2008

McCann, G. N.; **Tidal current turbine fatigue loading sensitivity to waves and turbulence – a parametric study**; 7th European Wave and Tidal Energy Conference (EWTEC 2007), Porto, Portugal, September 2007

McCann, G. N., Rawlinson-Smith, R. I., Argyriadis, K.; **Load Simulation for Tidal Turbines using Wind Turbine Experience**; International Conference on Ocean Energy (ICOE 2006), Bremerhaven, Germany, October 2006

Other tools in GL Garrad Hassan's toolbox:



WaveDyn

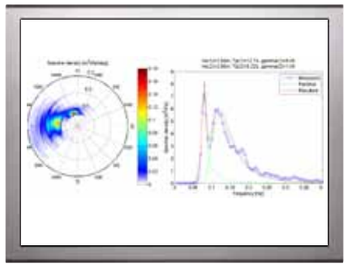
A calculation tool that allows the design of a wave energy converter (WEC) and its optimisation under a wide range of design variables and constraints:

- Frequency and time-domain modules (linear and nonlinear capabilities)
- Link to the wave site data toolbox (use of site-specific data)
- Hydrodynamic loads (radiation and diffraction)
- Definition of the structural restraints for multi-body systems
- Flexible PTO description facilitates modelling of mechanical, hydraulic and electrical systems
- Control module (control strategy iterations)
- Moorings module

Tidal site data analysis tool box

A program for the analysis of tidal current and height data, allowing the user to characterise the site flow regime. Functions include:

- Quality analysis of raw Acoustic Doppler Current Profiler (ADCP) data
- Analysis of flow profiles and speeds
- Analysis of turbulence intensity
- Harmonic analysis of tidal current and flow data
- Long-term prediction of tidal currents and speeds using harmonic constituents



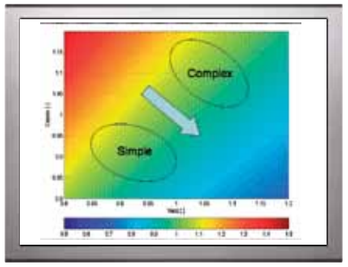
Wave site data analysis tool box

A program for the analysis of wave data, allowing the user to characterise the wave climate at a site. Functions include:

- Quality control and analysis of buoy data
- Shallow water modelling
- Calibration of modelled data against satellite and buoy measurements
- Determination of wave climate, variability and uncertainty
- Extremes analysis
- Weather windows

O2M: Optimising Operations and Maintenance

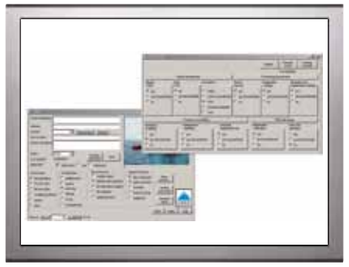
A tool for the optimisation of an operations and maintenance strategy for marine renewable arrays. The model allows, among other options, consideration of weather windows, vessel size, staffing options, availability of spares and wave climate. The cost of lost production due to device downtime is balanced against the cost of deploying a resource strategy, to find the optimum strategy for energy price.



Cost of Energy Modelling Tool

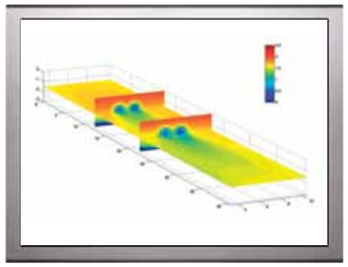
GL Garrad Hassan has a number of cost models, from the standard cost of energy calculator to more involved techno-economic modelling, although of course this type of tool needs to be used by experts with a core understanding of the limits of such a model.

Our incorporation of scaling factors and uncertainty analysis is central to many investor requirements. The suite of **GL Garrad Hassan** tools are designed to inform sophisticated financial modelling, as required by our clients.



Wave and Tidal Developer Database

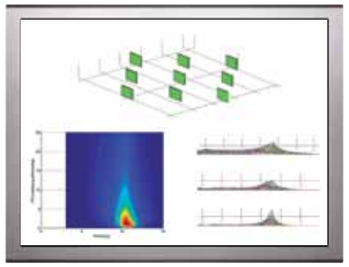
A database of wave and tidal device developers; this tool allows the user to rank technologies based on specified criteria. In this way, a weighted ranking specific to a site or project developer can be created.



Tidal array design tools

Tools for the design and optimisation of tidal arrays are under development. Key elements include:

- Array effect on global flow field
- Long-term prediction
- Spatial variation across the site
- Inter-array modelling (device interaction)
- Device operating characteristics
- Energy calculations
- Optimisation of array layout



Wave array design tools

Tools for the design and optimisation of wave energy converter arrays are under development. Key elements include:

- Array effects on wave field and individual WECs
- Long-term energy prediction
- Inter-array modelling (device interaction)
- Application of farm control strategies
- Energy calculations
- Optimisation of array layout

02C: Optimise Offshore Construction

A tool for the analysis of environmental delays and the optimisation of a construction sequence for marine renewable arrays.

The model breaks construction down into discrete operations which are simulated against an environmental time series. An assessment of the risk of the project, with regards to likely durations and delays, is undertaken through a Monte Carlo analysis.

Commercial software

As engineering consultants, the use of the best available tools is an essential part of our service. To support our analysis we make use of the following tools:

Hydrodynamic tools:
- Mooring analysis
- Boundary element methods for free surface interactions
- 3-d RANSE solvers
- Shallow water solvers

Finite Element Method (FEM) tools

CAD

Electrical system design tools

Additionally, **GL Garrad Hassan** works closely with other members of the GL Group with expertise in CFD and CAE tools.

The wealth of renewable energy experience at **GL Garrad Hassan** offers advantageous technology transfer opportunities to this sector

Mat Thomson (Head of Tidal Energy Group, **GL Garrad Hassan**):

"The next few years will be crucial in establishing marine energy as a significant contributor of energy from renewable sources. In order to reach this goal, however, a step change is needed to move from having demonstrators in the water to deploying commercial arrays. Developers' initial focus is on proving the survivability of their devices, but as the technologies develop the focus will move to improving performance and reliability."

GL Garrad Hassan continually strives to maintain its position at the forefront of the renewable energy field. In order to maintain this position and keep abreast of new developments, the company is heavily involved in not only participating in, but leading, R&D projects into many aspects of renewable energy. These include the development of models to predict the performance of wave and tidal arrays, the development of device design tools, innovative wave and tidal device controller design and implementation, dynamic modelling of multi-rotor systems, marine instrumentation, and operations & maintenance modelling.

GL Garrad Hassan has developed a number of industry standard tools for wind energy, including Bladed, WindFarmer, O2C, O2M, and **GL Garrad Hassan** SCADA Solution. Many of these tools have been or are being developed for wave and tidal devices and arrays, combining years of experience in wind energy with an in-depth knowledge of wave and tidal resource, devices and array systems.

Joao Cruz (Head of Wave Energy Group, **GL Garrad Hassan**):

"As for tidal, wave energy technology developers are at present trying to demonstrate their technology; we recurrently get involved in design or design assessment projects that emphasise this fact. The development of tools that allow such accurate assessment is therefore crucial, for both survivability and performance considerations. The extension of such methods and tools to the design of arrays of WECs (and their validation) will fill in a gap that would emerge in a post-demonstration scenario, as the absence of an array design tool would compromise the 2020 and 2050 targets."

Case Study: Performance assessment of wave and tidal array systems (PerAWaT)
Client: Energy Technologies Institute (ETI)

Performance Assessment of Wave and Tidal Array Systems (PerAWaT), is an Energy Technologies Institute (ETI) project led by **GL Garrad Hassan**, and including EDF Energy, EON, the University of Edinburgh, the University of Oxford, Queen's University Belfast and the University of Manchester. The project will develop a series of models to predict the performance of wave and tidal stream generator arrays.

ETI Chief Executive Dr David Clarke said: "Although the UK has huge marine potential, investment is being held back by uncertainty about the overall costs involved and the potential returns on investment in wave and tidal technologies. This project will deliver greatly improved modelling tools to provide more accurate forecasting of energy yields and reduce the uncertainty and investment risk faced by project developers when planning large scale wave and tidal energy schemes."

"It will build on existing knowledge to accelerate the development of sophisticated tools that will become essential as the marine energy industry matures. No single company or university would be capable of doing this work alone and the ETI has played a key role in bringing together a consortium of experts to deliver this critical work. It is an important step to unlocking the considerable potential of marine energy."

The Head of Marine Renewables at **GL Garrad Hassan**, Dr Robert Rawlinson-Smith, added: "Deployment of large scale arrays of marine energy conversion devices will only occur when project developers have sufficient confidence in the return on their investment. The ETI core objective of accelerating the commercial deployment of energy technologies that reduce greenhouse gas emissions will be addressed by this project, as it will both establish and validate numerical models capable of predicting the performance of wave and tidal energy converters (WECs and TECs) when operating in arrays. Once established, the models will enhance levels of confidence in the design of WEC and TEC arrays and therefore accelerate their large scale deployment."

"By accelerating deployment rates the project will directly address the ETI Marine Programme outcome goal of increasing deployment to 2GW by 2020 and 30GW by 2050. The PerAWaT consortium brings together universities, utilities and an engineering consultancy. In combination, this consortium will provide the skills and facilities necessary to significantly enhance our understanding of the performance of wave and tidal stream energy farms, and encapsulate that understanding in robust validated numerical models for use by the wider industry."

There is currently no independently developed software package or validated method of estimating the average annual energy production of a wave or tidal stream energy farm.

Unrivalled experience and understanding

GL Garrad Hassan has extensive R&D and device development experience which, when coupled with three decades of understanding in wind technology development and manufacture, makes it an ideal partner for those developing innovative technologies.

Designing for survivability of the device is, in the first instance, the highest priority. As the design and the device become more sophisticated, however, other factors increase in importance. For example, the reliability of devices operating not just offshore, but in submerged conditions, is vital to limit maintenance costs.

The control system plays a vital role both in maximising energy capture, and in mitigating loading by tailoring the dynamic response of the device structure to the environmental conditions.

GL Garrad Hassan has a multitude of specialists who regularly work together as a multi-disciplinary team to provide clients with design or analysis solutions. They also work in their individual areas of specialism where a client has very specific requirements. In this way, they are able to provide device developers and manufacturers with the range of services they require to create efficient, robust and cost-effective devices.

Particular concerns in the development of marine renewables are typically over the design of structures and moorings and riser solutions. Via the GL Group, **GL Garrad Hassan** is able to utilise specialist experts from GL Noble Denton, who possess expert knowledge on installation methodologies. Through this we are able to optimise the design to allow for the installation process to be built into the design model, therefore increasing safety and reducing costs. The in-house Metocean department and internationally-recognised Geotechnical experts are on hand to support and ensure that the right solution based upon existing conditions is provided to the client at the earliest stages of development.

Case Study: Dynamic modelling of multi-rotor system
Client: Tidal Stream Partnership

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As part of a collaborative R&D project, **GL Garrad Hassan** extended its in-house Multi-Body Dynamic Code (DYWIG) to:

- Create detailed models of marine environments including water depth, waves of arbitrary height and period, and currents
- Generate a full representation of hydrodynamic structural loading using Morison's equation and including hydroelastic feedback
- Represent hydrodynamic rotor loading using look-up tables of steady-state thrust and torque coefficients as functions of disc-averaged flow speed
- Represent lifting surfaces using look-up tables of lift and drag coefficients as functions of angle of attack
- Demonstrate ability to set initial conditions of structure (yaw, pitch and roll displacements and velocities)

Case Study: Due diligence
Client: Alstom Ocean Energy

W

GL Garrad Hassan provided technical due diligence to Alstom prior to their investment in AWS Ocean Energy. The 'hands on' involvement of **GL Garrad Hassan** specialists in technology development makes it possible for them to provide a robust assessment of the true costs and risks involved in new technologies. By developing constructive three way relationships, **GL Garrad Hassan** is able to act as both an interface and advisor, so that all parties gain from technical due diligence exercises. **GL Garrad Hassan** is able to mobilise the effort required for due diligence activities which are often undertaken in short time scales and are subject to significant commercial pressure.

Case Study: Design assessment and wave farm layout
Client: AW-Energy Oy

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AW-Energy Oy (AWE) has commissioned **GL Garrad Hassan** to perform an optimisation study focusing on single WaveRoller wave energy converter (WEC) units and arrays of WaveRollers. Firstly, **GL Garrad Hassan** used its in-house WEC modelling tool to optimise the WaveRoller design using various design variables and design constraints, such as aspect ratio, water depth, Power Take-Off (PTO) limitations and wave climate. Secondly, **GL Garrad Hassan** has developed a bespoke model of an array of WaveRoller WEC units (based on the study presented at the 2009 EWTEC conference) which allows the optimisation of the array layout and configuration, whilst estimating the performance and site-specific energy yield.

AWE's CEO John Liljelund said: "I can recommend **GL Garrad Hassan**'s wave team without the slightest hesitation. The co-operation between these two teams has been very fruitful and **GL Garrad Hassan**'s services and tools have provided a real value add and aid in our efforts to bring WaveRoller closer to a commercial success."

Case Study: Technology roadmap for device development and wave energy converter design
Client: Columbia Power Technologies LLC, Oregon, USA

W

Columbia Power Technologies LLC (Columbia Power), equipped with funding from the U.S. Department of Energy (DOE), has embarked on a research and development (R&D) initiative to develop, optimise, demonstrate and validate an intermediate-scale version of its Manta Wave Energy Converter device. **GL Garrad Hassan** has been tasked to review and analyse wave data at the scaled site, optimise the wave energy converter, develop control algorithms, and to provide real-seas control strategies and training. Additionally, **GL Garrad Hassan** provided services to the earlier phases of this project that included review and development of the technology roadmap, numerical modelling of the wave energy converter response and design optimisation, tank testing guidelines and on-site support during tank trials, and verification and validation of numerical model predictions.

Columbia Power President Bradford Lamb said "Experience has proven that working with a consortium of experts is the smartest way to operate in an R&D environment. Capital efficiency and speed are essential and collaboration with **GL Garrad Hassan**'s Marine Renewables Group has been vital to the project thus far. We look forward to their continued support."

Case Study: Energy yield assessment of tethered ocean current turbine
Client: Turner Hunt Ocean Renewables LLC (THOR)

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GL Garrad Hassan was commissioned to provide an independent assessment of the expected energy yield of the THOR device, a variable buoyancy tethered ocean current turbine, designed to extract energy from the currents found within the Gulf Stream. The analysis included quality checking of site data, characterisation of the resource, evaluation of the energy yield and expected losses, and uncertainty analysis.

GL Garrad Hassan offers comprehensive technical services across the project lifecycle

GL Garrad Hassan understands the diverse needs of the project developer, and supports these developers in understanding not only how renewable energy resources vary by region, but also how social, technical, environmental and regulatory constraints vary.

A crucial first step in assessing the viability of a potential site is the assessment of the available wave and tidal resource. Accuracy is paramount in the analysis of resource data, not only for the quantity of resource, but also its quality and location. Once the decision has been made to develop a site, the location of the array and the micro-siting of devices within it will greatly affect the output of energy generated by the array. It is therefore crucial that the array layout is optimised for energy yield.

Offshore renewable project construction represents a complex engineering challenge, and the costs of operating and maintaining arrays are considerable. This is particularly true for wave and tidal arrays, operating as they do in harsh and demanding environments. An appreciation of the requirements for construction and O&M, and an understanding of how the methodologies can be optimised, should feed into the project development process early on to prevent problems occurring at later stages.

GL Garrad Hassan offers developers a comprehensive range of technical services throughout the entire project lifecycle, and its project development experts coordinate with clients to provide a tailored service package which will provide solutions from the initial deployment methodology through to final decommissioning. Our in-house expertise, combined with the extensive knowledge in complex offshore operations from GL Noble Denton through the GL Group, places us in a world class position to be able to ensure that the project is installed in the optimum way. By early identification of the hazards and risks associated with the project we can incorporate these into the project procedures, and in association with our marine experts ensure that the right vessels are identified and inspected prior to installation. Through this we can significantly reduce the risks associated with this critical transition phase, reducing the risks of project damage or failure.

Our extensive relationship with the insurance underwriters also places us in the forefront of the provision of warranty services for the execution of these projects.

Case Study: Wave and tidal site selection in Chile
Client: Inter-American Development Bank

W&T

GL Garrad Hassan has been working with the Inter-American Development Bank, under the Sustainable Energy and Climate Change initiative, to identify priority areas for the development of marine energy projects in Chile. The definition of a priority area takes into account several positive attributes and constraints, combined with other relevant information, which are added to a specially created database to enable the objective selection of the most interesting sites.

Initial findings from the study estimate Chile's raw offshore wave power to be more than 100GW – many times the total capacity of the electricity system in Chile. The Chacao Channel was found to have the largest potential for exploitation of tidal currents, estimated to be several hundred MW.

While there are several levels of further work to undertake before embarking on a commercial project, these initial findings place Chile amongst the leaders of geographic regions that have conducted similar assessments of their raw wave and tidal capacity.

Proposed further stages of the study include ongoing data collection and analysis, identification of appropriate technologies and the development of demonstration projects.

Case Study: Development of techniques to assess resource, forecasting and O&M simulation at Wave Hub
Client: npower Juice

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GL Garrad Hassan secured funding to carry out an important new study for the Wave Hub project. The study developed and shared new analytical techniques in three areas: wave resource, short-term wave forecasting and operational simulation.

The wave resource work focused on the analysis of the short-term data gathered to date and culminated in a long-term prediction of the wave climate that can be used by device developers to estimate the energy output of machines to be deployed at the site. This was the first time that the MCP (Measure, Correlate, Predict) methodology, common in wind energy, has been implemented for wave energy. The results were peer-reviewed and presented at an international conference (OMAE).

GL Garrad Hassan's wind forecasting service, Forecaster, was trialled to predict sea-state conditions at the Wave Hub site to a horizon of 72 hours. The operations and maintenance at the Wave Hub were examined via special adaptation of an offshore wind industry simulation tool (O2M) to assess its suitability for wave energy projects.

Case Study: Wave and tidal technology review
Client: ScottishPower Renewables

W&T

GL Garrad Hassan assisted ScottishPower Renewables to identify a shortlist of wave and tidal developers. This was done using a database of over 160 wave and tidal concepts and a special plug-in tool, both of which were developed by **GL Garrad Hassan**. The tool allowed a weighted assessment of a series of scenarios that were driven by the client's development strategy.

Photo: Louise Forrest

Understanding the market and the risks, as well as the opportunities

Before entering a new market, it is vital to fully understand the risks as well as the opportunities. The detailed technical understanding of **GL Garrad Hassan**'s experts, formed through many years of supporting renewable investors, provides a solid basis on which to make decisions.

Due diligence, one of the many services required by investors and lenders, is necessary for both projects/portfolios and for companies themselves. Experts within the field are necessary to identify potential areas of risk, as well as possible means of technical and commercial mitigation. Similarly, an understanding of a company's position in the market, the technological capability of its design team, and an analysis of its competitors, is crucial before an investment decision is made.

In addition to an appreciation of the project and the company, the market as a whole must be understood. **GL Garrad Hassan**'s wide knowledge base, and the range of countries and markets in which it is actively involved, mean that it has a thorough grasp of the interplay between the various factors at work in a specific market which can affect the decision to invest.

Case Study: Marine renewable energy technical due diligence requirements
Client: The Carbon Trust

W&T

The Carbon Trust is actively investigating the status of and potential for wave and tidal stream devices, and recognises that if their potential is to be realised then it will be necessary to be able to obtain project finance from lenders. The Carbon Trust therefore requested that **GL Garrad Hassan** provide an outline technical due diligence report that could be used as a starting point for a due diligence study to raise project finance for marine renewables project in the future.

GL Garrad Hassan has been intimately involved in the technical due diligence of wind farms for many years and has provided independent assessments of renewable energy projects for lenders and investors for more operational wind farms than any other company. With this wealth of experience to draw upon, **GL Garrad Hassan** was therefore an ideal choice to develop due diligence requirements in relation to financing first projects for the emerging wave and tidal industry.

Front End Engineering Design (FEED) can mitigate risk and realise significant commercial savings

Many of the key decisions which determine the success of a project are taken early on in the development stages. Front End Engineering and Design (FEED) is a process by which the options available are explored, and their subsequent technical and commercial implications are evaluated. Undertaking a thorough FEED study early on can identify problems prior to engagement with the supply chain, thus mitigating risk and realising significant commercial savings.

GL Garrad Hassan has developed an extensive and advanced technical understanding of the requirements of owners and operators around the world, and uses this to maximise the potential of its renewable energy projects.

Case Study: Planning and optimising the construction and O&M strategy of tidal stream turbine arrays

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Presented at ICOE 2010 (International Conference on Ocean Energy)

The offshore operational costs of installing and maintaining tidal stream turbine arrays are considerable and are of great importance to the viability of the industry. In preparation for the continuing development of the marine renewables industry, **GL Garrad Hassan** has built on industry standard tools for the offshore wind industry to create two tools. The O2C tool has been developed for the analysis of environmental delays and the optimisation of a construction sequence. It breaks the construction down into discrete operations that are simulated against an environmental time series to obtain duration distributions of individual operations. A Monte Carlo analysis is used to obtain project durations from the operation duration distributions. The O2M tool is used to optimise an operations and maintenance (O&M) strategy. The O2M model balances the cost of lost production due to turbine downtime and the cost of the resources for a maintenance strategy, in order to find an optimum strategy.

Delivering unrivalled high quality strategic advice

GL Garrad Hassan is the world's largest independent renewable energy consultancy, with local experts in all the significant markets across the globe and technical competencies spanning the entire technology and project lifecycle. The company is uniquely positioned to understand the interplay between technology, policy, economics and regulation, and as a result, it is unrivalled in its ability to deliver high quality strategic advice of both a commercial and political nature.

GL Garrad Hassan's dedicated Strategic & Policy Studies group utilises its experience and expertise to inform Government and NGOs in policy-making decisions. **GL Garrad Hassan** assists these organisations in gaining a thorough understanding of policy and regulatory frameworks, by carrying out studies of policy best practices, and in providing support for developing renewable energy targets.

Case Study: Shetland Islands renewable energy strategy
Client: Anderson Solutions (Consulting) Ltd

In partnership with Anderson Solutions and O'Herlihy & Co., **GL Garrad Hassan** undertook renewable energy strategy and action plan development on behalf of HIE Shetland, Shetland Islands Council and Shetland Renewables Energy Forum (SREF). The purpose of the study was to move on from the previous renewable energy strategy created in 2004 by SREF, and to identify a direction for the development of renewable energy in Shetland.

GL Garrad Hassan's training courses have been informing renewable energy professionals for over 20 years

Courses

- INTRODUCTION TO WAVE AND TIDAL ENERGY CONVERSION
- INTRODUCTION TO WAVE ENERGY CONVERSION
- INTRODUCTION TO TIDAL ENERGY CONVERSION
- BESPOKE TRAINING COURSES FOR THE TIDAL BLADED SOFTWARE

Duration: One day

GL Garrad Hassan's training courses have been informing renewable energy professionals for over 20 years, and have been conducted in countries including the UK, Portugal, Spain, Canada, and the USA. The vast specialist technical and engineering expertise retained within the company has been honed to develop both packaged and bespoke training courses that deliver understanding to people at all stages of their career. Courses are delivered by specialist staff who are leaders in their individual fields and, when not training, are heavily involved in **GL Garrad Hassan**'s commercial consultancy work and R&D projects.

Each of the above courses is tailored for professionals who wish to increase their knowledge of the key issues associated with wave and tidal energy conversion technologies. They provide a detailed overview of the fundamental principles behind the main technological solutions to converting wave and tidal energy into electricity. The courses also explain the key methodologies applied to evaluate energy resource, device site suitability and device data, as well as addressing hydrodynamic modelling techniques (both numerical and experimental) and details of several power conversion mechanisms. Each course draws on examples of **GL Garrad Hassan**'s R&D and full-scale real seas experience to date.

Who should attend?

Project developers, device developers, lenders, network operators and regulators, R&D institutions, leading test centres and other professionals who wish to benefit from **GL Garrad Hassan**'s technical and commercial knowledge in the field.