Thesis offer – ESR01

MSCA Cofund - MISCEA

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Job Information

Organisation/Company: Ecole nationale des ponts et chaussées / Ecole des Ponts ParisTech (ENPC)

Department: CEREA (https://www.cerea-lab.fr/)

Research Field: Mécanique des fluides numérique / Computational fluid dynamics

Researcher Profile: First Stage Researcher (R1)

Country: France

Type of Contract: Temporary

Job Status: Full-time

Is the job funded through the EU Research Framework Programme?: Horizon Europe (HE) / Marie Skłodowska-Curie Actions COFUND

Is the Job related to staff position within a Research Infrastructure?: No

This project is co-funded by the European Union as part of the **HorizonEurope programme, Marie Skłodowska-Curie Actions, call COFUND-2022** and under grant agreement number 101126720

Offer Description

Thesis offer:

Context

A priori predictions of the potential of wind turbine farms are needed to assess their efficiency and profitability. For large farms made up of several tens of turbines, the uncertainty of these estimations is largely due to the modeling of the losses through the wakes which are often beyond 10% of the potential power. In addition to these losses, blockage effects which could lead to additional losses are not taken into account in standard engineering predictions. These blockage effects are up to now not well understood and are the topic of several experimental and numerical research works.
The turbulent wind evolution along very long periods representative of the farm's lifetime (around twenty years) is needed to estimate the potential power of wind turbines and leads to hundreds if not thousands of numerical simulations of the flow through the farms. This requires numerical tools easy to configure and allowing very fast computations. Considering the financial stakes, it is still very important to assess the performances of these fast tools and to improve them with reference data. The available experimental or on-site data being very scarce, carrying out reference fine computations is then mandatory.
The use of CFD (Computational Fluid Dynamics) is spreading among the "wind turbines" community since ten to fifteen years. The RANS (Reynolds Averaged Navier Stokes) approach which consists in solving the Reynolds averaged flow quantities (velocity, pressure, temperature, …) is still widely used among the industrial actors. These latter often use additional hypotheses to simplify the problem (such as by linearizing the equations) due to the aforementioned large computational costs. On the other hand, the academia community performs progressively more and more LES (Large Eddy Simulation) computations, in addition to RANS approaches. This is due to the fact that RANS results strongly depend on the closures which are used (linear eddy viscosity, non-linear eddy viscosity, Reynolds stresses, …) and the information provided by these computations are intrinsically limited as the physics of wind turbines is strongly unsteady either for the boundary conditions or the flow through the farm.
DNS (Direct Numerical Simulation) in which Navier-Stokes and energy equations are solved directly without any model would have been ideal but require huge computations which are still not feasible today considering the high involved Reynolds numbers. LES, in which the large space and time scales are solved and for which the dissipation due to the small scales is modeled through a subgrid scale of tensor or vector, is a good compromise between precision and cost. It allows to have finer and richer details of the flow than with RANS approaches and the computations are long but feasible today allowing to obtain reference data for few predefined meteorological situations.

Objectives

The main objective of the present work in to investigate fine predictions of the flow through wind turbines farms, as a prospective step in a project. One distinguishes two types of applications:
- The ones linked to the estimate of the potential power which can be produced by a farm including the wake and blockage effects. These two effects might be particularly crucial for large offshore farms. Minimizing the uncertainties in this estimate is an important key issue in the LCOE (Levelized Cost of Energy) reduction of the wind energy. The financial gain entailed by a reduction of the wind magnitude uncertainty at the hub elevation by 0.1 m/s is estimated to about 10 M€ /year (Hasager et al., 2013) for a large offshore wind farm, typically using tens of wind turbines for an installation power of a few hundreds of MW. **The objective is here to use LES approach to create reference computations allowing to :** 1) better describe and understand the mechanisms playing a role in the wake and blockage effects; 2) evaluate and confront the results issuing from engineering models; 3) identify ways to improve the results of the engineering models.

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- The ones related to the estimate of mechanical loads applied by the wind and turbulence on the turbines. This will impact the choice of the turbines, their maintenance and their lifetime. The impact of the mechanical loads is increasing as the turbine sizes are increasing. Currently, the data related to turbulence which are given to the engineering models are obtained thanks to tools using theoretical spectra, without taking into account the particularities of a given farm. LES simulations will allow providing more reliable and realistic data, including the additional turbulence generated in the wakes.

The CFD tool which will be utilized is code_saturne, already successfully used in the past years for RANS simulations of wind flow through wind farms (Dall'Ozzo et al., 2014, Defossez et al., 2015, Angot et al., 2017). The potential of LES has also been demonstrated through several academic and industrial configurations (see for example Afgan et al., 2011, Benhamadouche 2017, Gauffre et al., 2020).

State of the art

LES modeling applied to wind turbines has been the topic of several publications since approximately ten years and is more widely used today. Academia teams, among them the University John Hopkins (USA, Martinez-Tossas et al., 2015), EPFL (Switzerland, Wu et Porté-Agel, 2015) and DTU (Denmark, Nilsson et al., 2015), gained notoriety in the field. NREL (National Renewable Energy Laboratory) from the DOE (Department of Energy) has developed a LES approach called SOWFA (Simulator fOr Wind Farm Applications) (see Churchfield et al., 2012, Martinez-Tossas et al., 2015). This model is used today by several teams in the world among them IFP-EN in France. NREL is currently developing with Sandia National Lab the solver LES Nalu-Wind in the framework of the A2E (Atmosphere to Electrons) initiative. We can report specifically the wake effects modeling in Joulin et al., 2019, Lin & Porté-Agel, 2019 who combine LES with an actuator line model in order to represent the rotor part and its blockage effect.

Turbulence modeling using a LES approach is possible in code_saturne since Benhamadouche, 2006 PhD at the University of Manchester and has been successfully used for the prediction of various confined flow (see Benhamadouche 2017) among them the flow through fuel assemblies for fretting issues (see Gauffre et al. 2020) and the flow through a control rod guide card (2018-2021). It has been also utilized to predict the flow around obstacles such as two side-by-side cylinders, a thin plate or tube bundles (see Afgan et al. 2011 among others). Concerning atmospheric flows, first computations have been performed during C. Dall'Ozzo PhD (2013) during which an LES approach has been developed for a diurnal homogeneous boundary layer along a cycle of 24 hours (Wangara experiment) and compared to RANS modeling. These computations showed numerical instabilities in particular during the night where the thermal stratification is stable.

Several PhDs, which can help for the present thesis, have been dedicated to LES and hybrid RANS/LES approaches :

- Benoît de Laage de Meux developed a zonal hybrid RANS/LES approach for rotating flows with heat transfer for turbomachines (« Modélisation des écoulements turbulents en rotation et en présence de transferts thermiques par approche hybride RANS/LES zonale », 2012.
- Vladimir Duffal (« Développement d'un modèle hybride RANS-LES pour l'étude des efforts instationnaires en paroi », 2020), developed a new formulation of HTLES (Hybrid Temporal Large-Eddy Simulation) allowing a drastic reduction of the computational time compared to a standard LES. In this approach, the near-wall region is solved in RANS. He also showed that the use of ALF approach (Anisotropic Linear Forcing) developed by de Laage de Meux, 2015 at the HTLES-RANS interfaces allows a better representation of turbulent fluctuations.
- Li Ma (« Large-eddy simulation of purely buoyant diffusion flames », 2020), developed LES to simulate fire plumes. A new 2nd order time splitting algorithm has been implemented and verified for variable density flows at low Mach numbers in order to gain precision for unsteady cases where buoyancy forces are important.

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- Hector Amino (Modélisation CFD pour l'aéraulique des bâtiments, 2022) extended the 2nd order algorithm to compressible flows (Amino et al., 2022).
All these achievements have given the opportunity to develop additional capabilities of LES for atmospheric flows with code_saturne, in particular for offshore wind turbines farms, by integrating progressively a hybrid RANS/LES approach allowing to reduce the computational cost and preserve a mean law of the wall. Some additional developments have still to be performed concerning the wall roughness which has not yet been taken into account in previous works but might play a crucial role in atmospheric flows.

Scientific bottlenecks

Based on previous work conducted at CEREA and MFEE (Fluid Mechanics Energy and Environment department) at EDF R&D, the following bottlenecks have to be:
1. Setting up a method allowing to impose turbulent inlet boundary conditions,
2. Taking into account the wall roughness in LES and hybrid RANS/LES approaches based on existing laws already developed in code_saturne,
3. Dealing with the transitional areas (space and time) between RANS and LES in hybrid approaches,
4. Taking into account the thermal stratification in the atmospheric simulations,
5. Selecting a subgrid scale model suitable for modeling a wind turbine farm.

Detailed tasks of the three PhD years

The program contains two main phases over similar time lengths: the first one is dedicated to deal with the aforementioned bottlenecks common to atmospheric simulations, the second one focusing on the specific issues related to wind turbines farms modeling.
The first phase is decomposed into :
1. A literature review of LES and hybrid RANS/LES approaches for atmospheric flows at local scale (few kilometers to fifteen kilometers) focusing on the ones used for wind turbines farms,
2. Adapting existing methods to generate turbulent inlet boundary conditions. The ALF method could be introduced in this part (de Laage de Meux et al., 2015),
3. Modeling the subgrid scale tensor in the momentum equation. The performance of standard and widely used LES and hybrid RANS/LES approaches will be tested on atmospheric configurations. A special attention will be dedicated to the inclusion of the roughness at the wall (the ground). The numerical method will be the one developed and validated in Amino's Phd,
4. Modeling the thermal stratification. The dedicated models in Li's PhD and in the literature will be tested and possibly revisited,
5. Validating the previous approaches on a homogeneous boundary layer (Wangara experiment) for different thermal conditions (neutral, convective and stable). A special attention will be given to the transition between the RANS and LES resolutions in space and time. The transition between a convective boundary layer and a stable one is particularly important as it involves different characteristic turbulent length and time scales (from the order of one kilometer to the order of few meters).
At the end of the first phase, a hybrid RANS/LES approach with appropriate turbulent inlet boundary conditions and adequate treatment of the roughness will be fixed.
The second phase consists in:
6. Introducing a model for the turbines based on the actuator line approach. This will allow to distinguish the effect of the blades and to take into account their rotation. This model seems to be more reliable for unsteady approaches than the actuator disk model. However, it requires data which are not necessarily available, particularly the precise geometry of the blades. It will be then interesting to test both approaches on the following applications,
7. Modeling the wake on an academic configuration containing at least two wind turbines. The sub-grid scale models with the actuator line approach will be evaluated in this step,

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8. Modeling a real configuration. Depending on the priorities fixed by EDF-Renouvelables, the effects of the wake or the blockage will be evaluated. The studied configuration could be a full or a partial farm for which SCADA measurements are available. The candidates are for the moment Blyth (England, 5 turbines), Teesside (England, 27 turbines), Thorntonbank (Belgium, 54 turbines), Saint-Nazaire (France, 80 turbines). Concerning the blockage effects, interesting data should be available in the framework of GloBE project in which EDF-Renouvelables and EDF R&D are partners. These data include wind velocity upstream and aside a farm thanks to lidars. The results obtained with LES, namely, the wind velocity at the hub elevation, the turbulent intensity, and the electrical production, will be compared for a few atmospheric conditions to RANS results, to the results obtained with engineering models used at EDF-Renouvelables and to on-site measurements (measured velocity on the nacelle or with lidars, production).
Summary of the main steps:
Year 1 : steps 1 to 3
Year 2 : steps 4 to 6
Year 3 : steps 7 to 8

Thesis supervisor(s)

The main supervisor, Sofiane Benhamadouche (Dr, HDR), obtained his PhD from the University of Manchester (2000 to 2006) and developed the first LES approach in code_saturne. He co-supervised several PhD theses and post-docs on this field and particularly on synthetic generation of turbulent inlet boundary conditions and wall functions applied to LES. He also co-supervised several PhDs on advanced RANS modeling and heat transfer. He is involved in several industrial projects at EDF R&D within which CFD is widely used for predicting pressure wall fluctuations (Fuel Assemblies 2, Viper) and thermal fatigue (Modern).
Email address : sofiane.benhamadouche@edf.fr

Working environment

The PhD will be full time at CEREA (https://www.cerea-lab.fr/), on its site of Chatou, at EDF Lab Chatou, 6 quai Watier, 78400 Chatou. CEREA lab main focus is on research around measuring and modeling the physics in atmospheric boundary layers. The main targeted applications are around pollutant/species dispersion in the atmosphere and renewable energies (wind energy, photovoltaic). The present PhD thesis perfectly fulfills the topics covered by the lab.

CEREA is a joined laboratory in between ENPC and EDF R&D, with a mixed location on the site of ENPC at Champs-sur-Marne and on the site of EDF R&D at Chatou. The PhD project will be located on the site of EDF Lab Chatou and will benefit from the industrial environment and computational capabilities of EDF R&D.

Most of the time will be spent at EDF R&D facility of Chatou, industrial partner of CEREA laboratory. The PhD will benefit from the co-supervision of Dr. Martin Ferrand and Dr. Eric Dupont, both researchers at CEREA, and experts in atmospheric modeling and simulations.

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Description of the project and the candidates' eligibility criteria:

This position will be part of the EU-funded project **MISCEA**, which is an ambitious inter- and multidisciplinary Doctoral Training Network under the Horizon-Europe Marie Skłodowska-Curie Actions.

PhD candidates' can be of any nationality but you have to meet these eligibility criteria:

- **Not being a current employee** working at ENPC.
- Not having resided or carried out their main activity (work, studies, etc) in France **for more than 12 months** during the past 36 months immediately before the deadline of the MISCEA Programme's call. Compulsory national service, short stays such as holidays and time spent as part of a procedure for obtaining refugee status under the Geneva Convention are not taken into account.
- **Holding a Master's degree** (or about to obtain one) or having a University degree equivalent to a European Master's degree (5-year duration) at the deadline of the MISCEA Programme's call.
- Researchers must be doctoral candidates, i.e. not already in possession of a doctoral degree at the deadline of the co-funded programme's call. Researchers who have successfully defended their doctoral thesis but who have not yet formally been awarded the doctoral degree will NOT be considered eligible.
- **Signing a declaration** of the veracity of the information provided (Declaration of honour, free of form).

If you comply with the eligibility criteria and you wish to submit your application, you must:

- Contact the thesis supervisor and explain your thesis project to her/him so that she/he validates your application via a **letter of acceptance**.
- Submit a **5-pages thesis proposal** under the proposed research areas, with the agreement of the future supervisor + **1 page cover letter** with: *the relevance of your educational/professional background to carry out your thesis topic.*
- The applicant will have to complete an **ethics checklist** based on ethics guidance from the HorizonEurope programme guide.
- **English-translated transcripts** from the master's degree or equivalent.
- **Any specific requirements of the Doctoral School** corresponding to the targeted MISCEA fellowship offer.
- **English curriculum vitae**, including information about the level on English language knowledge.
- **One letter of reference**, at least.

See mandatory templates for your application and recruitment conditions on the Applicant's guide on the MISCEA website (link).

Then your candidature is complete, please send inquiries and applications to **miscea-program@enpc.fr**

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Requirements

Research Field: Mécanique des fluides / Fluid Mechanics

Education Level: Master Degree or equivalent

Skills/Qualifications: Programmation en C, C++, Fortan, Python / C, C++, Fortran, Python programming

Languages: English

Level: Excellent

Where to apply

E-mail: miscea-program@enpc.fr

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