A 3D Vs Q3D Vs 2D CFD analysis of 5MW NREL reference wind-turbine

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INTRODUCTION AND OBJECTIVES

Turbine-blade manufactured for a real wind-farm operation generally comprises of multiple-airfoil segments. These segments impart a complex 3D geometry to the whole blade involving span-wise variations of the chord length, blade thickness ratio and blade twist . Hence, there is a need to understand the influence of 3D bluff body effects. The current study focusses on stand-still aerodynamics, which has relevance in wind turbine operation. Generally, wind-turbine blades are designed for rotating conditions with tapering of blade thickness from root to tip and varied span-wise blade twist (which helps to maintain an optimum power coefficient and similar angle of attack throughout blade-span). This geometric optimization works well in the rotating operational environment for which it is meant. However, in non-rotating environment (i.e. the stand-still aerodynamics condition), the blade twist optimized for rotation will make the flow artificially 3D compared to the actual rotor flow itself. Such conditions of stand-still aerodynamics may arise when both yaw and pitch regulations are off-line, say during the turbine-erection phase before the wind turbines are connected to the electrical grid. In absence of a wind turbine control situation during off-line, the angles of attack of the flow on the blades are determined by the free wind direction, and the wind-turbine may operate outside the narrow normal operational range. In such stand-still situations, complex 3D effects may exist owing to both the operating circumstances and the 3D complex turbine geometry. Hence, the **main objectives of this work are : (a) To identify the impact of bluffness of turbine-geometry and impact of changing cross-section of NREL 5MW under a stand-still aerodynamics condition on the flow-physics, and, (b) Comparing the flow physics obtained from 2D Vs Q3D (2.5D) vs 3D simulations.**

METHODOLOGY- VALIDATION AND SIMULATION

The NREL 5 MW turbine is a popular reference industrial scale wind turbine and hence has been chosen for this study. Four airfoil segments of the NREL 5 MW blade which are located at varied span wise radial distance from hub (as shown in Table 1) are considered for comparing the 3D effects due to bluff shape and to compare the flow physics predicted by 2D Vs Q3D Vs 3D simulation. The 3D simulation refers to a full scale 3D blade simulations with computational domain (shown in Figure 1) and near blade mesh and segment location (shown in Figure 2) respectively. The Q3D (or 2.5D segments) are created by clipping the specific 3D airfoil section from the full scale 3D model so as to include the tapering effects along the radial direction Modeling this intermediate QSD (2.5D) behaviour enhances the intuition of the characteristic change in flow behaviour from simple two dimension to complete three dimension. 2D simulations involve four individual airfoil simulation along planes in Fig 2.

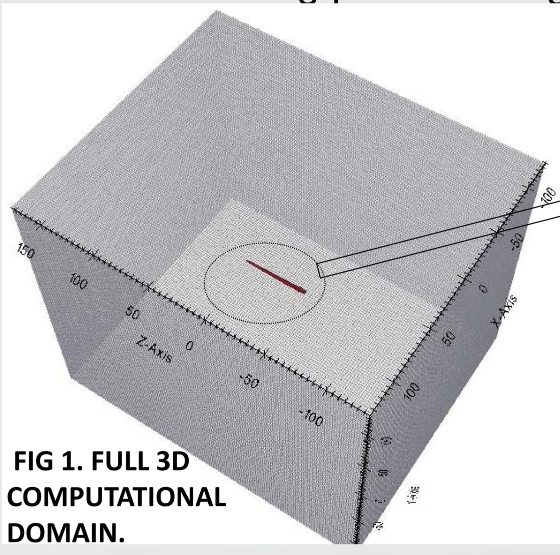

FIG 1. FULL 3D COMPUTATIONAL DOMAIN.

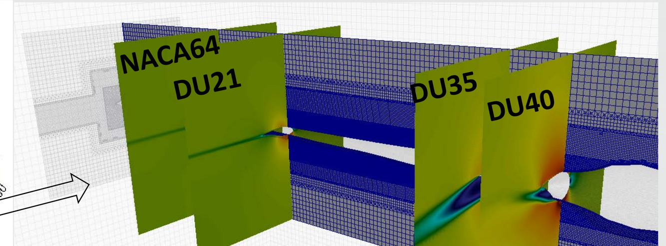

FIG 2. ZOOMED - LOCATION OF AIRFOIL SEGMENTS AND MESH NEAR BLADE.

Segment	location of segment from hub, *m*	Angle of attack, [0]	Chord length, m
NACA-64	at z=44.55 m	α=3.12°	c=3.01 m
DU-21	at z=36.35 m	α=-5.36°	c= 3.50 m
DU-35	at z=15.85 m	α=-11.48°	c=4.65 m
DU-40	at z=11.75 m	α=-13.30°	c=4.55 m

TABLE 1. LOCATION OF AIRFOIL SEGMENTS AND PROPERTIES.

The validation of results from 2D model is given below.

RESULTS – VALIDATION OF 2D MODEL AND COMPARISON OF 2D VS 2.5D AND 3D ON DRAG AND LIFT COEFFICIENTS.

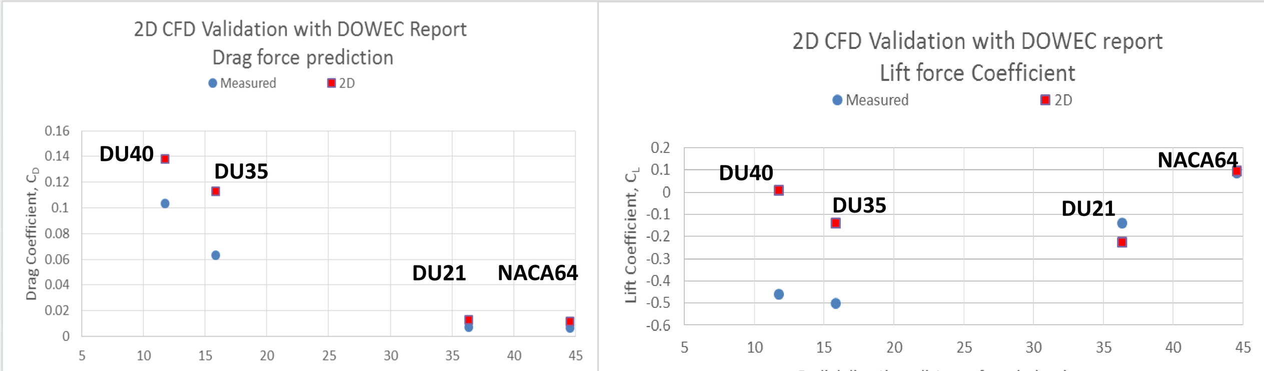

Figure 3 **above** – In regions away from hub (at NACA64), the 2D simulated lift and drag coefficient results are in close agreement with the measured results (DOWEC* report). This is because the flow is mostly 2D away from hub. As we move in the near hub region at DU40, the 2D results deviates a lot from measurements as influence of 3D effect dominates. **Figure 5** shows the increase in flow complexity as we move away from hub.

*Kooijman et. al.. 2003. DOWEC 6 MW Pre-Design. Public report - DOWEC 10046-009.

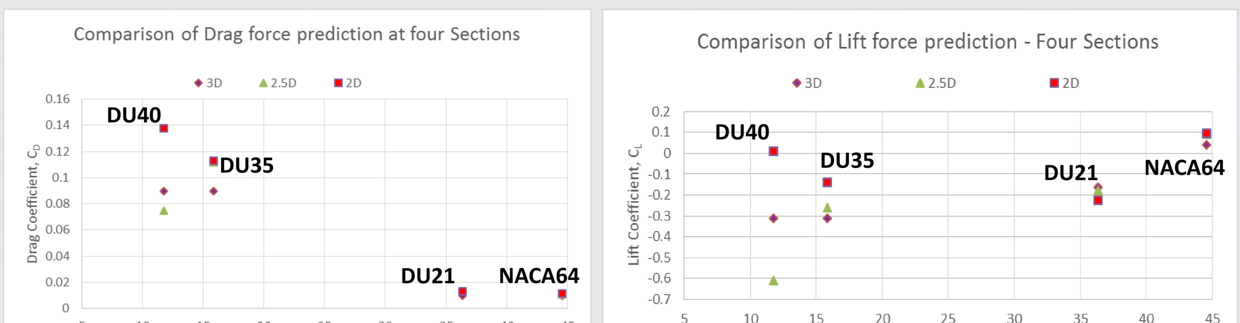

Figure 4 **above**[1] : Comparison of 2D Vs 2.5D Vs 3D predictions of drag and lift coefficient. 3D and 2.5D results cannot be compared with measured values reported in DOWEC because the turbine blade geometry has more tapering than the individual airfoil geometry studied in DOWEC.

RESULTS– 2D VS Q3D VS 3D PREDICTED FLOW AT FOUR AIRFOIL SEGMENTS.

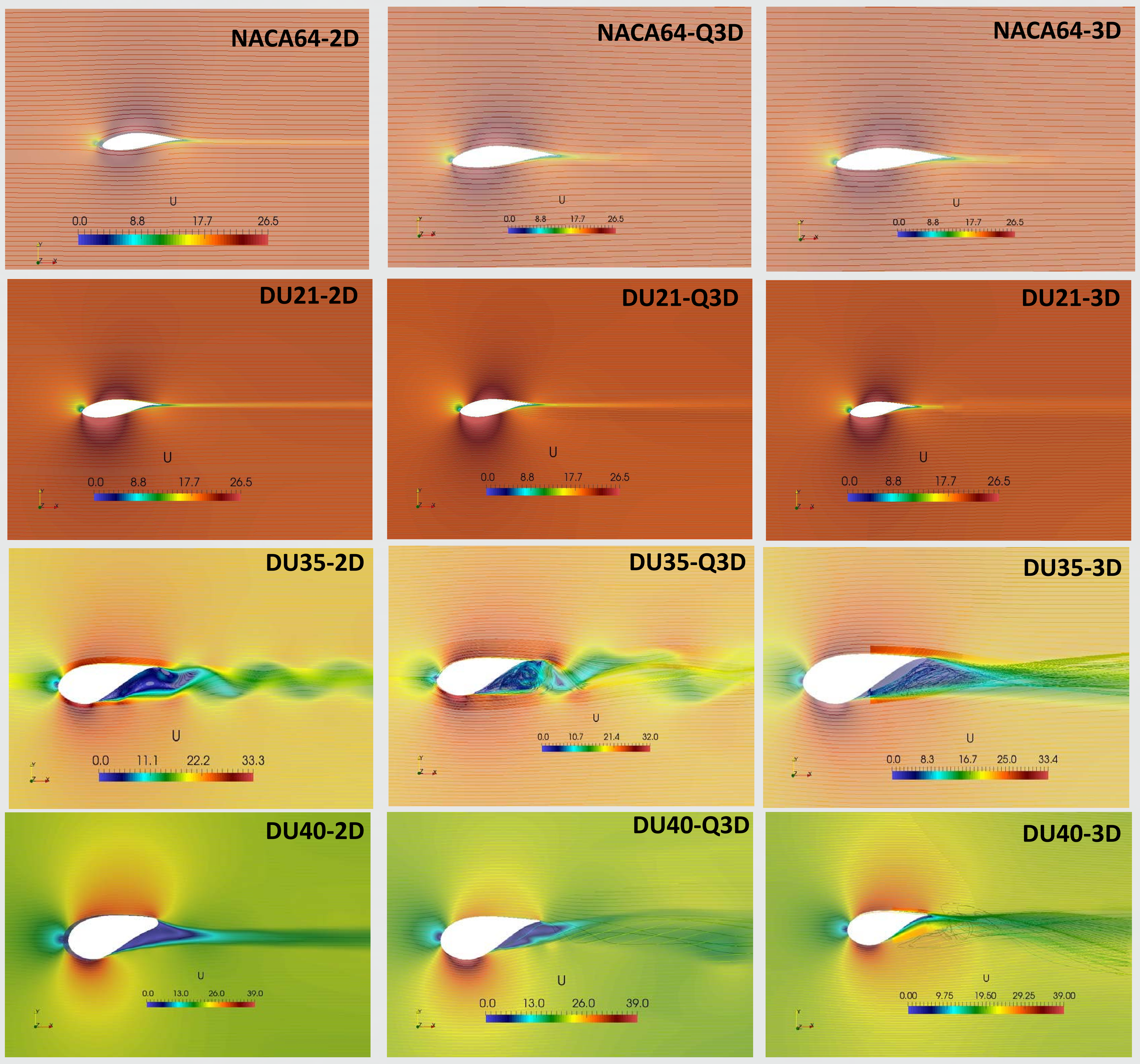

Figure 5: *Flow profiles obtained by 3D Vs 2.5D Vs 2D simulation at four airfoil segments of the turbine blade.*

NACA64 airfoil profile is located farthest from the hub (at z=44.5m) with an angle of attack of 3.12^0. It experience a streamlined flow and there is negligible difference between the three simulations (2D, 2.5D, 3D) and the predicted drag and lift coefficient, implying, a lack of three dimensionality and associated unsteadiness in the flow behavior.

The DU40 airfoil is the closest section to the hub that has been studied (at z=11.75m) with highest angle of attack of 13.3^0. Here, the reported drag and lift coefficient values (Figure 4) are higher in magnitude than the simulated values for DU35, DU21 and NACA64. Similar to DU35, the DU40 case also have shown a **high variations** in the predicted drag and lift coefficient values from the three approaches which can be attributed to difference in flow physics captured by 3 approaches (Figure 5).

CONCLUSION

This work has been able to identify the impact of bluffness of turbine-geometry. The results indicate that even for a non-rotating blade (in stand-still aerodynamic condition), the blade-segments nearer to the hub, the flow is dominated by complex 3D structures and as one moves away towards blade segments located towards the tip, the flow begins to loose its 3D characteristics and can be reasonably well represented by efficient 2D simulations. Since the outer part of the blade makes a significant contribution to the total torque generated, a 2D approach might be sufficient to predict torque and associated power reasonably well. However, a 3D approach will still be required to predict structural failure and for efficient blade design.

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