Analysing Fibre Composite Designs for High-Solidity Ducted Tidal Turbine Blades

Mitchell G. Borg[1], Qing Xiao[1,*], Steven Allsop[2], Atilla Incecik[1], Christophe Peyrard[3]

University of Strathclyde[1], University of Edinburgh[2], EDF R&D[3]

Abstract

This study elaborates a one-way fluid-structure interaction numerical model utilised in investigating the structural mechanics concerning the rotor blades comprising a ducted high-solidity tidal turbine. Coupling hydrodynamic outcomes as structural inputs in effort of acknowledging the most applicable setup, distinct designs are investigated, solid blades and cored blades, implementing fibre-reinforced composite materials, analysed within criteria related to blade axial deformation, induced radial strains, and rotor specific mass.

Methodology

- A fluid-structure interaction framework was developed consisting of a validated rigid blade-resolved hydrodynamic mathematical model coupled with a blade-isolated structural mechanics model [1]

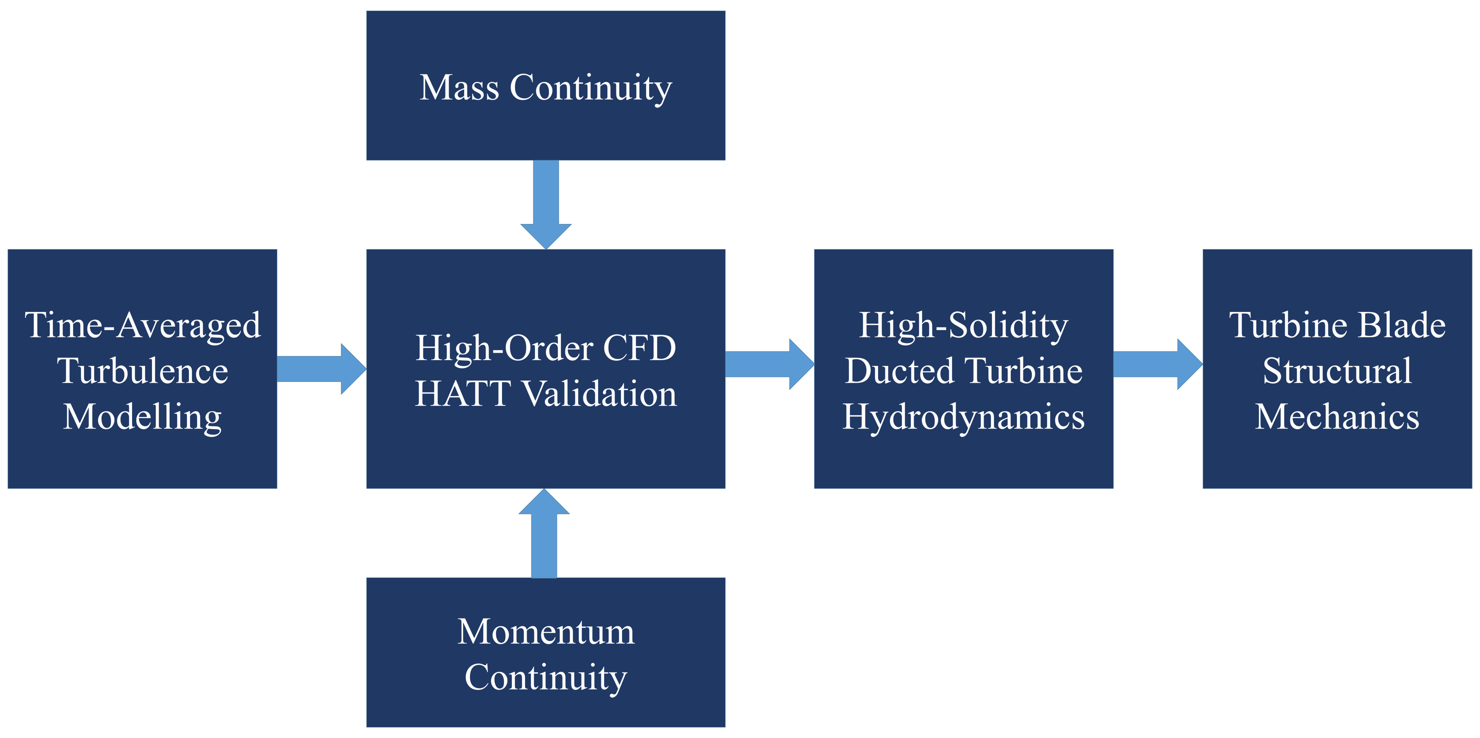
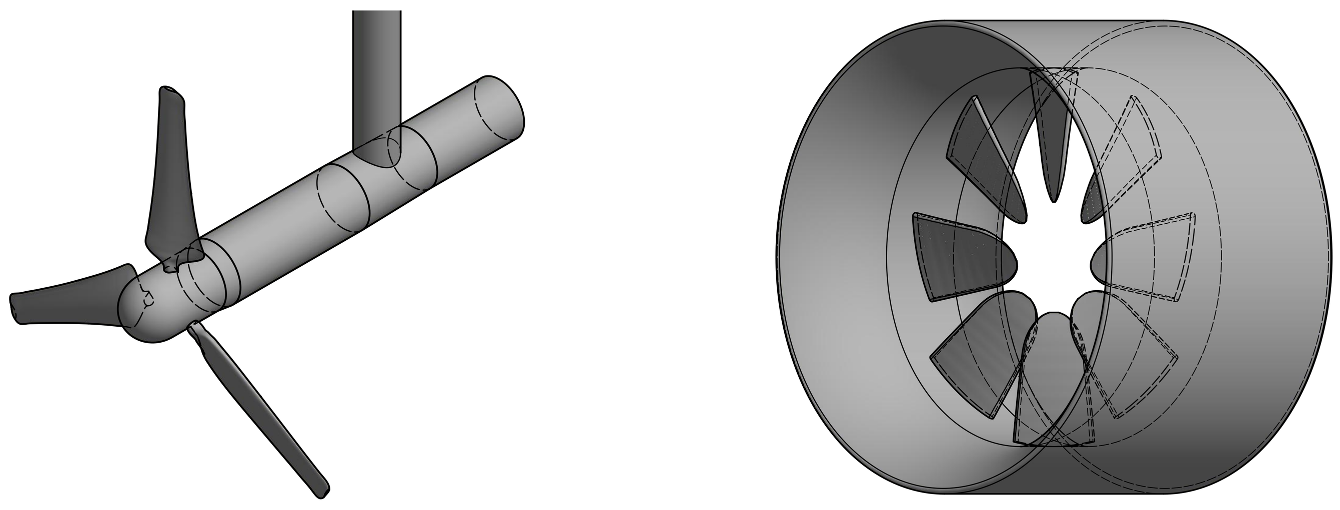


Figure 1: Ducted Turbine Fluid-Structure Interaction Framework Layout

- The real-scale URANS-CFD model was implemented to analyse the hydrodynamic performance of a bidirectional, high-solidity ducted tidal turbine in aligned and yawed flow
  - Hydrofoil geometry was provided by EDF R&D; similar to the design of the OpenHydro PS2 device



Three-Bladed Horizontal-Axis Turbine [2] — Ducted High-Solidity Turbine

Figure 2: Turbine models utilised for the numerical hydrodynamic analyses

- The 7-equation RSM turbulence model was utilised to close the Navier-Stokes equation and analyse the anisotropic flow domain

$$\rho\frac{\partial \tau_{ij}}{\partial t}+\rho U_k\frac{\partial \tau_{ij}}{\partial x_k}=\frac{\partial}{\partial x_k}\left[\left(\mu+\frac{\mu_T}{\sigma_k}\right)\frac{\partial \tau_{ij}}{\partial x_k}\right]-\rho P_{ij}-\rho\Pi_{ij}+\frac{2}{3}\beta^*\rho\omega k\delta_{ij}-2\rho\omega_k\left(\tau_{jm}\epsilon_{ikm}+\tau_{im}\epsilon_{jkm}\right) \quad (1)$$

$$\rho\frac{\partial \omega}{\partial t}+\rho U_j\frac{\partial \omega}{\partial x_j}=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_T}{\sigma_k}\right)\frac{\partial \omega}{\partial x_j}\right]+\alpha\frac{\rho\omega}{k}\tau_{ij}\frac{\partial U_i}{\partial x_j}-\beta_0 f_\beta\rho\omega^2 \quad (2)$$

- The CFD outcomes were employed as boundary condition inputs for the FEA modelling in analysis of the fibre-composite blade designs

Table 1: Material properties adopted in the structural numerical model

Material	E_1 (GPa)	E_2 (GPa)	G_{12} (GPa)	ν_{12}	Density (kg.m^{-3})	Design
DB GFRP	22.0	22.0	2.7	0.30	1850	Solid
UD GFRP	38.8	10.0	2.7	0.30	1950	Cored
Corecell	0.044	0.044	0.020	0.30	65	Cored

Results of the Fluid-Structure Interaction

- The resultant pressure distribution along the turbine blades was primarily evaluated via the high-order hydrodynamic URANS-CFD analyses

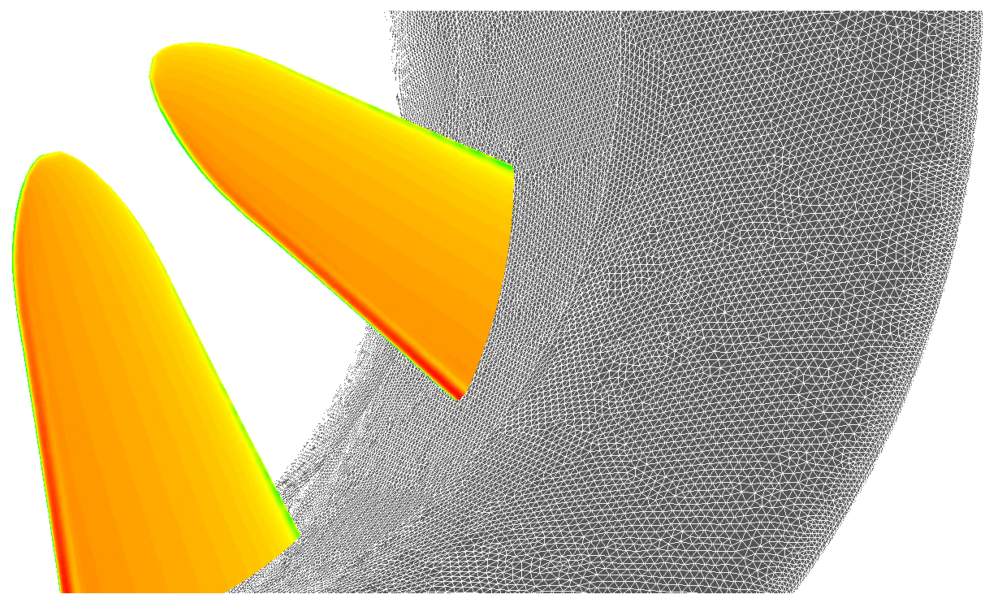


Figure 3: Pressure Distribution along the Turbine Blades; $U_\infty = 4$ m.s^{-1}, $TSR = 1.75$

- By transferring the pressure distribution data, the structural response of the solid and cored blades was established within the considered TSR range

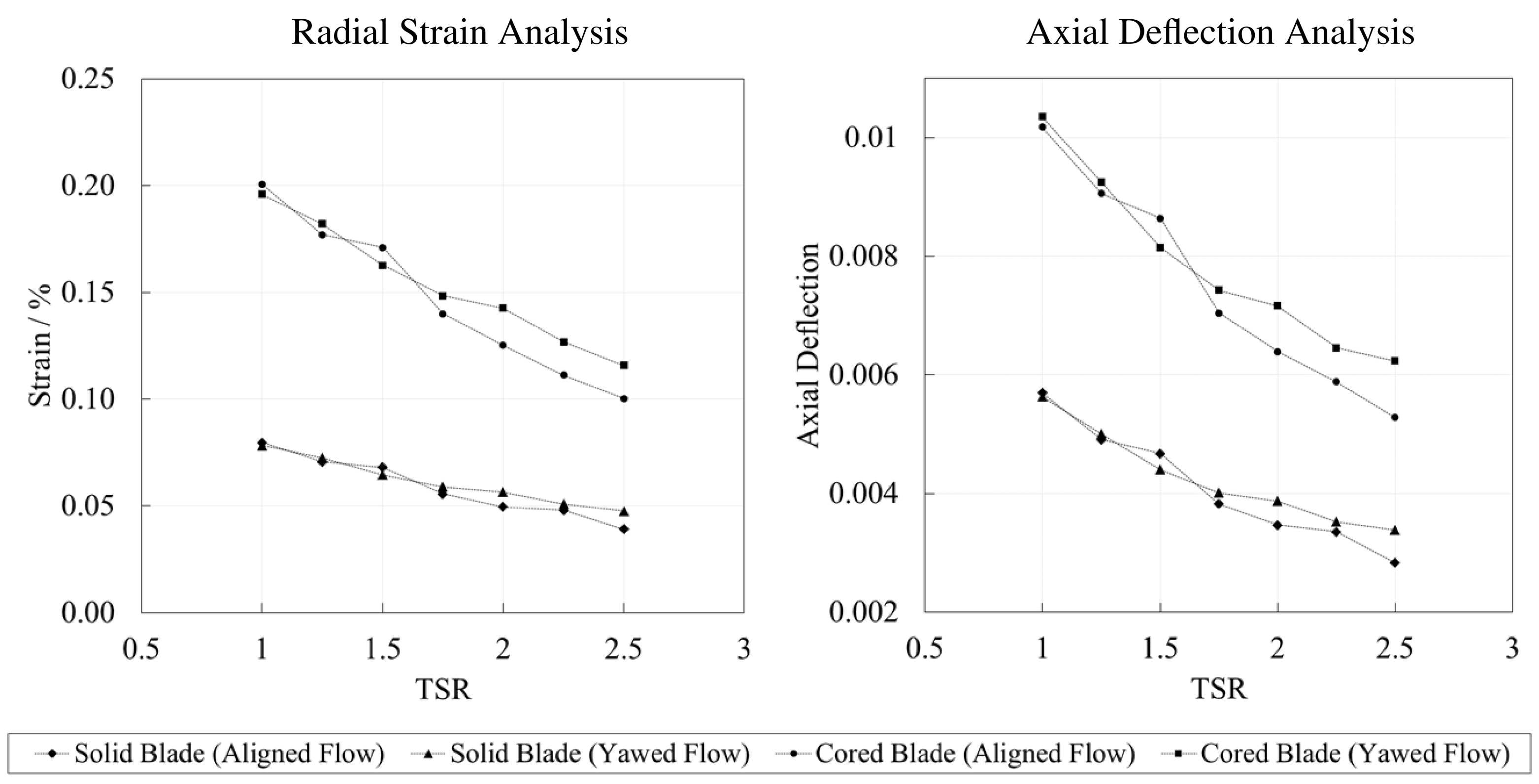
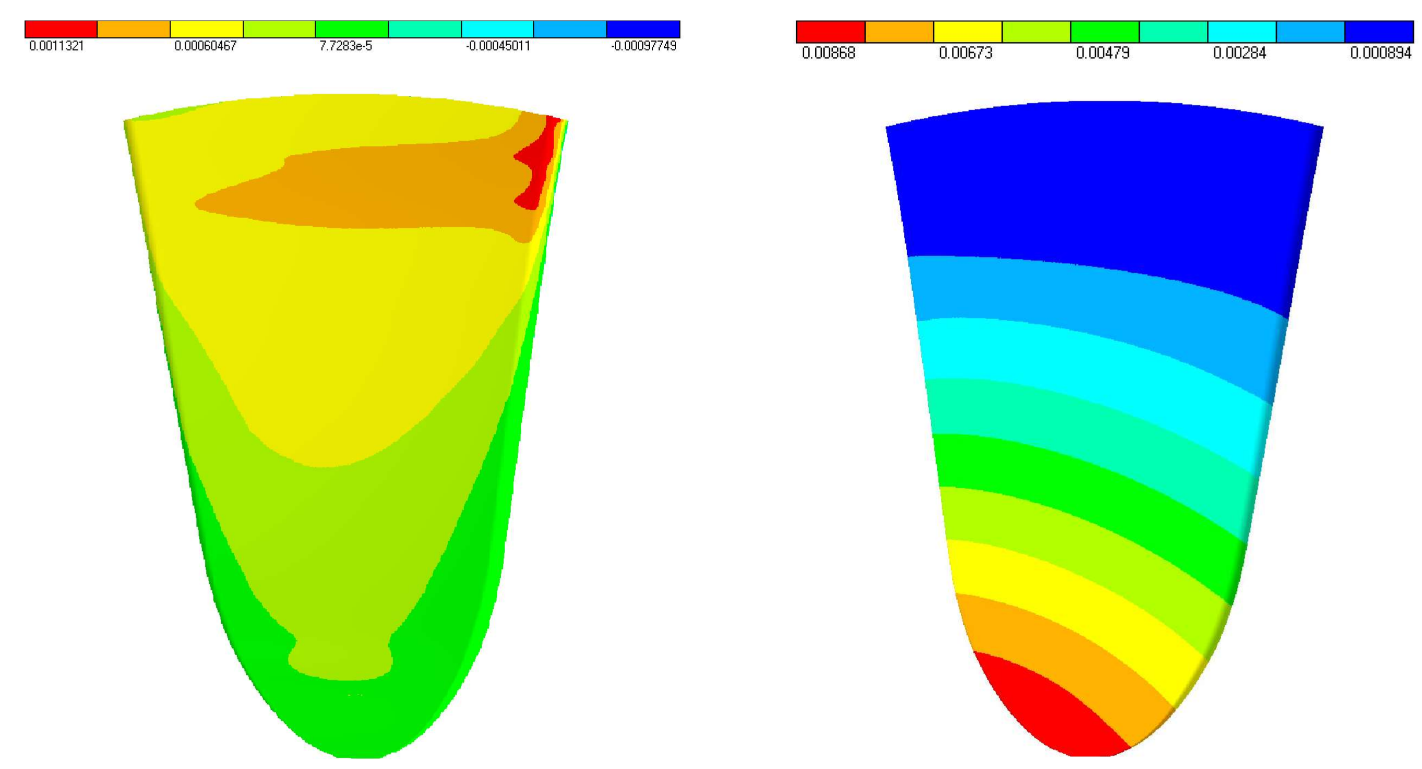


Figure 4: Structural Response of the Ducted Turbine Blades in Aligned and Yawed Flows

- A qualitative analysis of the response was carried out on the surfaces of the blades to acknowledge the strain distribution and deflection orientation



Radial Strain Analysis — Axial Deflection Analysis

Figure 5: Radial Strain and Axial Deflection Blade Analysis; $U_\infty = 4$ m.s^{-1}, $TSR = 1.75$

Conclusions & Evaluation of the Blade Design

- The outcomes depicted approximately double the axial deflection for a cored blade, with four times the degree of strain, and a fourth of the specific mass in comparison to a solid blade
- In consideration that the blade response of the cored design is within its structural property limits, the cored blade was established to be the preferred design

[1] M. G. Borg, Q. Xiao, A. Incecik, S. Allsop, and C. Peyrard, "A Numerical Performance Analysis of a Ducted High-Solidity Tidal Turbine," Renewable Energy (under review).

[2] P. Mycek, B. Gaurier, G. Germain, G. Pinon, and E. Rivoalen, "Experimental Study of the Turbulence Intensity Effects on Marine Current Turbines Behaviour," Renewable Energy, vol. 66, pp. 729-746, 2014.