Wind turbine aerofoils

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LARGE EDDY SIMULATION OF WIND TURBINE AEROFOILS NEAR STALL: A NUMERICAL STUDY

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ABSTRACT

A large eddy simulation (LES) study of the flow pattern around a typical wind turbine aerofoil sections is performed. The DU-96-180 is investigated in attached and nearly-stalled conditions (4-20 deg of angle of attack) with two ranges for the Reynolds number ($\mathcal{R}e=1.50\times10^5\div1.13x10^6$). The resulting flow pattern is then compared and validated with available results from the literature.
This configuration has been chosen, because it is a challenging setup to be modelled with accuracy using Reynolds Averaged Navier–Stokes (RANS) technique. Also mesh requirements and transitional behavior constitute a complexity for Large Eddy Simulation (LES), which usually requires large grids and small time-steps. The behaviour of an aerofoil near stall is characterized by the formation of a laminar separation bubble (LSB), which triggers transition or separation due to the adverse pressure gradient which is present because of the enhanced angle of attack α.
In this study the alternative wall-modelled LES (WM-LES) approach is implemented as an alternative to the traditional wall-resolved LES (WR-LES): the two approaches will be using the Smagorinsky technique with vanDriest damping at the wall.
The purpose is to optimize the grid requirements towards a more cost-effective simulation, without losing accuracy.

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NOMENCLATURE

c	=	Chord length (m)
LES	=	Large Eddy Simulation
LSB	=	Laminar Separation Bubble
RANS	=	Reynolds-Averaged Navier-Stokes
$\mathcal{R}e$	=	Reynolds number (-)
SGS	=	Sub-Grid Scale
URANS	=	Unsteady RANS
WM-LES	=	Wall-Modelled LES
WR-LES	=	Wall-Resolved LES
α	=	Angle of attack (deg)

INTRODUCTION

Large Eddy Simulation (LES) is accounted as a fast-growing tool to be used also for industrial applications especially when enhanced accuracy for the fluctuating statistics of flows are needed [1]. Among other industrial and aeronautical applications, this also applies to wind turbine aerodynamics [2]. LES was shown to predict accurate statistics for the calculation of the radiated noise from aerofoils [3]. LES is also accurate, when specific fluctuating inlets are investigated [4], in particular regarding the prediction of the decay of turbulence in wakes [5]. Therefore, a large number of application with complex geometries have also been fulfilled successfully [6], [7]. However, using LES for actual industrial flows, still remains an expensive task [8]. This has a twofold reason: (i) the mesh requirements because of the complexity of boundary layers; (ii) the time-stepping requirements, as high-order schemes are often unstable and need for a short time step to be considered.

The research community has been working on the optimization of LES requirements [9]. The main areas of concern are recognized in: (i) the use of wall-functions [10]; (ii) the use of a dynamic mesh local refinement or further computational techniques [11]. The problem is then twofold: on one hand the accuracy of LES is dependent on strict computational setups, which the research is trying to loosen up by proposing improved Sub-Grid Scale models; on the other new computational setups are investigated to overcome the limitations within the dependency of SGS models to grid and time-stepping, however this has a major impact on the accuracy of the simulation.

Nevertheless, LES remains the best technique to reproduce fluctuating statistics [9].

This work is aimed to test the effectiveness of LES to simulate the fluctuating and peak characteristics of the flow pattern around a wind turbine aerofoil, in order to be used on the response under turbulent structures. This work is the outcome of a collaboration between the Department of Civil Engineering of the University of Birmingham (United Kingdom) and the Department of Environmental and Applied Fluid Dynamics of the Von Kármán Institute of Fluid Dynamics (Belgium), under the European Commission Framework Horizon2020, funded by the Marie Skłodowska-Curie Innovative Training Networks (ITN) "AEOLUS4FUTURE - Efficient harvesting of the wind energy" (H2020-MSCA-ITN-2014: Grant agreement no. 643167).

METHODOLOGY

In this study, the ability of LES to produce accurate fluctuating flow statistics will be investigated for a model wind turbine aerofoil in a uniform smooth flow. Both the URANS and the LES technique will be implemented for comparison. The comparison will be based on the fluctuating statistics of the flow pattern, as introduced. The aerofoil to be tested is the DU96w180 of the University of Delft, designed specifically for wind turbine aerofoil. It has a thickness of 18% and a smooth stall behavior [Ref.]. The aerofoil is modelled in two configurations, namely the pre-stalled configuration and the stalled one. The Reynolds number range which is chosen is based on the uniform inflow velocity u and the chord length c and is $\mathcal{R}e=1.5\times10^5\div10^6$.

The computational domain is 2D for both computational techniques, whereas in LES the span-wise dimension is indeed discretized by 5-10-20 cells in order to understand the effect of a quasi 2D computational domain in the accuracy of results. Moreover, a brief evaluation of the discretization schemes is proposed in order to understand the possibility of having an even more cost-effective computational strategy using hybrid or bounded schemes. The computational Domain is sketched in Fig. 1.

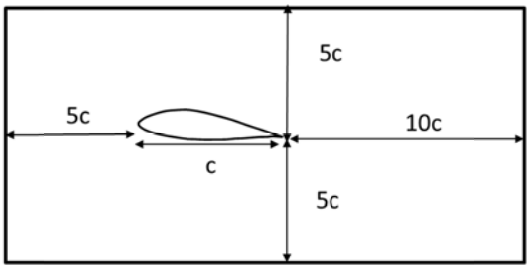

Figure 1. The main domain configuration (Case #1)

A series of LES SGS models is tested, comparing them with RANS technique. Table 1 summarises the computational models to be setup.

Table 1. List of computations

Computational models			
CFD technique		2D models – DU96w180	
		Pre-stall 4deg	Stall 20deg
1	RANS *k-ω* SST	×	×
2	URANS *k-ω* SST	×	×
3	WRLES Smagorinsky y+=1	×	×
4	WMLES Smagorinsky y+=5	×	×

As the aim is to setup a CFD framework to yield accurate fluctuating statistics, different mesh, from hybrid to structured grid, will be implemented and tested with respect of their refinement. This is of extreme importance for the assessment of the separation point and its intermittent behavior as well as the existence of a separation bubble. Fig. 2 shows the structured mesh, with the adjustments undertaken to limit the Courant number in the regions of accelerated flow on the suction and pressure side of the aerofoil.

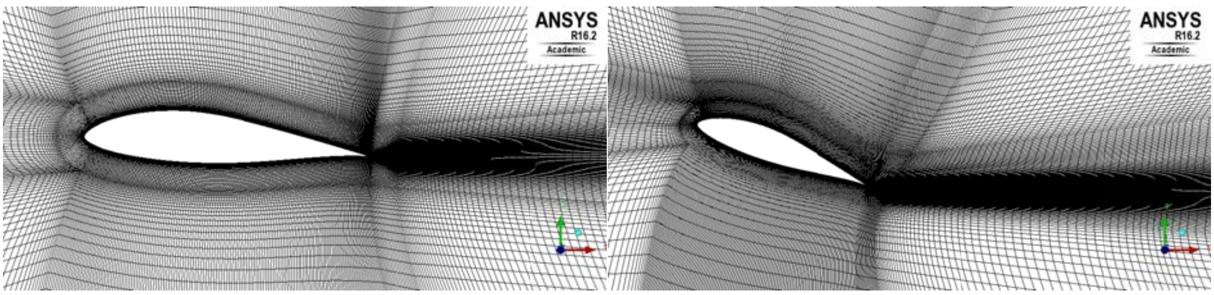

Figure 2. Structured hexa block C-Grid for the pre-stalled (a) and stalled (b) configurations.

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