Aerodynamic simulation of airfoils with TE flaps for multi-MW wind turbines

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Introduction

This paper presents recent results from the EU FP7 project WINDTRUST. The project lasts 3 years and is carried out in a consortium with 3 industry partners and 6 research institutes:

- GAMESA Innovation and Technology, GAMESA (Spain, coordinator)
- LM Wind Power AS, LM (Denmark)
- SEMIKRON Elektronik GMBH & Co. KG, SEMIKRON (Germany)
- Technical University of Denmark, DTU (Denmark)
- National Renewable Energy Centre, CENER (Spain)
- University of Strathclyde, STRATHCLYDE (UK)
- Centre for Renewable Energy Sources and Saving, CRES (Greece)
- University of Southampton, SOTON (UK)
- Greenovate! Europe, GREENOVATE (Belgium)

The objective of WINDTRUST is to demonstrate the technical and economic feasibility of innovative and more reliable solutions for multi-MW wind turbines in order to improve the competitiveness of wind energy technologies. The selected components of the wind turbine are the rotor, power electronics and control and communication system.

The work presented here is related to aerodynamic control technologies. The design of flow control devices, oriented towards longer blades or load reduction, is a target of the project. Furthermore, the methodology involves different levels of simulation in order to increase the accuracy and reliability of the final solution.

The specific work included in this paper deals with TE flaps. As a first step in the design process, the methodology for 2D aerodynamic simulations, validation activities and a detailed parametric study are described. The selected solution will be evaluated in the reference wind turbine in terms of load reduction and power production, in future activities of the WINDTRUST project.

Approach

For aerodynamic control purposes, the flap technology can be distributed in the blade and applied in short time scales for high frequencies. In addition, the deformable flap is an efficient solution, avoiding the drag penalty imposed by other flow control devices. In terms of lift, the flap exerts a continuous and significant effect, becoming suitable for load control.

For the aerodynamic analysis, different levels of tools have been used, in order to cross-check the results and validate the methodology. CFD methods are represented by WMB, AdaptFoil2D is a panel code based on vortex methods and AdaptFoil1D is an analytical code based on thin airfoil theory. The tools have been developed by CENER (WMB in collaboration with the University of Liverpool). The tools are able to simulate changing geometries in unsteady conditions. Attending to the different characteristics of the codes, the methodology can be adapted to deal with the requirements of each particular problem.

The methodology has been validated using experimental results of the University of Stuttgart. The cases are different static deployments of an articulated flap in the TL190-82 airfoil.

After the validation, a parametric study has been performed to evaluate the influence of the flap in the aerodynamic response. Moreover, the investigation is useful to choose the optimum flap configuration for a specific wind turbine. In order to perform the study in a next generation multi-MW platform, the Innwind.EU 10MW reference wind turbine have been used, kindly provided by the Innwind.EU project and DTU WIND (rotor data).

Main body of abstract

The validation of the modelling methodology is critical to support the conclusions of the parametric study and the selection of the TE flap configuration. Measurements of the TL190-82 airfoil with an articulated TE flap, carried out at the Laminar Wind Tunnel of IAG in the frame of the EU Upwind project, have been provided by the University of Stuttgart. The flap length is 10% of the chord and 5 static positions have been tested: 10º, 5º, 0º, -5º and -10º (Reynolds 2.5e6 is selected).

The experimental cases have been reproduced using AdpatFoil1D, AdaptFoil2D and WMB. Figure 1 shows the Cl comparison for flap 5º between experimental data and simulations. The results of WMB show a good agreement with the experimental data in terms of α_0 and slope of the linear region. In the case of AdaptFoil2D and AdaptFoil1D, the slope of the linear region is a bit higher and lower respectively with respect to the experimental data, and the α_0 is slightly displaced to the negative α. The maximum Cl given by WMB is slightly overestimated, and the value of AdaptFoil2D is closer to the experimental data.

Figure 2 shows the Cl comparison for different flap angles, including experimental data and results of AdaptFoil2D. The effect of the flap in the linear region is captured by AdaptFoil2D, although the influence in Cl is slightly overestimated. The maximum Cl of the experimental data is approximately captured, and the values in the region after the maximum Cl are generally underestimated between 10º and 20º.

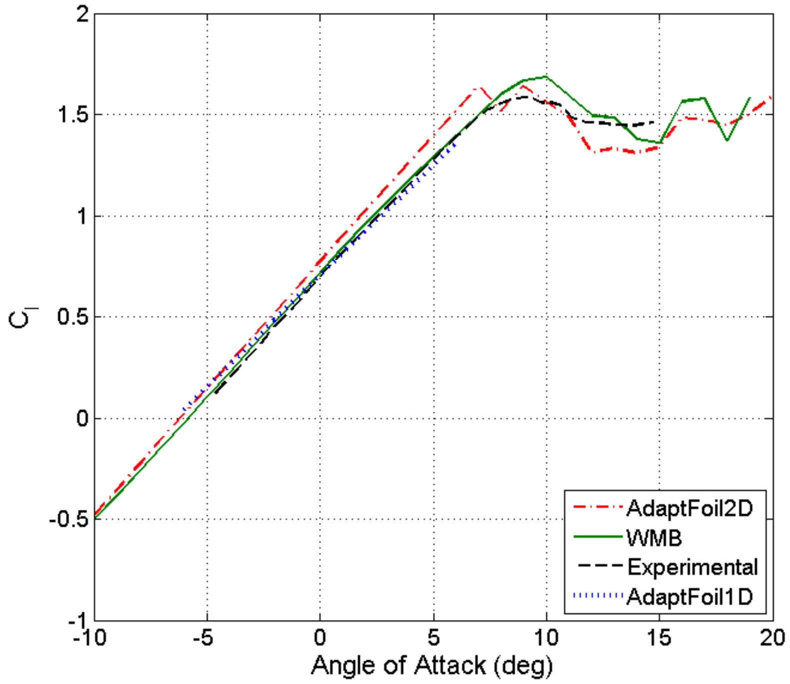

Figure 1: Cl vs α, TE flap 5º

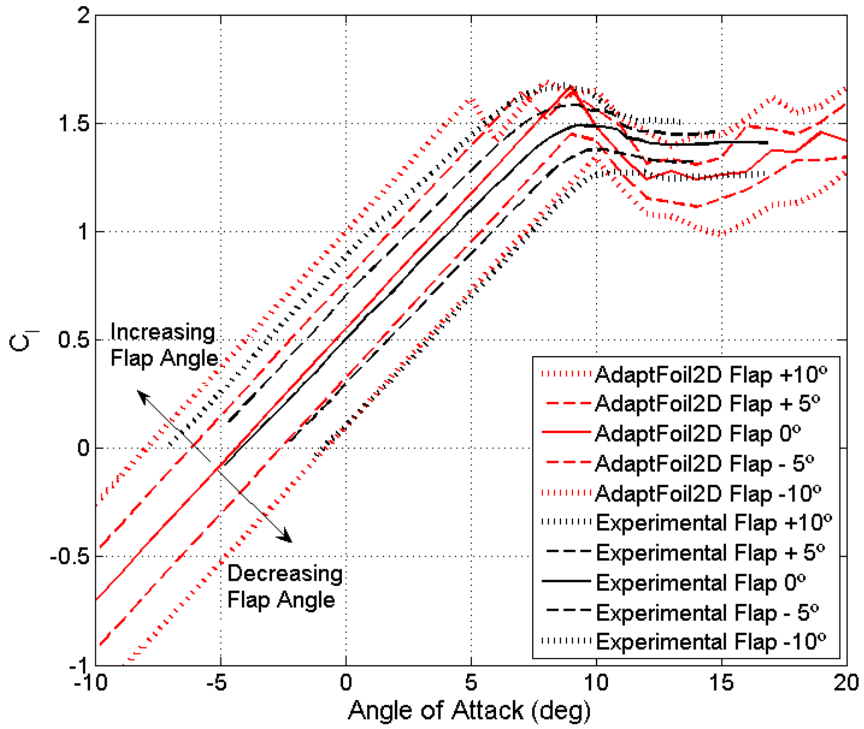

Figure 2: Cl vs α, TE flap 10º, 5º, 0º, -5º, -10º

A parametric study of the flap technology in a 2D airfoil approach is performed as a previous step to the integration in the blade. The objective is to evaluate design parameters or operating conditions in the aerodynamic response, in order to choose the optimum configuration.

Several parameters are selected taking into account the importance of the parameter in the aerodynamic response, the potential range of variation in wind turbine applications and the reliability of the study with the available tools:

- Flap shape
- Flap deployment
- Flap length
- Reduced frequency of flap oscillation
- Operational angle of attack

The selected parameters will be varied and tested at the 0.75 radial station of the Innwind.EU reference blade. The airfoil is the FFAW3-241, and the conditions are Mach≈0.2 and Reynolds=$15.556x10^6$. During the simulations, CFD and panel code results have been cross-checked in order to measure the reliability of the aerodynamic modelling. Figure 3 shows a Cp comparison for a continuous deformable TE flap of 10% chord, with a deployment of 5º and α=6º. The agreement is very good with minor deviations at the TE and near the LE in the suction side.

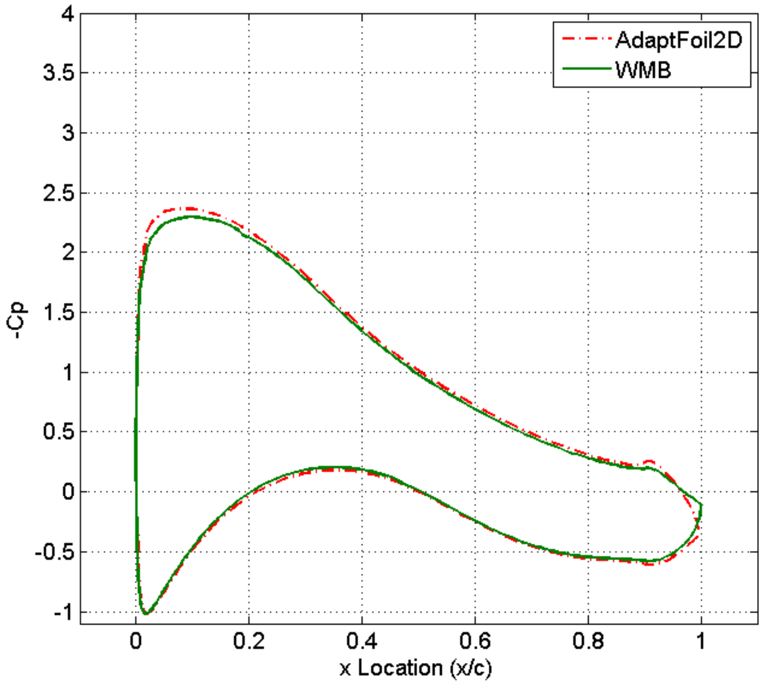

Figure 3: Cp at α 6º and flap angle 5º, continuous deformable flap of 10% chord length

An example of the parametric study related to the shape of the flap is presented in Figure 4, with a comparison of WMB results of Cl/Cd for an articulated TE flap and a continuous deformable one at different flap deployments. For most of the angle of attack range, the deformable geometry shows better aerodynamic efficiency.

Another example of the parametric study performed is found in Figure 5, which shows the AdaptFoil2D Cl results for a continuous TE flap of different lengths, with flap angle 5º. Table 1 shows the values to evaluate the effect in the Cl curve.

	$\Delta\alpha_0$	ΔCl (α=0)	ΔCl_{max}
Flap length = 5% chord	-1.345	0.175	0.0084
Flap length = 10% chord	-2.035	0.265	0.0607
Flap length = 20% chord	-2.998	0.391	-0.0384

Table 1: Cl vs α, flap deployment 5º

In the linear region, the effect of the flap is more significant for shorter flaps. In fact, the increase in Cl for the 5% flap with respect to the case without flap is significantly higher than the increase obtained from length 5% to 10% and larger than from 10% to 20%. The flow separation starts at lower angles of attack for longer flaps. Regarding the maximum Cl and stall process, there are no clear trends observed associated to the length of the flap.

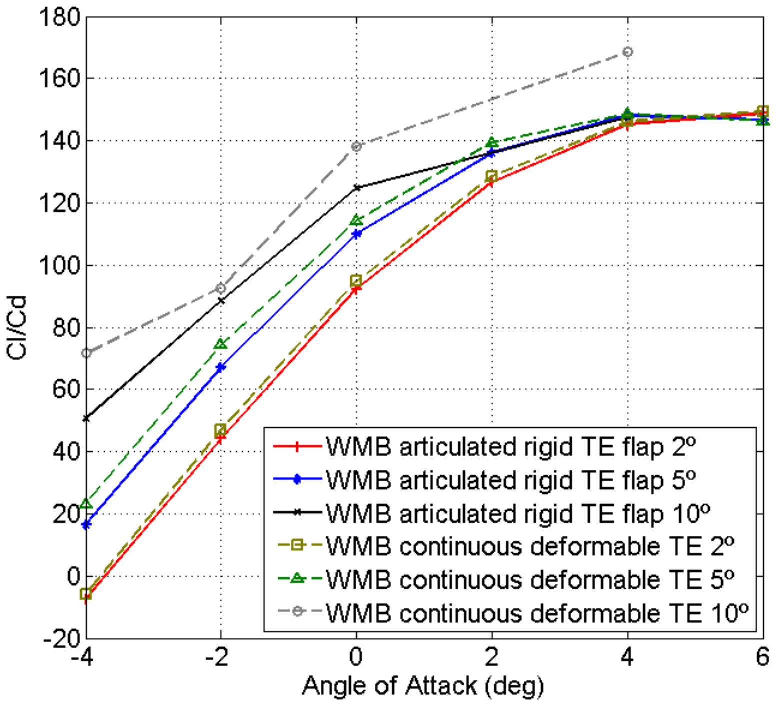

Figure 4: Cl/Cd vs α at flap deployment 2º, 5º and 10º, articulated and deformable flap, WMB results

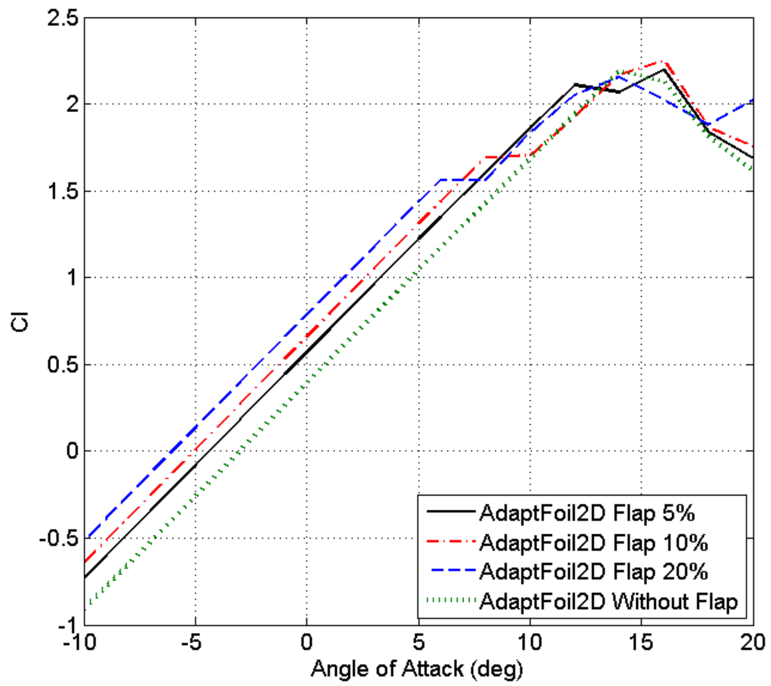

Figure 5: Cl vs α at different TE flap lengths 5%, 10% and 20% chord, flap deployment 5º, AdaptFoil2D results

Conclusions

The validation of the aerodynamic tools has been successful, with a good agreement between the simulations and the experimental data. In addition, the deviations are limited and can be explained taking into account the models used in the different codes.

The parametric study allows the selection of design parameters and operating condition for the flap. The selected solution for flap shape is a continuous deformation of the TE region. In terms of flap deployment and in the context of the Innwind.EU rotor, a negative and positive flap angle of 15º has been chosen. Moreover, the recommended length for the TE flap is a 10% of the chord. Finally, from a control point of view and dealing with frequencies up to 3P, a range of flap actuation from 0 to 5Hz is decided. The selected values for the parameters of the flap to be integrated in the Innwind.EU rotor are shown in Table 2.

shape	βmax (º)/ βmin (º)	Frequency (Hz)	length (%c)
deformable	+15 /-15	0 to 5	10

Table 2. Parameters of the TE flap.

Learning objectives

The learning objectives of the present paper lie on the aerodynamic modelling of flow devices (concretely TE flaps) for application on large (10MW+) wind turbines. The definition of the modelling methodology, validation and parametric study are the first step in the design process towards the integration of flow control devices in the wind turbine blade.