# Generalization of the tidal turbine wakes dynamic in unsteady operating conditions.

Les modèles hydrodynamiques côtiers permettent d'évaluer le comportement d'hydroliennes sur plusieurs cycles de marées, mais de façon trop peu précise. Les modèles numériques plus locaux commencent à être suffisamment fiables pour généraliser leur utilisation pour simuler le comportement et le développement du sillage d'un ensemble d'hydroliennes dans des écoulements instationnaires.
Nous proposons dans le cadre de ces travaux de thèse de poursuivre les développements de DOROTHY pour développer à terme des modèles de type puits/source permettant de prendre en compte la prédiction de production et de dissipation d'énergie au passage d'un parc d'hydroliennes. Ces modèles pourront être utilisés pour initialiser précisément les termes sources des modèles régionaux pour simuler des parcs industriels réalistes. Il s'agira de :

- **généraliser les types de technologies d'hydroliennes pouvant être modélisés** ;
- **effectuer une étude comparative des sillages** proches et lointains émis par les différents types d'hydroliennes en **conditions de fonctionnement instationnaires** ;
- **développer des modèles analytiques de prédiction de production et de dissipation d'énergie** au passage d'un parc d'hydrolienne.

**Mots-clés :** **hydrolienne, sillage, modèle numérique, dissipation d'énergie, turbulence, houle**

## Profil de candidature souhaité – *400 caractères*

Le/la candidat.e devra avoir des connaissances en mécanique / mécanique des fluides et des compétences en mathématiques appliquées et en modélisation numérique.

## English summary – *1200 characters*

Coastal hydrodynamics models make it possible to evaluate the behaviour of tidal turbines over several tidal cycles, but not very precisely. The models developed on a more local scale are beginning to be sufficiently reliable to generalize their use to simulate the behaviour and the wake dynamics of a set of tidal turbines in unsteady flows.
As part of this thesis work, we propose to continue the developments of DOROTHY to develop sink/source type models making it possible to take into account the prediction of energy production and dissipation when passing through a tidal turbine farm. These models can be used to precisely initialize the source terms of coastal models to simulate realistic industrial farms. The main objectives of this work are:

- **to generalize the types of technologies that can be modelled** (vertical and horizontal axis turbines);
- **to carry out a comparative study of the near and far wakes** emitted by the different types of tidal turbines in unsteady operating conditions (turbulent flow, swell) ;
- **to develop analytical models** (sink/source type) **for predicting energy production and dissipation** when passing through a tidal turbine farm in unsteady conditions.

**Key words:** **marine current turbine, wake, numerical model, energy dissipation, turbulence, wave**

## Preferred profile of the PhD student– *400 characters*

The candidate must have a solid training in Mechanics / Fluid Mechanics and skills in applied mathematics and numerical modelling.

# Detailed Research Project

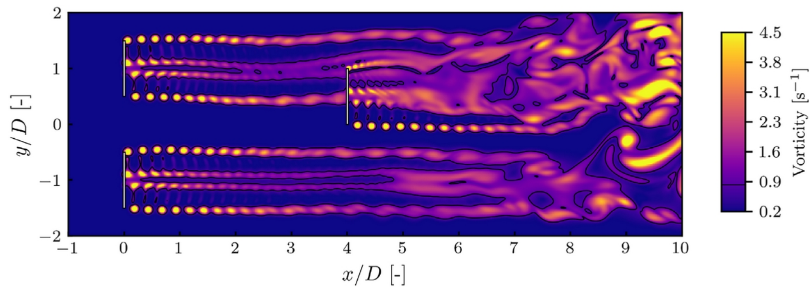
(Max. 3 pages long, without the bibliography which can appear on page 4).

## 1- Background and scientific/ technological context

In the United Kingdom, tidal farm projects are significantly developing while in France the first industrial projects (FloWatt and Normandie Hydroliennes in the Raz Blanchard) have entered the contractualization phase. The installation of such machines (of the order of 1 to 4 MW in a space of a few km$^2$) will cause disturbance to the marine environment which it is important to anticipate. There are different kinds of disturbance: modification of the currents (intensity, direction, spatial and temporal repartition), the level of turbulence (intensity and spectral repartition) and therefore the agitation of the environment. This modification of the environment in terms of physico-chemical properties can modify the primary production (phyto/zoo-plankton) [1, 2]. It is therefore essential to have efficient and reliable tools to assess such impacts.

**Normandie Hydroliennes project (on the left) and FloWatt project (on the right), based on the two main types of technologies: horizontal and vertical axis turbines, for a deployment in the Raz Blanchard**

There are now regional models making it possible to generally evaluate the behavior of a set of machines deployed in a specific region over several tidal cycles [3, 4]. These models allow (using expensive calculation times) to have an idea of the physical disturbance caused in the marine environment, but not in a very precise manner (strong simplification for taking turbines into account, like with the use of actuator disks model). Numerical models developed on a more local scale (from a single machine to a set of around ten turbines) are now beginning to be sufficiently reliable to generalize their use [5, 6]. M-A Dufour has recently validated the use of the DOROTHY code to simulate the behavior and development of the wake of a set of horizontal axis tidal turbines in unsteady flows, high turbulence levels, turbines interaction [7] and in the presence of swell. These simulations requiring significant calculation resources are possible thanks to the optimization of the code carried out by M. Roperch [8, 9] and to the validations carried out using experimental databases [10]. It is now possible to simulate the wake development of a set of around ten machines in the presence of swell and high levels of turbulence in controlled times (a few hours on Datarmor or CRIANN) with a high spatio-temporal accuracy.




**2D vorticity map around three turbines in interaction (the upstream turbulence induced vorticity is filtered).**

In this work, we propose to continue the developments of DOROTHY to ultimately **develop sink/source type models [11, 12] to better take into account the prediction of energy production and dissipation when passing through a tidal turbine farm**. These sink/source type models could be used to precisely initialize the source terms in coastal hydrodynamics models [13] and ultimately offer realistic industrial farm simulations in order to assess the physical impacts on the environment.

## 2- Strategic positioning within one of the 4 flagship themes

Thanks to this project, **a better knowledge of the energy exchanges encountered in tidal farms and of their impact on hydro-sedimentary processes by turbulence modification is expected**. These results should also **enable the evaluation of the impact on the primary production.** This subject is fully in line with Challenges 2 & 3 of the Horizon 2030 Institute project and also with projects conducted at RDT Unit (FloWatt [15] and Verti-Lab projects [16], Dorothy [17]). If the developed strategy proves its efficiency, it could be enhanced through the development of future commercial tidal turbine farms. This proposal is clearly part of the European and Ifremer Marine Renewable Energy roadmaps.

## 3- Scientific objectives

As part of this PhD work, we propose to pursue the developments of DOROTHY to develop sink/source type models making it possible to take into account the prediction of energy production and dissipation when passing through a tidal turbine farm whatever the kind of technology used. These models can be used to precisely initialize the source terms of coastal hydrodynamics models to simulate realistic industrial farms. As part of this work, this will involve:

- **to generalize the types of technologies that can be modelled** (vertical and horizontal axis turbines) with DOROTHY;
- **to carry out a comparative study of the near and far wakes** emitted by the different types of tidal turbines in unsteady operating conditions (high turbulence levels, in the presence of swell and in interaction);
- **to develop analytical models** (sink/source type) **for predicting energy production and dissipation** when passing through a tidal turbine farm in unsteady conditions.

## 4- Methodology

We propose an approach based on the **complementarity of experimental and numerical modelling**. To this aim, the existing experimental databases (which will be supplemented in the Ifremer wave and current flume tank according to new needs) will be fully used to validate the new numerical developments (particularly to model vertical axis turbines [14]). The numerical wake characterisation in unsteady operating conditions will then be used to develop analytical sink/source type models [11, 12] for predicting energy production and dissipation during the passage of the flow through tidal turbine farms in unsteady conditions.

## 5- Resources available to the PhD student for the duration of the research project

The PhD student will carry out her/his research work in the LOMC laboratory at the University of Le Havre and will occasionally be hosted at Ifremer Boulogne to validate numerical developments from specific databases. The host teams will provide their skills and resources in hydrodynamics to study the phenomena of fluid structure interaction, through tank tests and numerical calculations.

If necessary, the experimental study will be carried out at the Boulogne/Mer hydrodynamic test basin. The instrumentation required to data acquisition is already available (Laser Velocimetry systems, hydrodynamic balances, trajectometry system), as are various prototypes of instrumented tidal turbines (vertical and horizontal axis ones). The numerical calculations will be carried out with the use of Datarmor and the CRIANN (Région Normandie).

## 6- Expected results and valorization (publications and public dissemination)

The expected scientific benefits are multiple and particularly include the characterization and the understanding of the link between turbulent processes in the presence of complex realistic flows and energy converter devices. The obtained results will facilitate the development of numerical tools as DOROTHY. The main difficulty will lie in the capture of the physical processes at different spatial and temporal scales. A better understanding of the physical mechanisms will enable the parametrization considered in large-scale numerical models used for resource characterisation and production assessment. All of these results could also be used within the framework of the industrial projects FloWatt (vertical axis tidal turbine from HydroQuest) and Normandie Hydroliennes (horizontal axis tidal turbine from Proteus). The use of such OpenSource code would allow the Normandy Region **to formulate informed opinions to industrial project leaders**.

The results will also be the subject of A-rank publications and participation in international conferences (RENEW, EWTEC) with also potential impacts in the field of offshore wind and tidal energy whose support structures impact hydro-sedimentary processes by turbulence modification and thus the primary production.

## 7- Originality and innovation

While tidal farm development projects are becoming a reality, there are still no generic tools to anticipate the environmental impacts of this new human activity. This work aims to ultimately produce a numerical code making it possible to understand the different physical phenomena in action **to help regulate this new industry**. The proposed models are based on Lagrangian monitoring of fluid particles that can take into account numerous physical characteristics of the marine environment and simulate the processes encountered on the French coasts, particularly in the English Channel where the first developments of tidal farms will be carried out. The precision of those kind of models is high with a relatively low computational time. With this work, we will be able with DOROTHY to simulate the behaviour of both kind of turbines (vertical and horizontal axis) tacking into account wave, turbulence and interaction effects. Our last publication [6] highlights **DOROTHY capability to simulate both offshore wind and tidal turbines behaviours**.

## 8- Does the project come under the ABS Nagoya Protocol and/or does it involve the use of genetic resources? **No**

## 9- Has the project been submitted in the context of the Ifremer's Overseas Action Plan (PAOM)? **No**

## 10- Potential partnerships

The obtained results will strongly contribute to the DOROTHY developments with University of Le Havre (LOMC). The valorization of this work will also be done within our participation to the GDR EOL-EMR and the RISEnergy projects. The valorization via the Verti-Lab common laboratory (with HydroQuest) and the Ifremer partnership in the FloWatt project should also be considered.

## 11- Provisional schedule

1/ Bibliographic study on the experimental and numerical modelling of wind and tidal turbines in unsteady operating conditions.

2/ **Extension of the DOROTHY lifting line model** to vertical axis tidal turbines.

3/ **Validation of the lifting line model from experimental databases.**

4/ Comparative study of the near and far wakes emitted by the different types of tidal turbines in unsteady operating conditions and in interaction, with (if necessary) extension of the experimental databases.

5/ **Development of analytical models** (sink/source type) for predicting energy production and dissipation during the passage of a tidal turbine farm in unsteady conditions.

During the three years, a particular attention will be paid so that the scientific questions listed above are adequately addressed, in particular that relating to the development of numerical tools making it possible to reproduce the physical process between tidal turbines, strong current and wave.

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