

# DEVELOPMENT OF A DESIGN TOOL FOR TIDAL CURRENT TURBINES

Graeme McCann, Robert Rawlinson-Smith  
Garrad Hassan and Partners Ltd., Bristol UK

## ABSTRACT

With Support from the DTI New and Renewable Energy Programme, Garrad Hassan (GH) has begun work on a project to develop a design tool for tidal current turbines which will be significantly more sophisticated and accurate than the calculation methods presently available to the industry. This paper describes the work undertaken in the development of the new design tool and, in the context of the lessons learned from the wind turbine industry, points to the features of the model that will require validation.

## INTRODUCTION

The development of tidal current turbines has now reached the point where prototype systems are operational. Certification and due-diligence review of tidal current turbines will inevitably be required as part of the commercialisation process and these will demand validated design analyses. Given that the first projects to be developed will attract much public scrutiny it is crucial that the technology has a sure footing if it is to attract project developers and investors.

This project will provide the first integrated design tool to meet the needs of the emerging tidal turbine industry. The tool will be developed to be relevant to all forms of axial flow tidal current turbines and will not be tied to any one design configuration.

Over the past twenty years, GH has played a key role in the development of mathematical models to represent the behaviour of wind turbines. This work has resulted in the GH *Bladed* computer program which offers reliable models of wind turbine behaviour and provides the quality, robustness and ease of use required by designers. *Bladed* has become a “wind industry standard”, certified by Germanisher Lloyd and used by more than fifty commercial organisations for the design and certification of wind turbines.

The *Bladed* code provides an excellent basis for the development of a tidal current turbine design tool. It is anticipated that the design tool resulting from the work described in this paper will have as beneficial an impact on the development of tidal stream technology as the *Bladed* code has had in the wind industry.

## PROJECT AIMS AND OBJECTIVES

The objective of the work reported here is to undertake a major advance in the technology of tidal current turbine design calculations, significantly beyond those available to the industry at present. Although existing calculation methods may be suitable for prototype developments, this advance is important in order that the manufacturers are adequately equipped to tackle the complex problems associated with the design of commercial tidal current turbines which are reliable, structurally optimized, and cost-effective. The innovation of the project is that it represents the first ever attempt to develop a sophisticated design tool to meet the needs of this emerging industry.

The project can be broken down into the following work packages:

- Development of a comprehensive specification of requirements for the tidal turbine design tool through consultation with industry and academia.
- The development of the wind turbine code *Bladed* to adapt, and where necessary, include new engineering models to meet the requirements of the new industry.
- Development of the user interface.
- Validation of the new engineering models using measured data from a prototype tidal current turbine.
- Proving of the new design tool by undertaking design trials and beta testing.
- Final development, documentation and dissemination of the design tool and project results.

The interaction of the work packages is illustrated in Figure 1.

## INDUSTRY CONSULTATION

To determine a specification of requirements for the tidal current turbine design tool, GH canvassed the opinions of a broad range of commercial organisations and academic research groups involved in various aspects of tidal device development, based both in the UK and overseas. The communication took the following forms:

### **Questionnaire**

A questionnaire, including a description of the project, was supplied to more than twenty parties identified as having a relevant interest in tidal stream technology. The questionnaire was designed to establish the technical requirements such organisations would have of a design tool. The questionnaire also provided an opportunity for the parties to record any general comments or ideas that they believed to be relevant.

### **Meetings**

Meetings were held with representatives from a number of the parties contacted through the questionnaire. This allowed for detailed discussion of the design tool specification requirements.

The feedback from this communication, coupled with GH in-house experience of the wind industry, has formed the basis of the tidal current turbine design tool requirement specification.

## REQUIREMENT SPECIFICATION

### **Preliminary Specification**

The preliminary specification of the tool is based upon the *Bladed* (Bossanyi, 2003) code for wind turbine modeling as many of the features are directly transferable. These include detailed models of the:

- Rotor
- Support structure
- Drive train
- Generator and electrical systems
- Control systems
- Flow field
- Structural dynamics

Examples of the data input screens provided by the Windows based Graphical User Interface are shown in Figures 2 and 3.

Sophisticated calculation output and post-processing facilities are also included. Figure 4 provides a graphical overview of these capabilities.

### **Extension of Engineering Models**

The specification requirement study identified a number of mathematical models that would need to be extended or developed to suitably model marine current turbines.

#### *Blade element-momentum method*

The blade element – momentum (BEM) model currently implemented in *Bladed* (Bossanyi, 2003) assumes that the stream-tube develops within an infinite fluid domain and hence boundary effects are unimportant. In the specific case of tidal stream devices, it is questionable whether this assumption remains valid. It is plausible that typical devices with rotor diameter ~15m will be located in tidal environments with water depth as low as 25m. The rotor diameter is thus potentially a significant proportion of the total water depth, suggesting that boundary effects from both the sea-bed and sea-surface may become influential.

A model that includes these influences will be developed and eventually tested against device measurements.

Furthermore, it will be important to determine the required complexity of the revised BEM model. Specifically, it remains to be determined whether the sea-surface can be suitably modelled as a rigid boundary or if a more complex dynamic boundary condition is necessary.

#### *Cavitation*

The ability of the design tool to predict the type and occurrence of cavitation inception will be important, given the nature of the operating environment.

No fundamental difficulties exist in predicting the occurrence of the phenomenon. However, a more detailed description of the hydrofoil properties will be necessary than is currently required for airfoils in *Bladed*. Specifically, minimum pressure coefficients ( $C_{pmin}$ ) are needed to determine the localised pressure distribution over the rotor blades. These can either be obtained from the blade manufacturers or calculated using standard software packages (e.g. XFOil).

#### *Hydrodynamic loading of structure*

The hydrodynamic loading of the support structure will be modelled using Morison's Equation (Morison et al, 1952). This includes consideration of inertial (added mass) effects.

Modelling of the rotor will involve developing an understanding of unsteady hydrofoil behaviour, considering how these concepts relate to the unsteady aerodynamic models already implemented in *Bladed*.

This understanding will be developed through further consultation with academics working in this research area.

#### *Tidal flow turbulence*

*Bladed* represents the turbulent structure of wind flow using standard spectral models. The wind turbine rotor disk is ‘covered’ by a grid of discrete points, each of which has an individual time history of wind speeds. The wind model is generated such that each time history has the correct single-point wind turbulence spectral characteristics and each pair of time histories has the correct cross-spectral or coherence characteristics.

In the context of tidal stream devices, the aim is to model the turbulent tidal flow in a similar manner. However, corresponding standard spectral models for tidal flow do not, to date, appear to exist. Determining the nature of such models and implementing them will form an important aspect of the design tool development. This is likely to be achieved through close consultation with academics working in this research area.

There is also a concern that tidal flow turbulence characteristics may be shown to be site-specific, and thus difficult to describe using standardised models.

#### *Buoyancy forces on submerged members*

Submerged structural members will be acted upon by a pressure from the surrounding fluid, creating a buoyancy force proportional to the volume of fluid that the member has displaced. This effect will be accounted for using a suitable model.

#### *Combination of wave-currents*

To model the complexity of the operating environment adequately, it will be necessary to model the combined effect of waves and currents in time domain simulations. *Bladed* (Bossanyi, 2003) already offers this capability for offshore wind turbines, where waves and currents impinge on the support structure. This feature will be extended to model the water particle kinematics acting on the tidal stream turbine rotor.

The total unsteadiness in the flow experienced by the turbine rotor and support structure will therefore be a sum of wave effects and background turbulence.

Furthermore, a Doppler effect is observed when surface waves and current velocities interact. The

mean current velocity alters the apparent wavelength of the surface waves, as observed at a fixed reference point (eg. a tidal stream turbine). It is proposed that this Doppler shift may be modelled by simply altering the dispersion relation already in *Bladed* (Bossanyi, 2003) which relates the wavenumber ( $k$ ) and wave frequency ( $w$ ).

$$w^2 = gk \tanh kd \quad \rightarrow$$

$$(w - kU \cos \alpha)^2 = gk \tanh kd \quad (1)$$

As well as the tidal and wave-induced loading on the structure, wind loads may be observed on surface-protruding members. A model to account for this will also be developed.

## TOOL VALIDATION

To validate the models described above, a range of environmental and device measurements will be required. This represents the fourth step in the work package described in Figure 1.

The validation study will require a full parametric description of the device and its control system. Further environmental and device measurements needed are detailed below.

### **Environmental Measurements**

- Current measurements (flow speed / direction distribution, turbulence intensity, density, shear profiles, inclination angles)
- Wave measurements (significant wave height, wave period, instantaneous surface elevation)
- Wind measurements (flow speed / direction distribution, density)

### **Device Measurements**

- Electrical power output
- Rotor speed
- High-speed shaft speed
- Blade pitch angles, all blades
- Yaw angles (if applicable)
- Control system status signals
- Blade root bending moments all blades
- Blade distributed bending moments on (minimum) one blade
- Support structure distributed bending moments

## PROGRESS TO DATE

A detailed requirement specification for the new tidal turbine design tool has been finalized. This has been made possible in no small part due to the open and

helpful consultation of a wide number of industrial and academic organizations.

On the basis of this specification, enhancement and development of the necessary engineering models is underway. Progress has been made in modeling the hydrodynamic loading of the rotor, and identifying a suitable model by which to predict cavitation inception.

Other work has focused on assessing the application of combined blade element momentum theory to tidal turbines. It is concluded that more fundamental research into this area is required to identify any corrective terms that may be necessary to adapt the underlying equations.

The issue of tidal current turbulence has also been identified as an area where more fundamental research is needed. The importance of this issue is inferred by the authors from the significant influence flow field turbulence has on wind turbine loading. Accurate modeling of tidal current turbines is likely to depend on valid turbulence models of the marine environment.

### CONCLUDING REMARKS

An overview of a project to develop a sophisticated design tool for tidal current turbines has been presented.

### ACKNOWLEDGMENT

The authors wish to acknowledge the support of the UK DTI New and Renewable Energy Programme for funding of the project.

### REFERENCES

Bossanyi E A, "GH Bladed Theory Manual", GH & Partners Ltd, 2003.

Bossanyi E A, "GH Bladed User Manual", GH & Partners Ltd, 2003.

O'Brien M.D. and Morison J.R., "The forces exerted by waves on objects." Trans. of the American Geophysical Union, Vol. 33, No. 1, 1952.

<http://raphael.mit.edu/xfoil/>

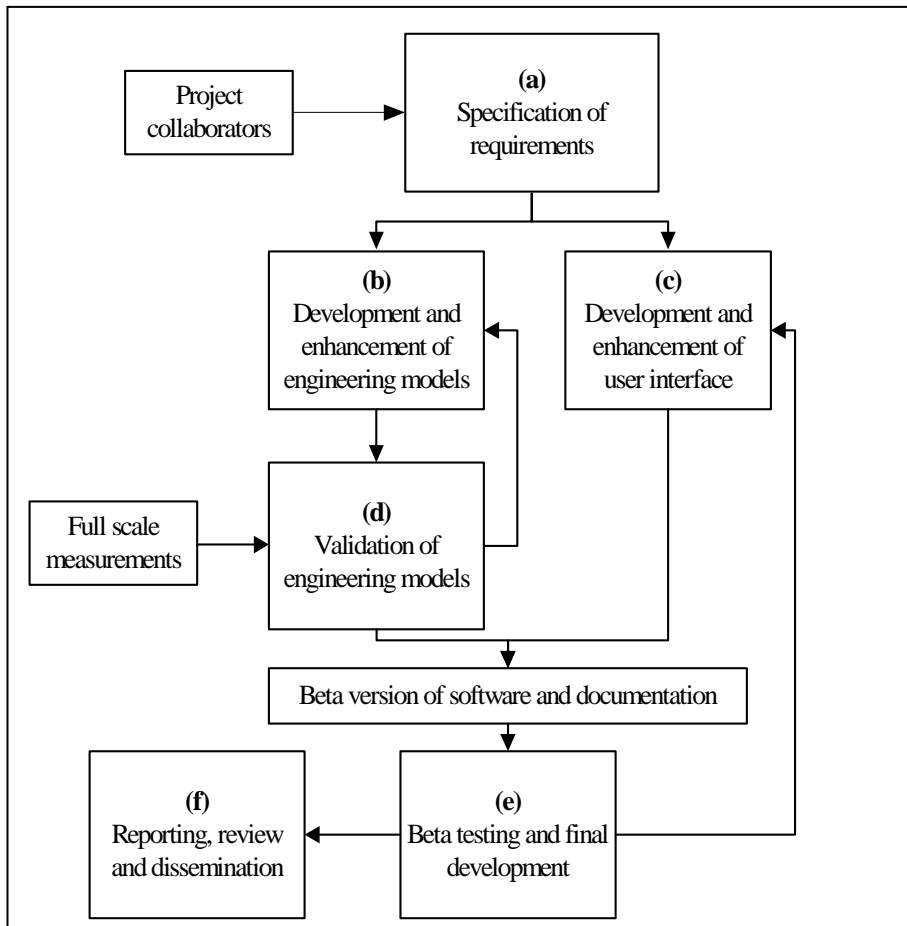


Figure 1 Flow diagram of tidal turbine design tool development work package.

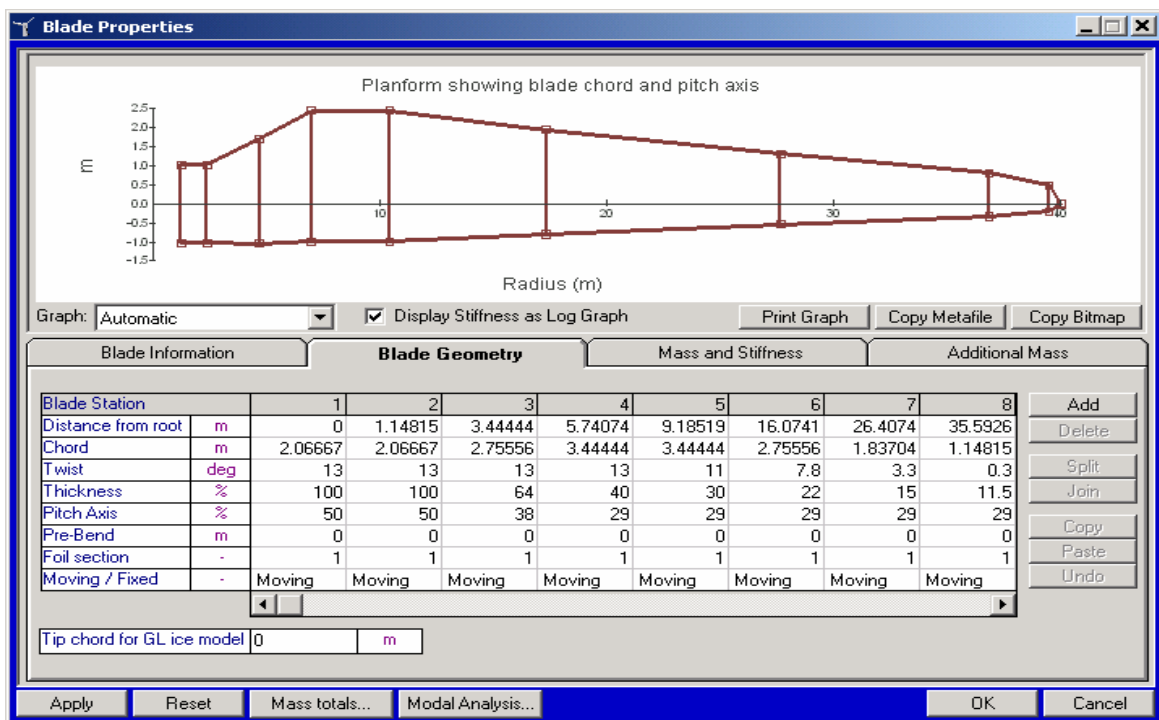


Figure 2 Blade description input screen

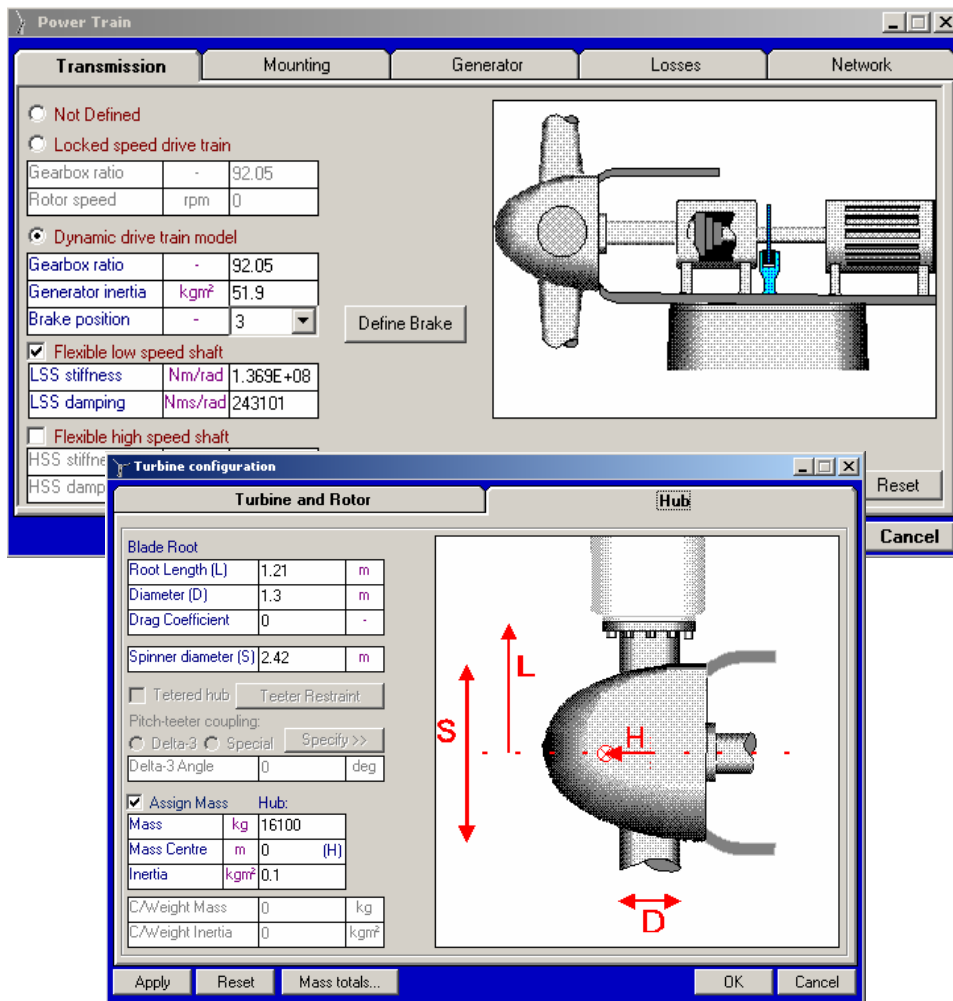


Figure 3 Drive train and hub data input screens

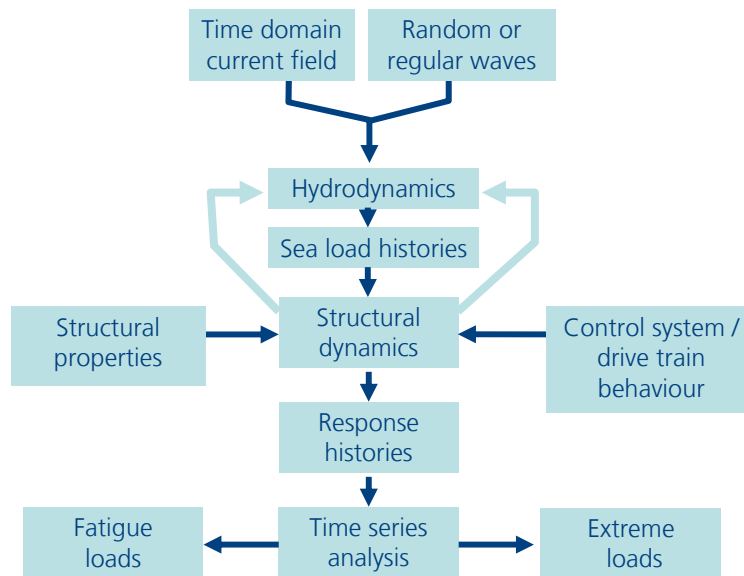


Figure 4 Flow diagram of Bladed simulation specification