Analysis of the high Reynolds number 2D tests on a wind turbine airfoil performed at two different wind tunnels

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1.Introduction

Within the EU FP7 AVATAR project (AdVanced Aerodynamic Tools of lArge Rotors), 2D tests have been performed at high Reynolds numbers in order to evaluate airfoil performance under the expected conditions of the future multi-MW wind turbine blades. The DU00-W-212, a 21% relative thickness airfoil from the DU wind turbine dedicated airfoil family, has been tested at the DNW High Pressure Wind Tunnel in Göttingen (HDG) at 5 different Reynolds numbers (3, 6, 9, 12 and 15 million) and low Mach numbers (below 0.1). In parallel, LM Wind Power has performed at his own wind tunnel facility a test on this same airfoil at two different Reynolds numbers, 3 and 6 million, and Mach numbers of 0.14 and 0.28 respectively.

The comparison of the results from these two experiments gives a good opportunity to check the repeatability of the results of airfoil aerodynamic performance data when obtained at different facilities, but also, as one of the most important difference between the tests is the different Mach numbers conditions, the comparison also gives some sight into the compressibility effects on airfoil aerodynamic coefficients.

2.Approach

Both wind tunnel tests have been performed on a 2D model of the DU00-W-212 airfoil arranged horizontally in a closed test section. The models were instrumented with pressure taps to capture the static pressure distribution around the airfoil and a wake rake downstream to measure the total pressure of the wake. Lift and Pitching moment coefficients were obtained by integration of the pressure distribution around the airfoil and Drag coefficient was calculated from the wake loss of momentum by integrating the wake total pressure distribution.

The description of each of the wind tunnel facilities and their particular test arrangement is described below:

HDG wind tunnel test:

The DNW HDG is a closed return circuit wind tunnel with a closed test section of 0.6 x 0.6 m. (width x height) and 1 m. length, and a contraction ratio of 5.85. The wind tunnel speed range is 3.5 to 35 m/s and the maximum Mach is 0.1. This tunnel can be pressurized up to 100 bars to achieve high Reynolds numbers.

A 150 mm. chord 2D airfoil model was horizontally installed in the middle of the test section and was equipped with 90 pressure taps.

Test at LM:

LM wind tunnel is an atmospheric closed return circuit wind tunnel with a closed test section of 1.35 x 2.7 m. (width x height) and 7 m. length. The maximum wind speed at the test section is 105 m/s.

A 900 mm. chord 2D airfoil model instrumented with pressure taps was horizontally installed in the test section.

The main differences between the tests can be summarized, on one hand in the geometric set up of the models and test sections, and on the other in the different wind conditions. Table 1 summarizes the geometric differences while table 2 shows the compared wind conditions.

	HDG	LM
Test section (W x H)	0.6 m x 0.6 m	1.35 m x 2.7 m
Model span (S)	0.6 m	1.35 m
Model chord (c)	0.15 m	0.9 m
Model aspect ratio (S/c)	4	1.5
Geometric blockage (c/H)	25%	33%

Table 1 Geometric set up differences between the two experiments

	Reynolds 3million test		Reynolds 6 million test	
	HDG	LM	HDG	LM
Mach number (M)	0.08	0.139	0.03	0.279
Turbulence intensity (Ti)	0.1 %	0.05 %	0.2 %	0.1 %

Table 2 Wind condition differences between the two experiments

Comparisons of Lift and Drag data between both experiments at Reynolds numbers of 3 and 6 million have been done and analyzed. Some computations using the panel method code XFOIL version 6.96 have been performed for the Reynolds 6 million case at different Mach numbers and at different factors of the e^N transition method, in order to try to match the inflow turbulence effect.

3.Main body of abstract

A comparison of the results obtained in both tests are presented below. The Lift Coefficient against AoA, the lift coefficient against drag coefficient and the efficiency (lift/drag) against angle of attack have been plotted for the Reynolds number 3 million case and for the 6 million one.

Reynolds 3 million comparisons:

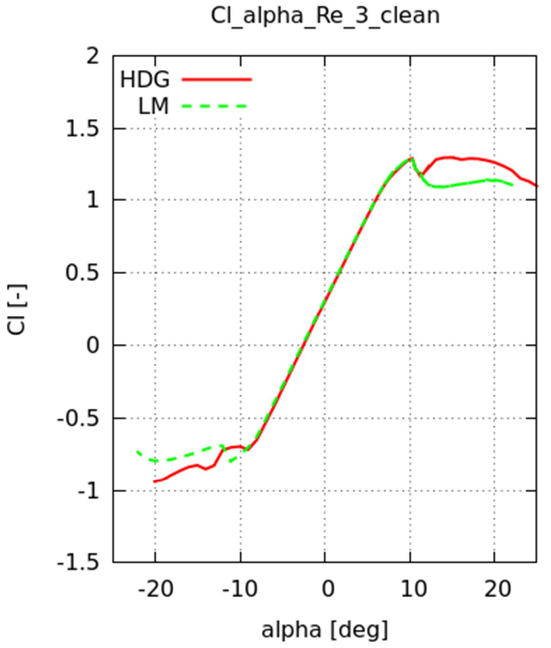

Figure 1 Cl vs AoA comparison at Re=$3\cdot10^6$

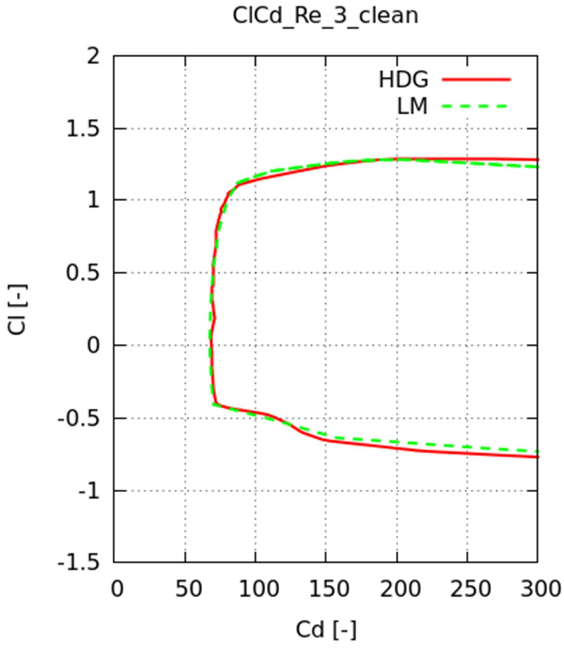

Figure 2 Cl vs Cd comparison at Re=$3\cdot10^6$

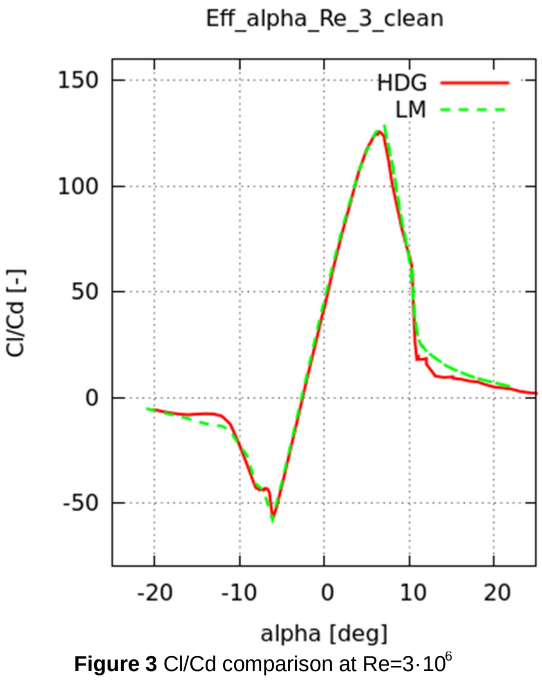

Figure 3 Cl/Cd comparison at Re=$3\cdot10^6$

The comparison at 3 million Reynolds number of the lift coefficient is very good. The curves match in the linear region. Only different behavior is observed at stall, where 3D effects are observed and the differences in test section and model aspect ratio can derive into different results. Also the drag matches very well. Figure 2 shows how the drag bucket is completely reproduced in shape and values. Therefore, the efficiency curve is as well repeated in both tests.

Reynolds 6 million comparisons:

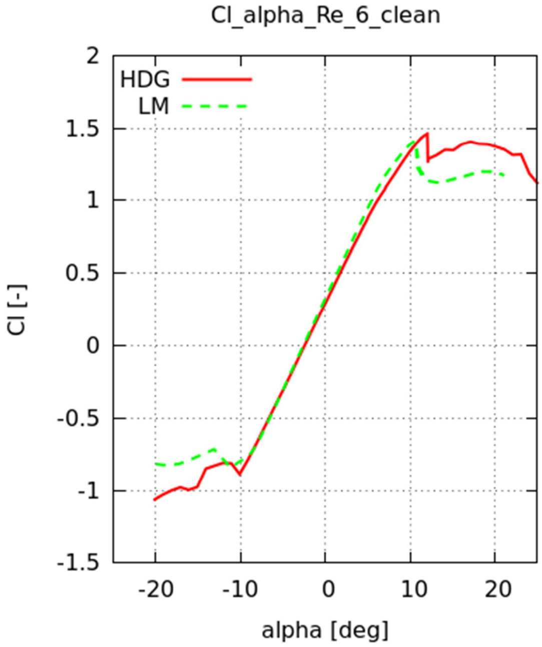

Figure 4 Cl vs AoA comparison at Re=$6 \cdot 10^6$

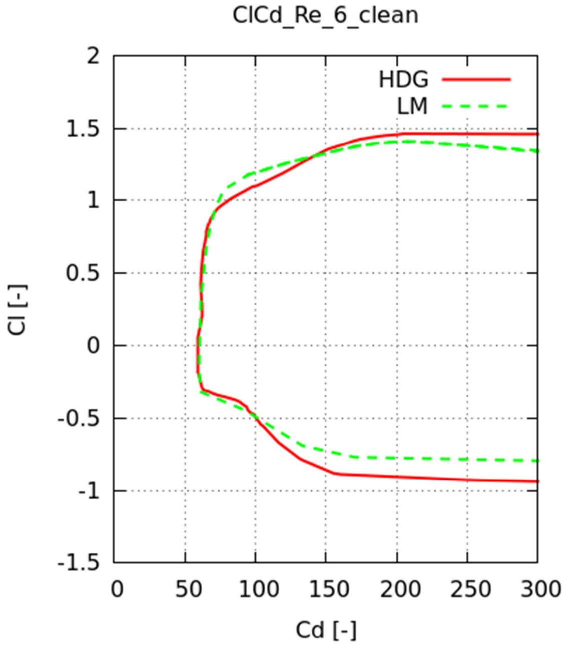

Figure 5 Cl vs Cd comparison at Re=$6 \cdot 10^6$

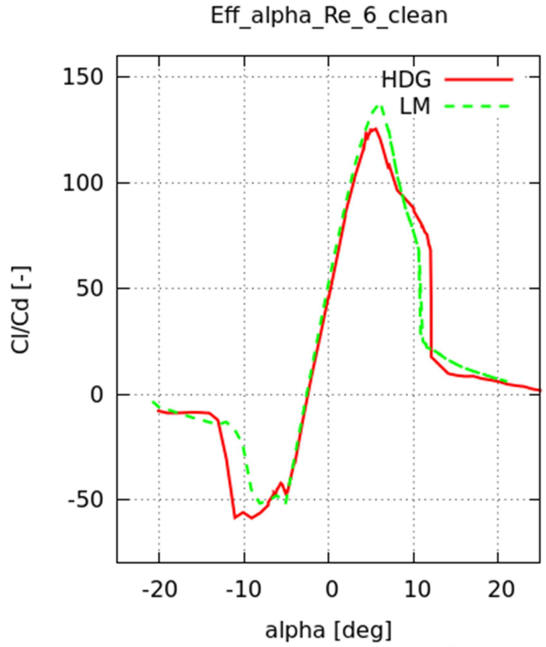

Figure 6 Cl/Cd comparison at Re=$6 \cdot 10^6$

In this case the results from both tests don't show such good agreement. We can already see in figure 4 how the lift slope is different and greater in the data from LM test. The drag values keep a very good comparison in the linear region but the bucket corners (as it can be seen in figure 5) are different, indicating a different behavior on separation. Attending to these differences between lift and drag, the efficiency curve shows the worst agreement in the maximum values, as LM results have a greater lift due to its higher slope and a lower drag in the upper bucket corner.

The next step is to check if it is coherent to have different repeatability results at each Reynolds number. We look therefore to tables 1 and 2 to see the differences we have at each condition. The set up differences listed at table 1 are the same for both Reynolds. Although their effect on the results could have some variability depending on Reynolds, they affect mainly the results when separation occurs, at high angles of attack. Table 2 shows different wind conditions at each Reynolds number. The turbulence is in both cases twice at HDG. What it could be most expected from different air stream turbulence level is a different measurement in drag.

On the other side, we can see that Mach is in the same order for the Reynolds 3 million case (although higher at LM), but for the Reynolds 6 million case is one order of magnitude higher at LM. This happens because at LM, which is an atmospheric wind tunnel, the Reynolds number is increased by increasing the wind speed. But at HDG, the higher Reynolds numbers are achieved by increasing the wind air pressure but always with low Mach numbers.

The higher slope of the lift coefficient is compatible with higher Mach number. An analysis using the panel method code XFOIL version 6.96 to evaluate the differences we can expect by modifying Mach number and inflow turbulence. In figures 7 to 9, the experimental differences for Reynold number 6 million case (at the left) are compared to computations differences when Mach number and N factor are modified.

The XFOIL computations are coherent with the idea that Mach effect influences mainly the lift slope and the different inflow turbulence affect the drag especially at separation. Then the different values at 6 million Reynolds can be explained with the different wind conditions in each tunnel.

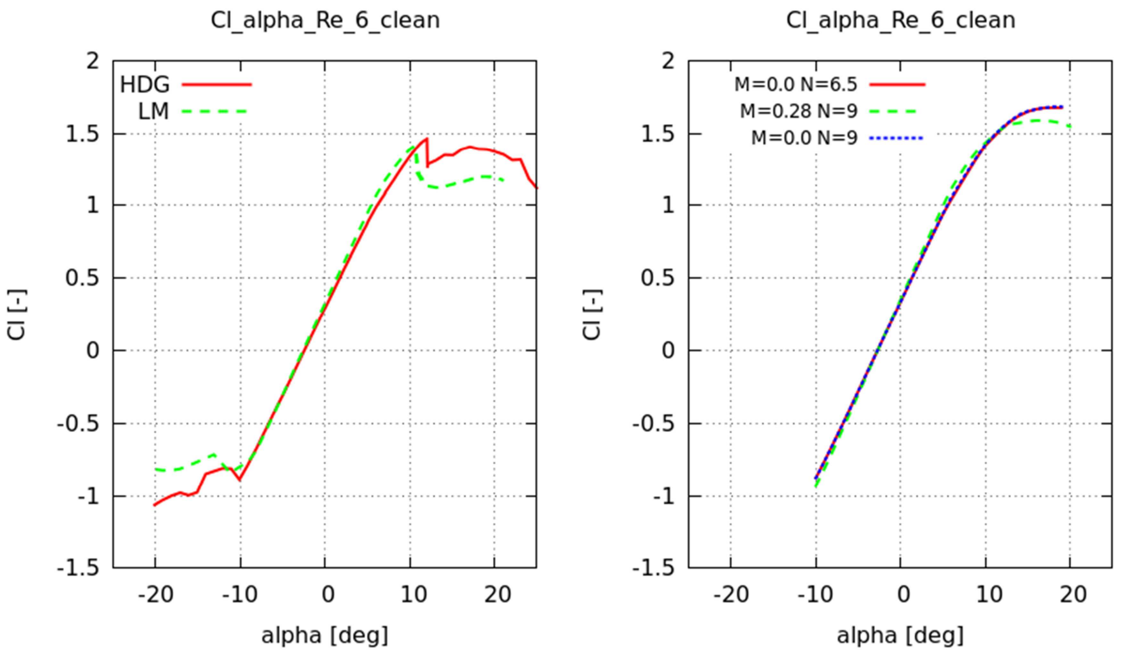

Figure 7 Experimental and XFOIL computations of Cl vs AoA at Re=$6\cdot10^6$

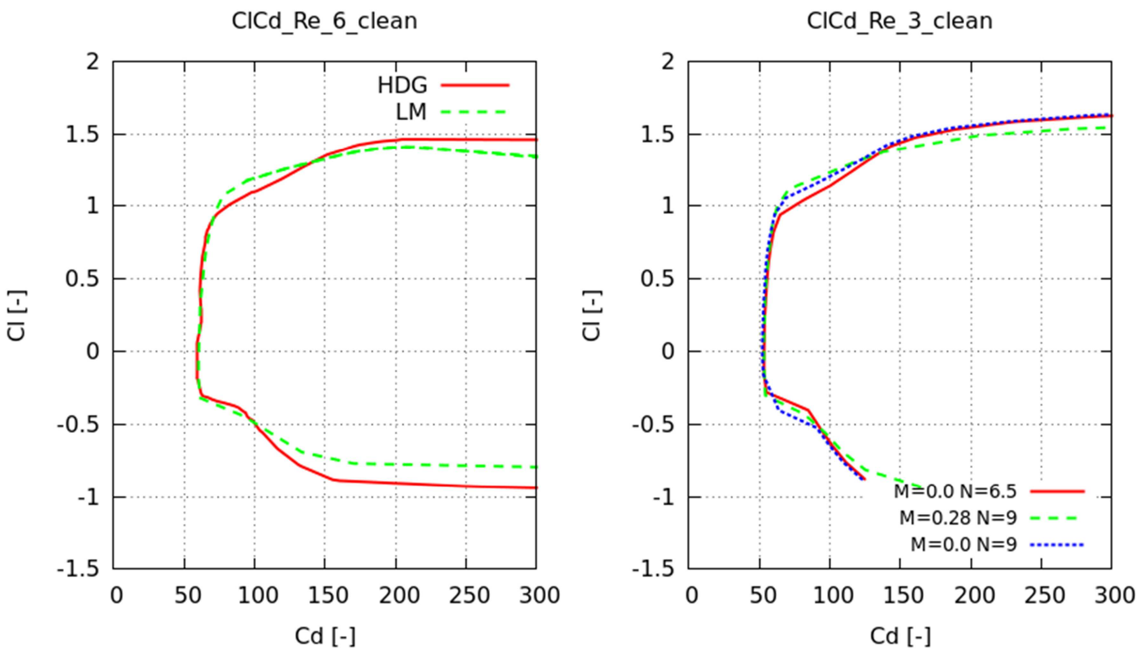

Figure 8 Experimental and XFOIL computations of Cl vs Cd at Re=$6\cdot10^6$

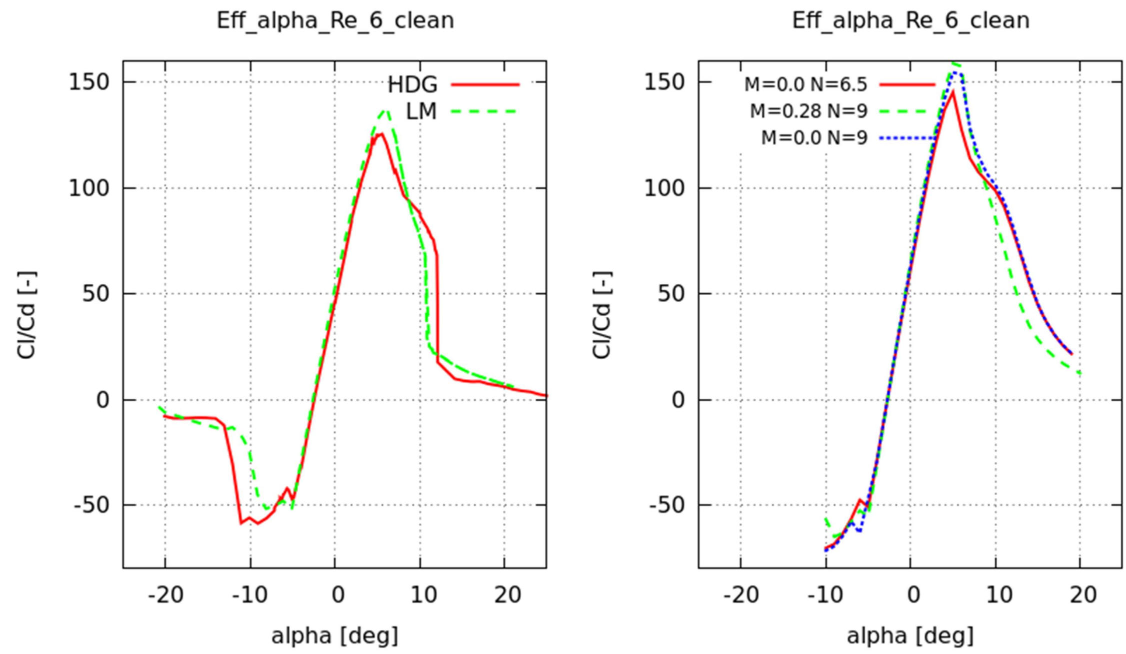

Figure 9 Experimental and XFOIL computations of Cl/Cd at $Re=6\cdot10^6$

4.Conclusions

- Comparison of two wind tunnel tests of the same airfoil have been done obtaining very good results. This implies that the methods and technics used to obtain experimental data from the airfoils at different Reynolds numbers are reliable.
- Since HDG can test one airfoil at different Reynolds numbers at low Mach numbers, their data can be used to analyze the separate effect of the Reynolds number.
- The comparison done shows an example of the Mach effect observed at Reynolds 6 million.

5.Learning objectives

- To check the reliability of 2D wind tunnel tests by comparing results from different facilities.
- To evaluate the separated effect of compressibility at a constant Reynolds number

References

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[2] Schewe G 2001 Reynolds-number effects in flow around more-or-less bluff bodies J. Wind Eng. & Ind. Aerodyn. 89 1267-1289