Composite Tidal Turbine Design: From the hydrodynamic efficiency to the structural safety of the MJM concept

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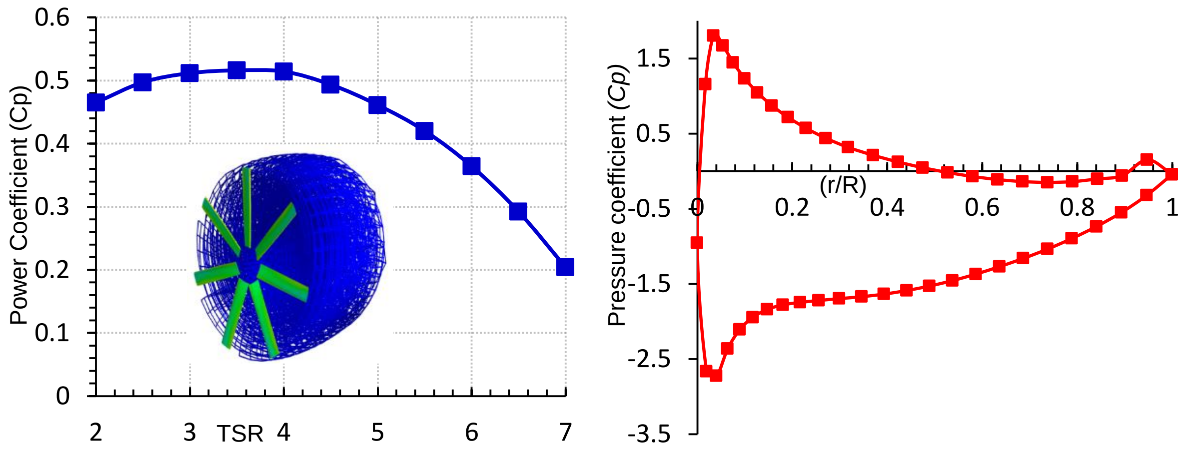
ABSTRACT

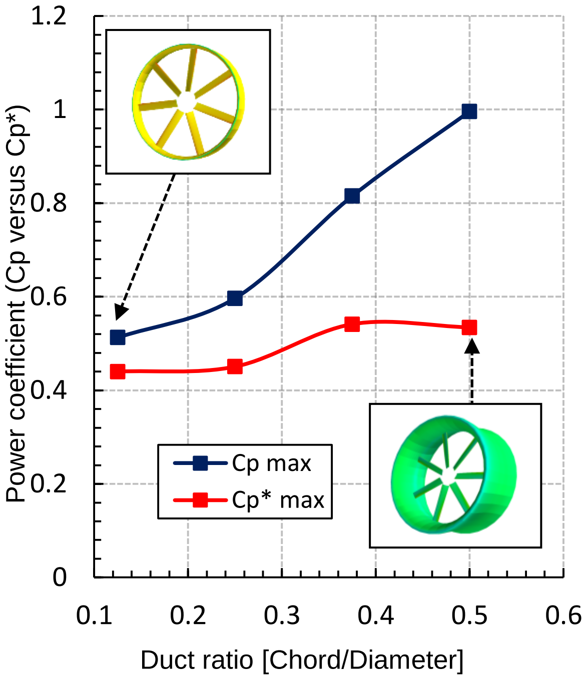
The concept of underwater turbine, called tidal current turbine, designates the device which allows the conversion of kinetic energy produced by marine currents into electric energy. The present study shows that the world of marine propellers presents an interesting avenue of research with regard to the hydrodynamic behaviour of tidal current turbines. As a marine propeller has to be adapted to a specific ship, a tidal current turbine has to be adapted to a specific site [1]. We chose the most promising site on the French coasts, the race of Alderney. The main numerical tool is a propeller code based on the potential flow model. Putting aside the structure constraints, the design of tidal turbine is restricted by the hydrodynamic efficiency which means that flow separation and cavitation occurrence are to be avoided. An optimization procedure has allowed us to obtain a bare turbine geometry presenting a power coefficient (Cp) reaching 88% of the Betz (see Figure **1**).



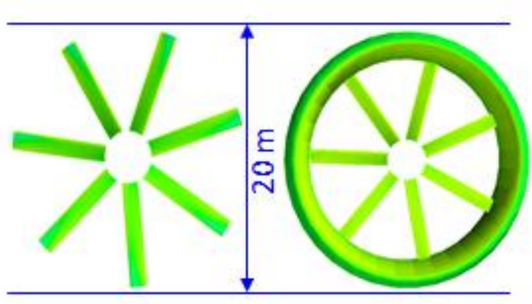
(a) Bare turbine hydrodynamic performance *(b) Pressure coefficient at TSR=4*

Figure 1: Hydrodynamic design of the bare turbine

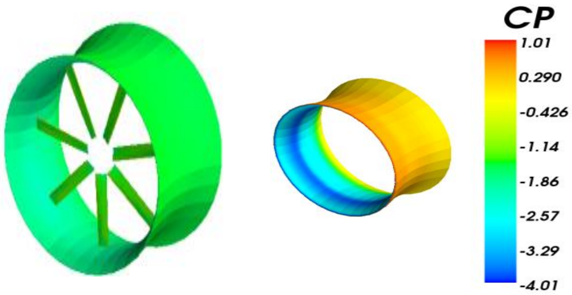
It has been suggested that the addition of a duct can significantly increase the power output of the turbine [2]. In this paper, the authors show that to properly assess the hydrodynamic benefits of a ducted design, a constant overall cross-section area has to be considered (Cp*). The optimization of the duct leads to an additional power output of 20% compared to the bare turbine and respecting a constant overall cross-section area of the ducted configuration when computing the power coefficient using Cp* definition (see Figure **2**).



*(a) Comparison between Cp and Cp**



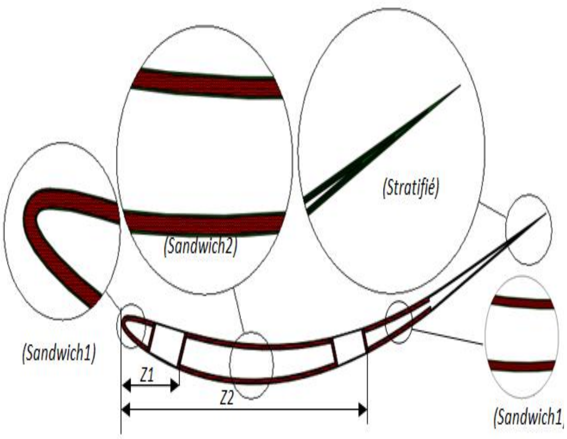
(b) Bare and ducted tidal turbine at the same overall cross section of 20m



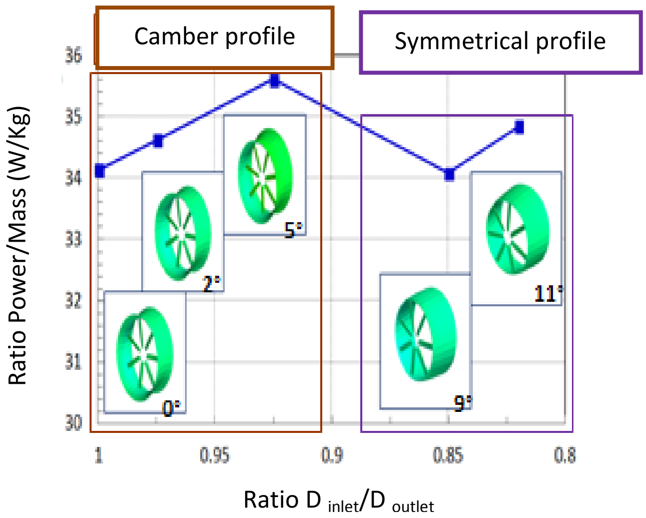
(c) Final ducted turbine design (left) and hydrodynamic pressure (right)

Figure 2: Design assessment of the ducted configuration

The second part deals with the design of the duct to find a balance between hydrodynamic performance and structural integrity using composite materials. However several iterations of material distribution have been performed to satisfy two main criteria. These criteria are the maximum deflection ($\varepsilon_{allowable} < 2\%$ of the chord) and the Hashin failure criteria. This approach leads the authors to introduce the ducted configuration presenting the best ration ‹‹power/mass», see Figure **3**.



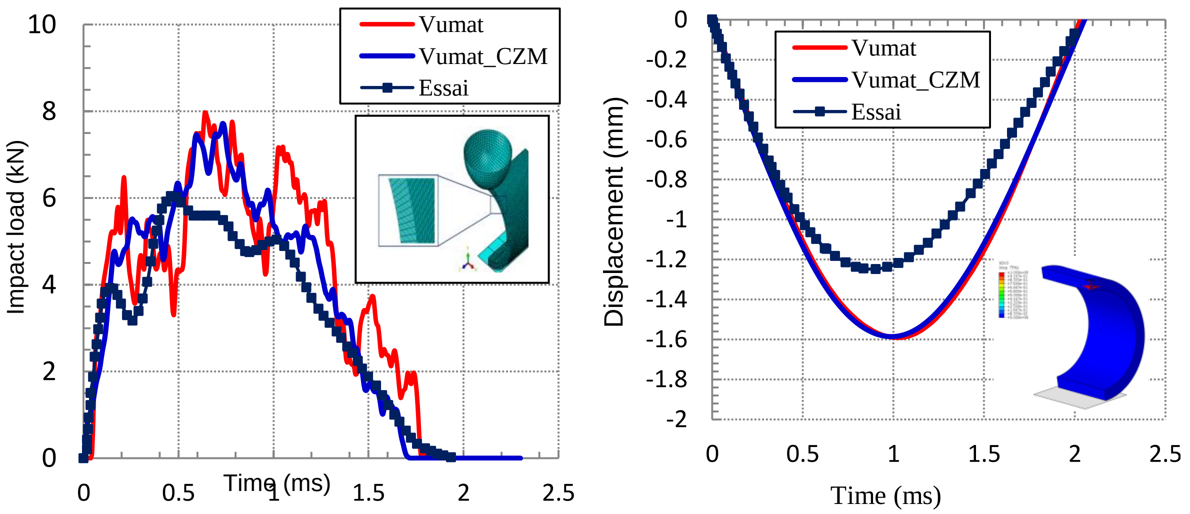
(a) Final iteration using the maximum deflection and the Hashin failure criteria



(b) Duct ratio <power/Mass> versus <D_{inlet}/D_{outlet}>

Figure 3: Structural design of the ducted configuration using composite materials

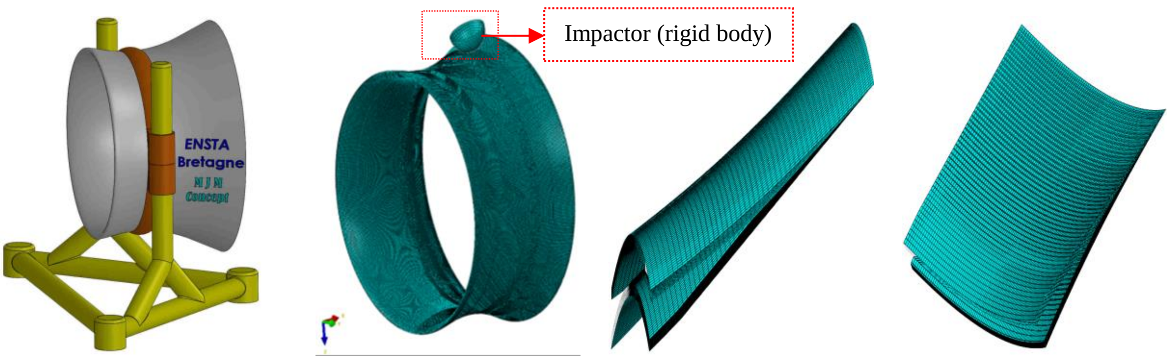
The third part of this work presents a numerical study of the dynamic behaviour of an all composite ducted tidal turbine. The numerical analysis has been performed by means of advanced numerical models implemented into Abaqus/Explicit. The interlaminar damage was modelled using the cohesive zone model (CZM) available in Abaqus/Explicit. On the other hand, the modelling procedure in term of intralaminar damage model was implemented using the VUMAT subroutine which has been validated through comparison with experimental data available in [3], as shown in Figure 4. Several comparisons for various impact velocities have been performed in [4].



(a) Impact force *(b) Displacement*

Figure 4: Comparison of experimental data (Essai) and numerical results (Vumat_CZM) under impact energy of 5.20 J (V=2.5 m/s)

The main objective of the third part is to propose a structural design methodology leading to improve the design safety and reduce the certification cost of ducted tidal turbine, keeping in mind a commercial scalability of the MJM[1] concept. The proposed approach reveals some interesting points concerning the severity of the impact damage and the safety of the duct (Figure **5**). The computations performed in this study concern only the degradation of the zone in contact with the impactor (Figure 5 (c)) and the region in front of it (Figure **5** (d)) but the procedure could be applied to other zone of the duct regardless of the impact scenario.



(a) Final design of the MJM Concept *(b) Impact scenario in the trailing edge area* *(c) Substructure 1using 3D elements* *(d) Substructure 2 using 3D elements*

Figure 5: Dynamic approach proposed for the assessment of the damage occurrence

[1] MJM concept : Mahrez, Mostapha & Jean-Marc Water Turbine Design

REFERENCES

[1] J.-M. Laurens, M. Ait-Mohammed and M. Tarfaoui, "Design of bare and ducted axial marine current turbines," *Renewable Energy*, vol. 89, pp. 181-187, 2016.

[2] A. M. Mahrez, M. Tarfaoui and J.-M. Laurens, "Numerical Investigation of Bare and Ducted Horizontal Axis Marine Current Turbines," in *5th International Conference on Ocean Energy ICOE2014-November 4-6*, Halifax, 2014.

[3] M. Tarfaoui, P. B. Gning, P. Davies and F. Collombet, "Scale and Size Effects on Dynamic Response and Damage of Glass/Epoxy Tubular Structures," *Journal of Composites Materials*, vol. 41, pp. 547-558, 2007.

[4] Mahrez AIT MOHAMMED, "Study of Composites Ducts for Optimal Design of an Horizontal Axis Tidal Turbine," PhD Thesis ENSTA Bretagne, January 2017.