AEROACOUSTIC OPTIMIZATION OF DIFFUSER-AUGMENTED WIND TURBINES

zEPHYR Marie Skłodowska-Curie project: towards a more efficient exploitation of on-shore and urban wind energy resources

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CONTEXT

A Diffuser-Augmented Wind Turbines (DAWT) is a turbine with an aerodynamic annular device that increases the mass-flow through the rotor and thus **increasing performance**. Besides the enhancement in power output, the diffuser also aligns the incoming flow, reducing the effects of yaw conditions and its relatively smaller size make it possible to be placed inside **urban areas**, reducing the costs of energy transportation.

The limited acceptance of DAWT within urban areas can be linked to three key factors: bad perception from previous failed attempts, economic constraints, and stricter noise regulations.

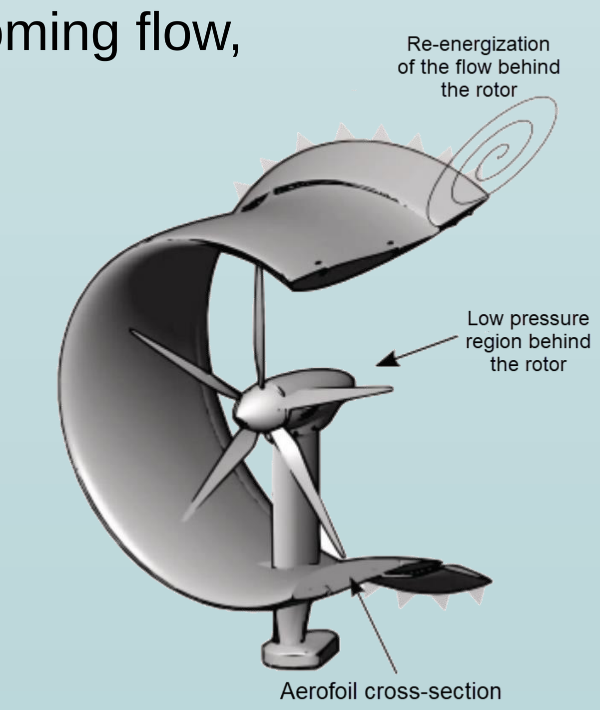

Fig 1: example of DAWT [1].

PROBLEM DEFINITION

To be attractive, DAWT must be efficient and with minimal noise pollution. To correctly assess the aerodynamic and aeroacoustic performance of DAWT with low computational effort is a difficult task since the rotor and the diffuser have a non-linear mutual interaction.

Therefore, it is necessary to come up with methodologies that take into account this interaction and, at the same time, can be fast implemented into a design and optimization process. In this regard, low fidelity models are a viable option not only to help in the design of the DAWT, and thus making it more commercially viable, but also to provide insight into the physical working principles of these turbines.

This research will use the DonQi DAWT model as a reference case due to the large amount of data found in the literature.

OBJECTIVES

- ❑ To develop a low-fidelity methodology to correctly assess the aerodynamic behavior of DAWT.
- ❑ To investigate aeroacoustic noise of DAWT using low-fidelity models.
- ❑ To investigate procedures for a coupled aerodynamic-aeroacoustic optimization of the DAWT.

METHODOLOGY

To address the first objective and correctly assess the thrust distribution (C_T) of the rotor when is placed inside the diffuser, the Blade Element Momentum Theory (BEMT) was used coupled with an Actuator Disk (AD) model as shown in Fig. 2.

The AD model is carried out by the means of a RANS solver. The model consists of an airfoil symmetrically placed about the center axis; the flow is parallel to the axis of symmetry. The rotor is represented using a pressure jump (ΔP) that can be calculated based on the thrust of the actual rotor.

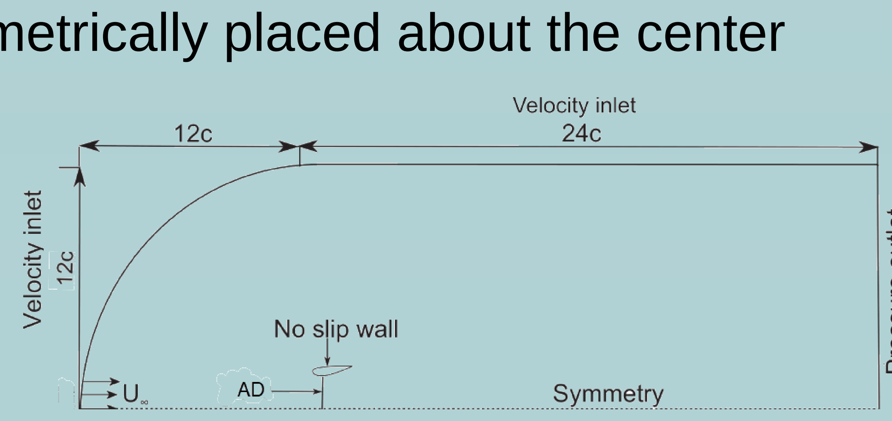

Fig 2: AD model [2].

The C_T distribution is then evaluated by the BEMT code (based on the aerodynamic inviscid solver XFoil) that takes into consideration the velocity augmentation at the rotor plane of the AD model. The algorithm of this interactive process is shown in Fig. 3

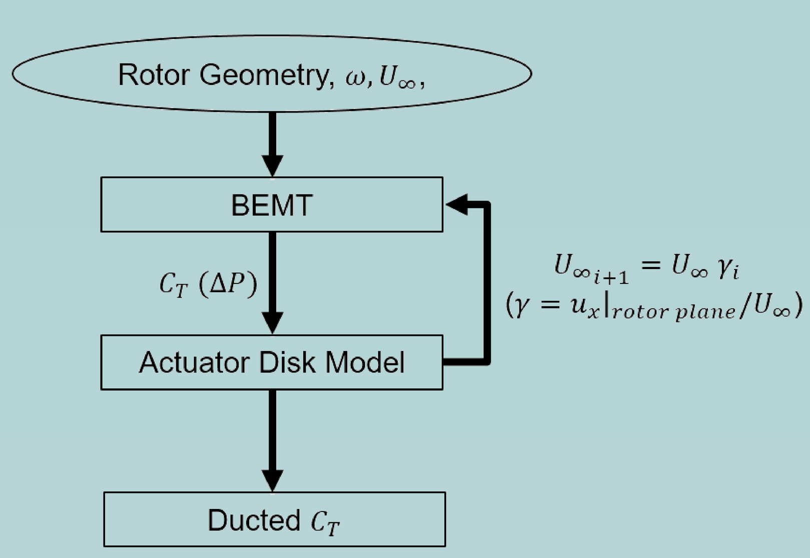

Fig 3: BEMT-AD coupling algorithm.

RESULTS

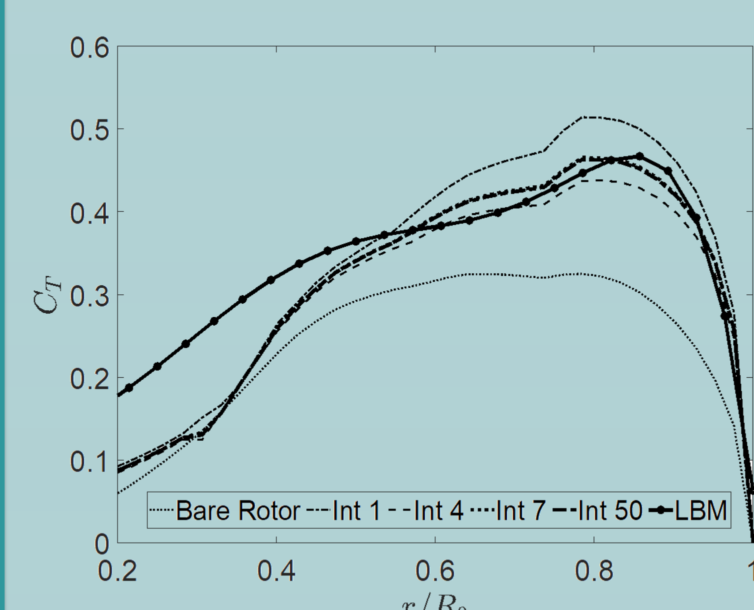

Fig 4: Radial thrust distribution.

It was observed that the radial Ct distribution evaluated by the methodology proposed quickly converges to the C_T calculated using the high fidelity model computed via Lattice Boltzmann Simulation (LBM) [3]. The increase in C_T on the tip of the blade is mainly due to the circulation effect around the diffuser.

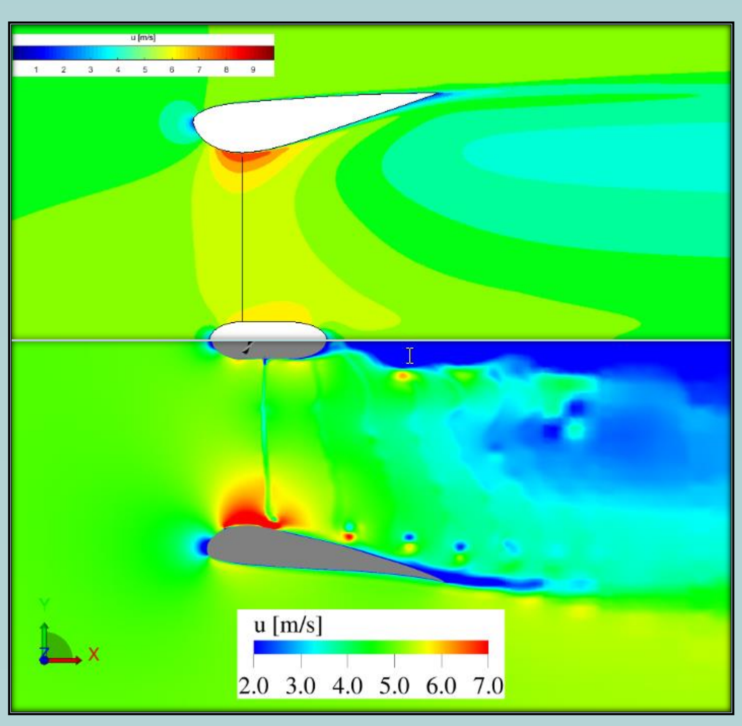

Fig 5: Axial velocity field.

In Fig. 5, the flow-field results from the AD model (top) show similarities with the LBM model (bottom), Although the AD over predicts the velocities through the gap between blade and diffuser, the stagnation point on the diffuser and general characteristics of the wake are conserved.

Since the approach successfully represented the aerodynamic performance of the rotor when place inside the diffuser, the next step is to use low fidelity modeling for the aeroacoustic evaluation of the DAWT.

[1] Dighe, V. V. "Ducted wind turbines: A potential energy shaper." *Leonardo times* 2016.3 (2016).
[2] Dighe, V. V. "Ducted wind turbines revisited: A computational study." (2020).
[3] Avallone, Francesco, Daniele Ragni, and Damiano Casalino. "On the effect of the tip-clearance ratio on the aeroacoustics of a diffuser-augmented wind turbine." *Renewable Energy* 152 (2020): 1317-1327.

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