Tidal Stream Turbine Modelling using High Performance Computing

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Introduction

With the world supply of oil and gas fast depleting, significant interest is growing towards renewable energy. One such major source is the untapped energy coming from oceans in the form of tidal or wave energy. However, there is limited understanding of how the wakes of marine hydro kinetic devices such as tidal stream turbines (*TST*) are affected by the ambient turbulence of the tidal flows. Full scale experimental or field measurements of such devices are both costly and extremely difficult. To complement field trials, detailed insight into the flow physics of turbulent flow, turbine loading and wake dynamics field trials can also be obtained by Computational Fluid Dynamics. Such complex coupled problems require High Performance Computing. Our research analyses the suitability of employing massively parallel *CFD* for horizontal axis *TST* load predictions and wake analysis to enable efficient design optimization.

Project Breakdown/Milestones

- Implementation of a new sliding mesh technique in Électricité de France (*EDF*) open source *CFD* solver (*Code_Saturne*) to enable simulations of rotors within a channel.
- Benchmarking a lab scale Tidal Stream Turbine (*TST*) model for optimized code modifications for High Performance Computing (*HPC*).
- Implementation of moving free surface boundary in *Code_Saturne* to model wave motion, thereby, coupling rotating *TST* turbines with waves.
- Benchmarking and design optimization for Tidal Generation Limited (*TGL*) 1MW *TST*, with actual field measurements.

Modelling

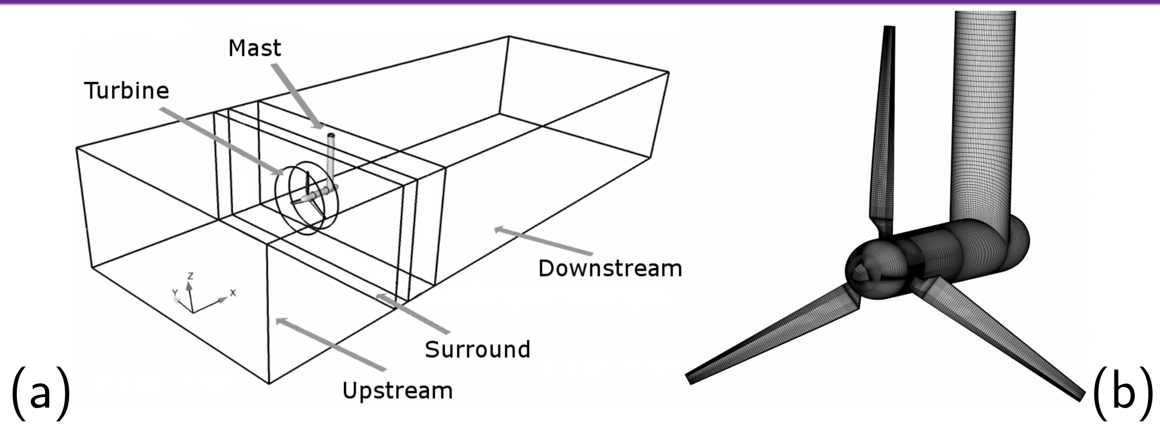

Figure 1: (a) Full *TST CFD* domain (b) View of the surface mesh.

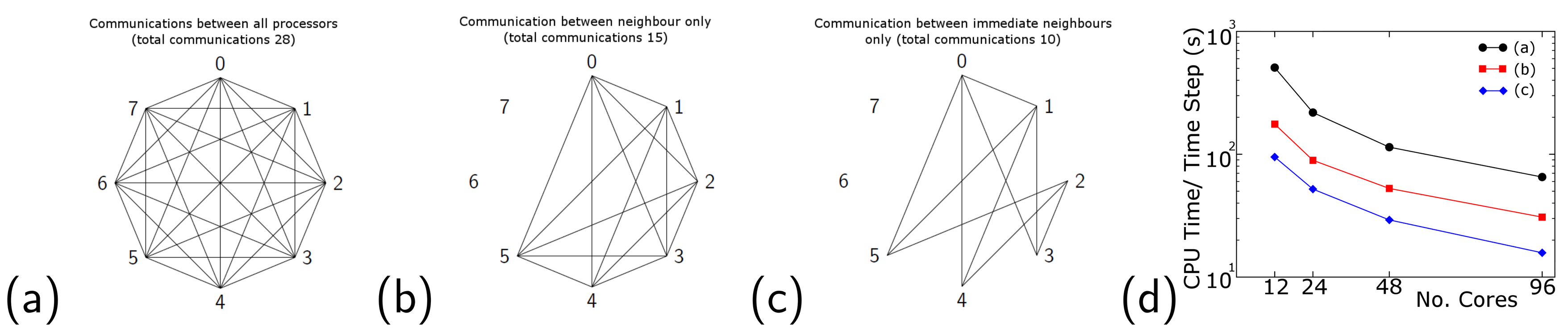

Figure 2: Sliding mesh procedure optimization (a-c) Various communication methodologies between processors (d) Speedup with different methodologies.

- Complete horizontal axis laboratory scale *TST* with 3 blades, nacelle and a mast (see Fig. 1).
- *CFD* simulations performed with both Reynolds Average Navier-Stokes (*RANS*) and Large Eddy Simulation (*LES*) using *Code_Saturne*.
- Numerical simulations performed on *EDF* Blue-Gene P super-computer with fine simulations costing about 4.4 million CPU hours for each run (approximately 4096 cores for 45 days).
- Optimization of *Code_Saturne*'s modified subroutines for *HPC* scalability (see Fig. 2).

Results and Discussion

- Large vortex shedding behind the vertical support with strong flow meandering (see Fig. 3).
- Three-dimensional helical wrapping of the flow around surface of nacelle and extending downstream beyond the mast (see Fig. 4).
- Shedding from the mast becomes inclined as it propagates downstream and is broken down by the large scale structures of the tip vortices.
- Mean blade loadings, thrust ($\overline{C}_T$) and power ($\overline{C}_P$) coefficient from *LES* are within 3% of measurements (see Fig. 5).

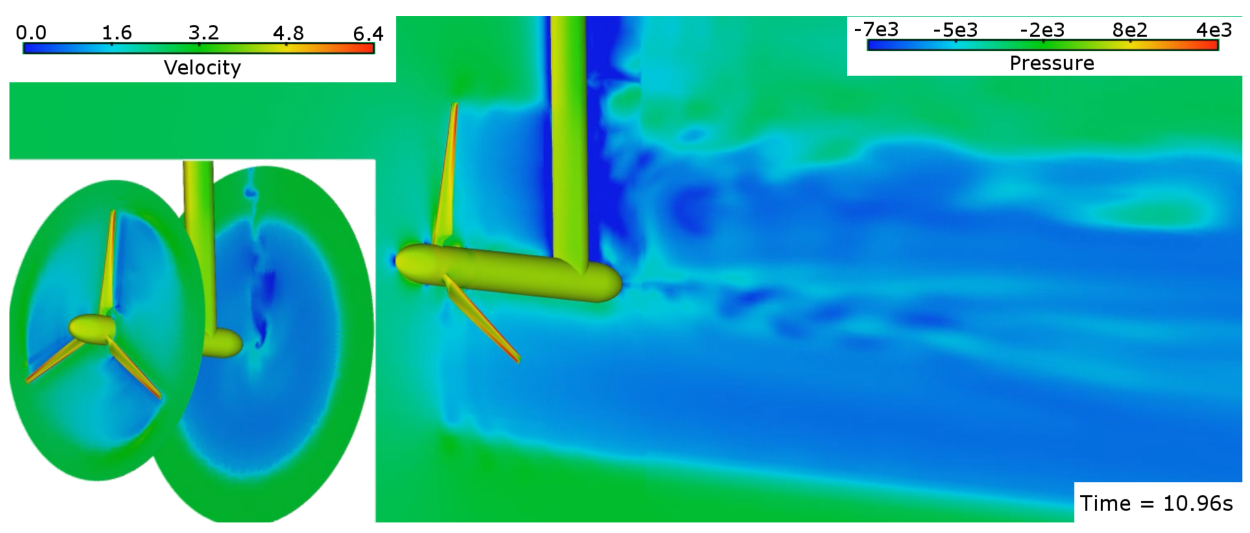

Figure 3: Instantaneous velocity and pressure field.

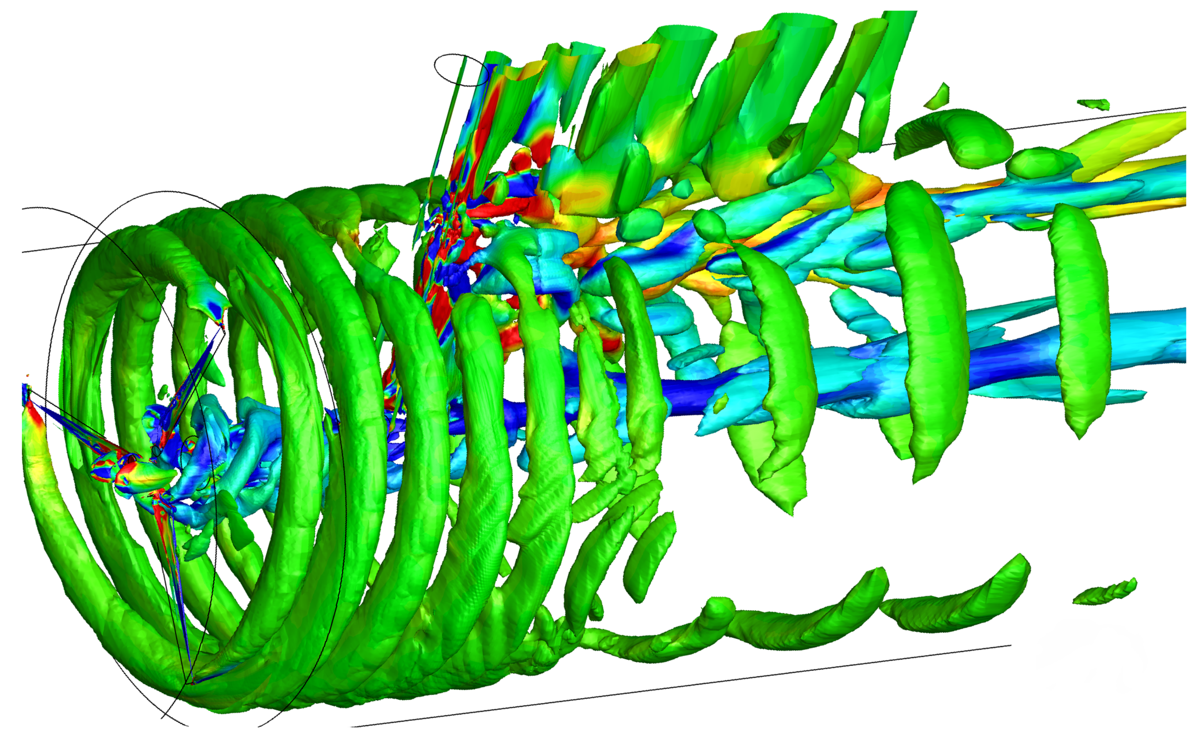

Figure 4: 2^{nd} invariant of the velocity gradient tensor (Iso-Q).

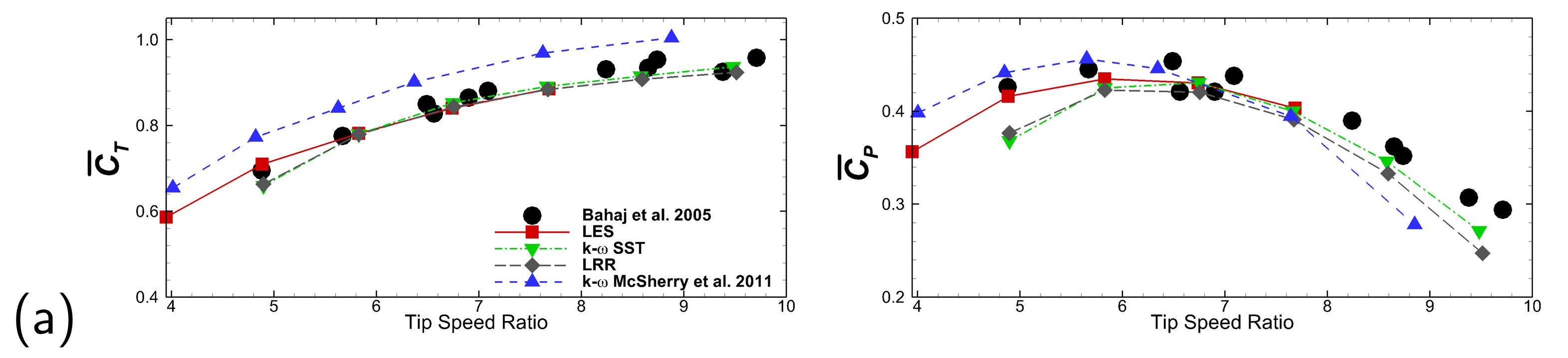

Figure 5: Mean performance coefficient comparison at various tip speed ratios (*TSR*) (a) Mean Thrust $\left[\overline{C}_T = \left(F_X / \left(0.5\rho U_0^2 A\right)\right)\right]$ (b) Mean Power $\left[\overline{C}_P = \left(\left(T_Q \Omega R\right) / \left(0.5\rho U_0^3 A\right)\right)\right]$.

- Pressure and velocity fields with different wave speeds (ratio of a characteristic velocity to a gravitational wave velocity, $Fr = (v/c)$) are shown in Figs. 6 & 7.
- The velocity on the upper part of the domain is no longer uniform, whereas underneath a wave, the turbine is subjected to pressure waves.

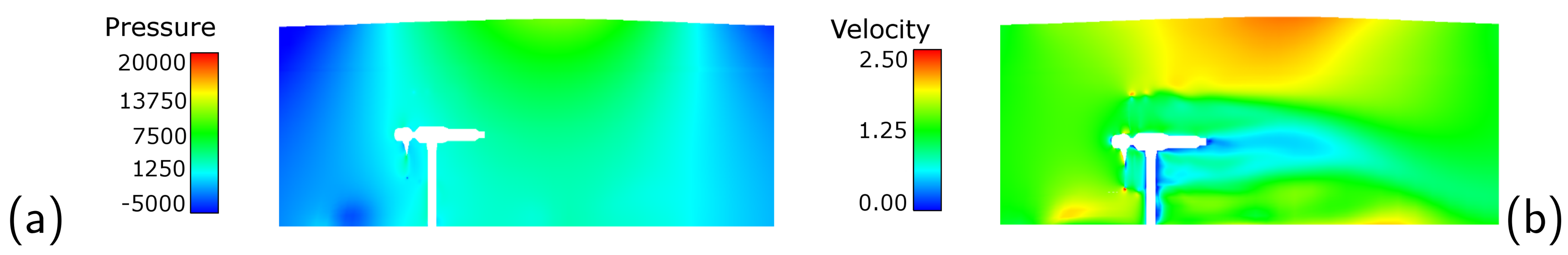

Figure 6: *TGL* 1MW *TST* with waves (Fr = 0.09) (a) Pressure field (b) Velocity field.

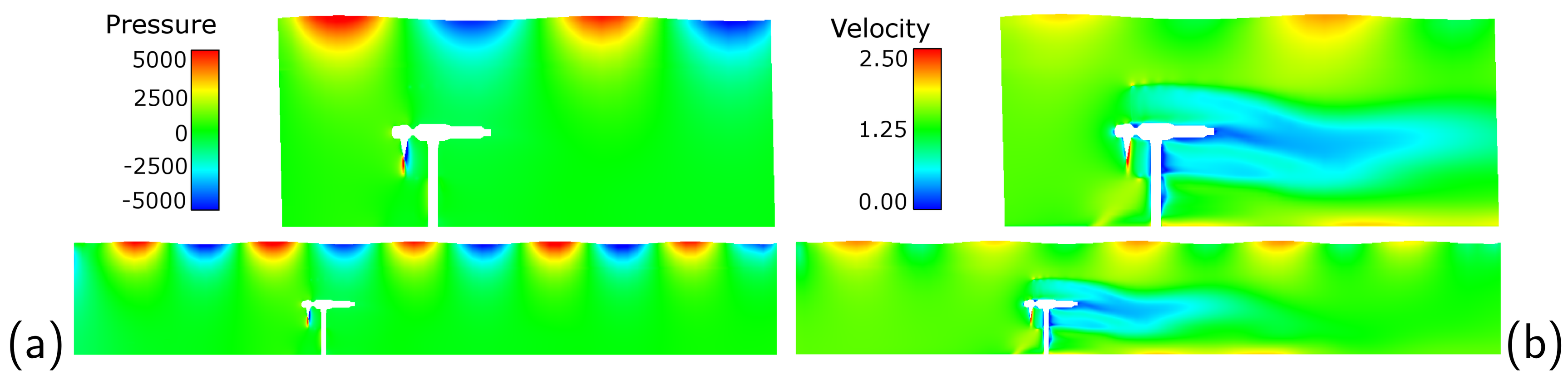

Figure 7: *TGL* 1MW *TST* with waves (Fr = 0.12) (a) Pressure field (b) Velocity field.

Conclusions

A new formulation has been developed for implementing sliding meshes in *Code_Saturne* in order to model tidal stream turbines with and without waves. A lab scale model was tested with HPC optimization, resulting in *CFD* predictions which were within 3% of the experimental data. The latter half of the study was based on wave modelling on top of *TST*. The research also encompasses the numerical issues related to the modelling of tidal stream turbines. To the authors' knowledge, this is the only *LES* of a *TST* with blade geometry resolved.

Future work

Assess the accuracy of unsteady loads predicted by the present methodology by developing incident flow with large-scale turbulence representative of the *EMEC* test-site and comparing loads to full-scale measurements.

Acknowledgments

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Publications

- I. Afgan, J. McNaughton, D. Apsley, S. Rolfo, T. Stallard & P. Stansby. Large-Eddy Simulation of a 3-bladed Horizontal Axis *TST*: Comparisons to *RANS* and Experiments. In *Proc. Turbulence, Heat and Mass Transfer 7*. Sicily, Italy, 2012.
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- I. Afgan, J. McNaughton, S. Rolfo, D. Apsley, T. Stallard & P. Stansby. Turbulent Flow and Loading on a *TST* by *LES* and *RANS*. Under review *Int. J. Heat and Fluid Flow*.
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