CFD wake modeling using a porous disc

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SUMMARY OF THE WORK

Single wakes over flat terrains are modeled with a finite-volume CFD RANS code (WindSim). The RANS equations of an uncompressible flow are solved with a multigrid coupled solver (MIGAL); turbulence is closed with the standard k-ε model. The tower and the nacelle of the wind turbine are modeled by solid cells while the rotor is modeled by a porous disc providing a resistive force which is calculated from the thrust coefficient C_T. Comparisons of CFD results are presented against experimental data, wind tunnel tests from Vermeer *et al.* [1]. The numerical results are further compared against three analytical models for wakes [2,3,4].

1. ACTUATOR DISC

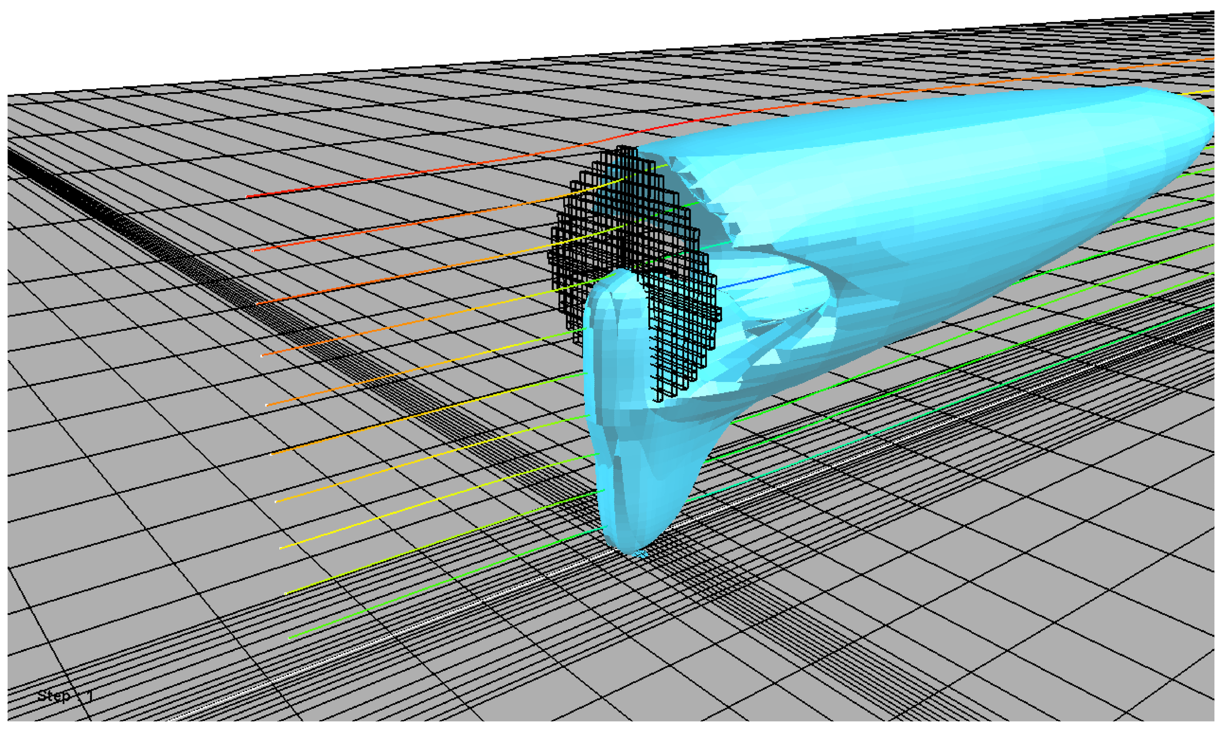
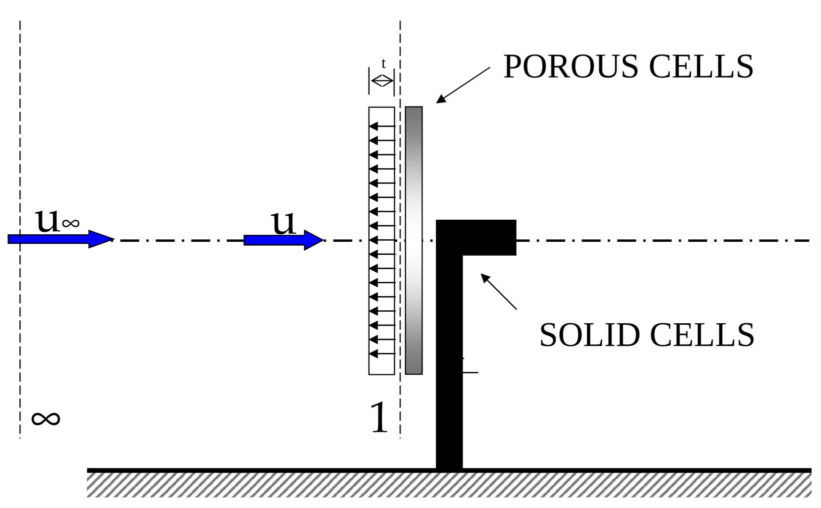


Figure 1. Perspective view of the actuator disc, streamlines and iso surface of turbulent kinetic energy (1,4 m²/s², U_e 10 m/s at 500m a.g.l.).



Axial induction factor:

$$a = \frac{u_\infty - u_1}{u_\infty} \quad \textit{By definition}$$

$$a = \frac{1}{2}\left(1 - \sqrt{1 - C_T}\right) \quad \textit{Betz's theory}$$

The thrust, momentum sink for the axial flow, is supposed evenly distributed on the swept area (pressure drop):

$$t = T/A = C_T \frac{1}{2}\rho u_\infty^2$$

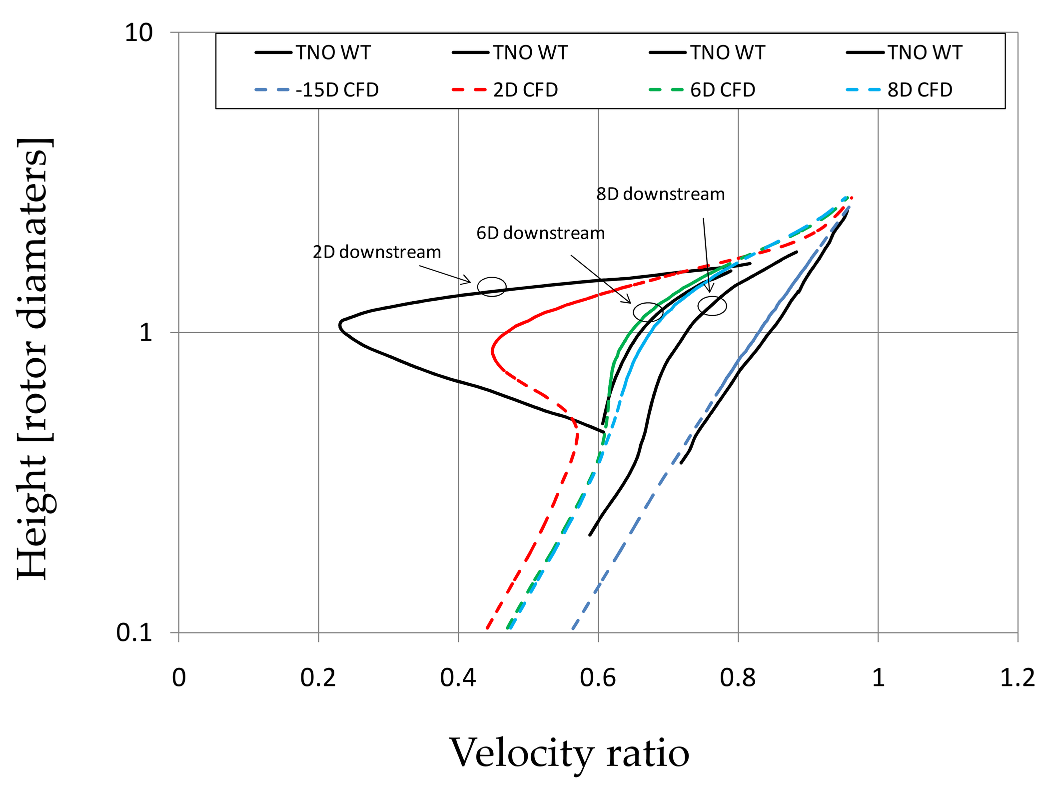


Figure 2. Vertical profiles of normalized velocity from TNO Wind Tunnel tests (solid black lines), from Vermeer *et al.* [1], predicted by the actuator disc CFD model (coloured lines).

2. COMPARISONS WITH WIND TUNNEL DATA

Vertical profiles of velocity ratios (U/U_e; beeing U_e the free stream velocity) downstream of the wind turbine are presented in Figure 2, comparisons are done with wind tunnel measurements from TNO and reported in Vermeer *et al.* [1]. The behavior in the near wake (2D downstream) is not captured but a simulation with a porous plate does not pretend to solve exactly the near wake flow. The velocity profile at 6 diameters downstream is instead fairly forecasted but further downstream there are again discrepancies between the velocity profile predicted by the CFD calculations and the wind tunnel measurements by the TNO, this difference could be explained by a not sufficient turbulent mixing predicted by the CFD calculations.

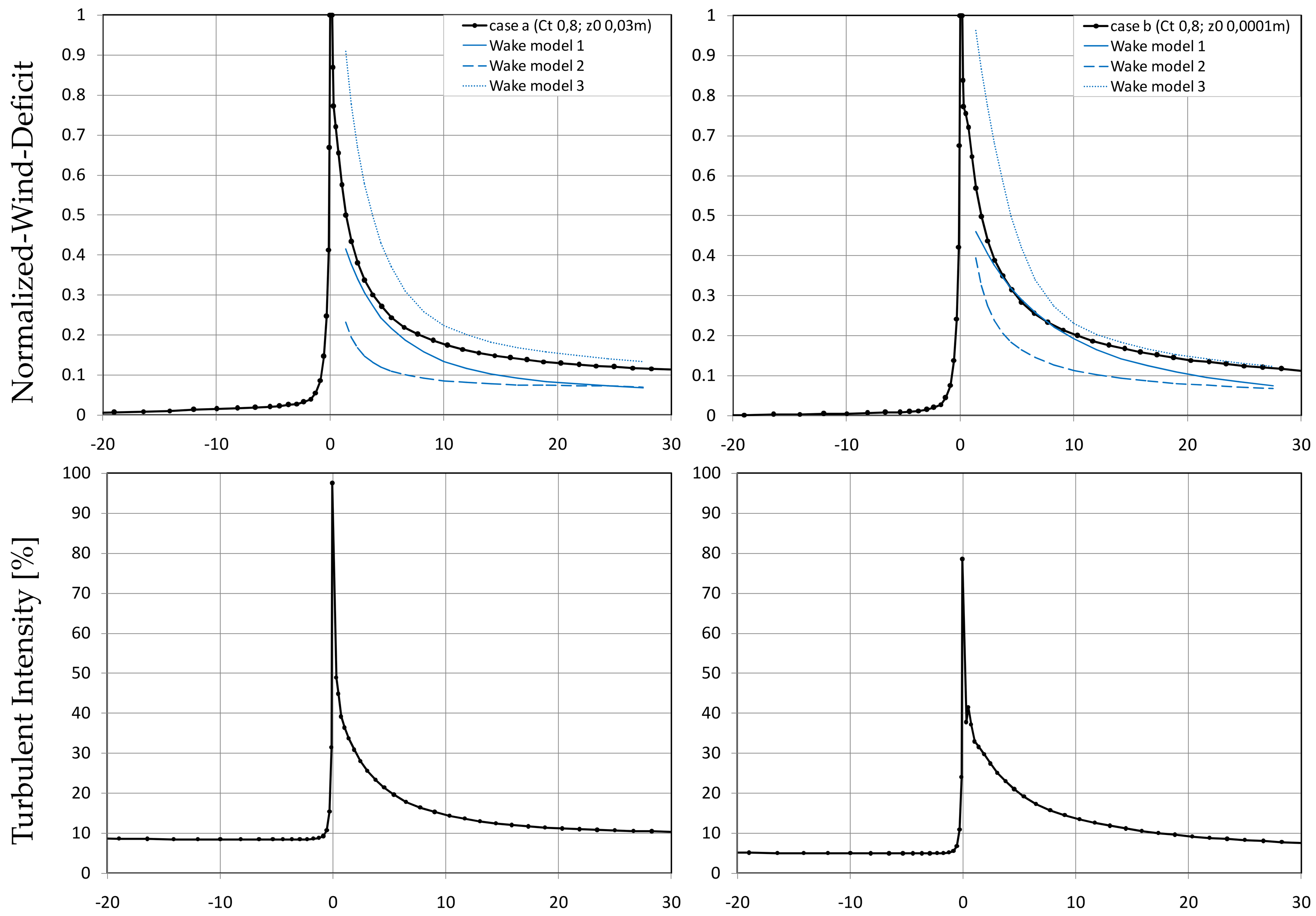
3. COMPARISONS WITH ANALYTICAL MODELS

Analytical models:

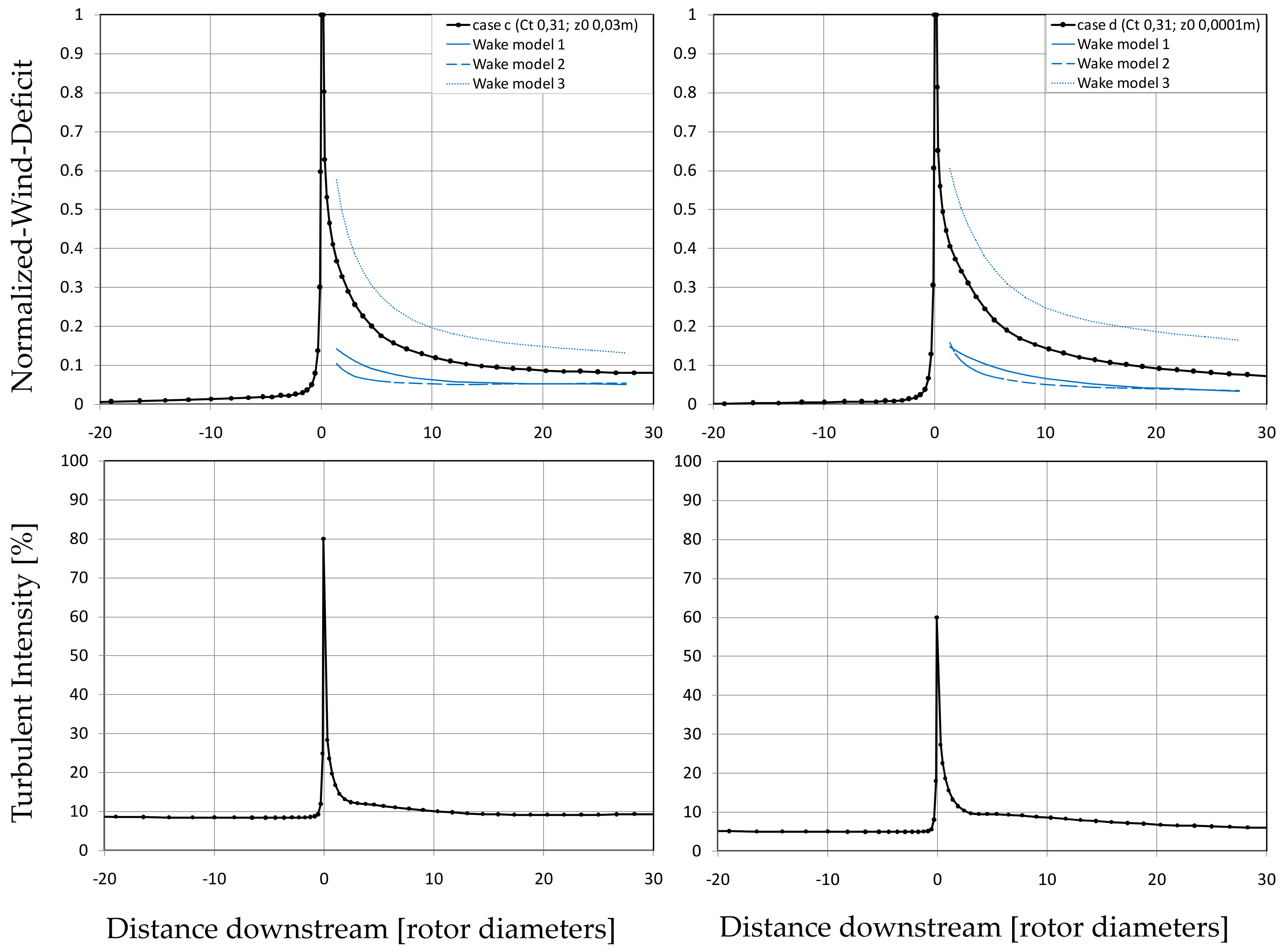
1. Jensen model [2]
2. Larsen model [3]
3. Ishihara et al. model [4]

Cases:	z_0 0,03m	z_0 0,0001m
C_T 0,80	a	b
C_T 0,31	c	d

Case a: C_T = 0,80; z_0 = 0,03 m (onshore) **Case b:** C_T = 0,80; z_0 = 0,0001 m (offshore)



Case c: C_T = 0,31; z_0 = 0,03 m (onshore) **Case d:** C_T = 0,31; z_0 = 0,0001 m (offshore)



REFERENCES

[1] VERMEER L.J, SØRENSEN J.N., CRESPO A. (2003). WIND TURBINE WAKE AERODYNAMICS. PROGRESS IN AEROSPACE SCIENCES 39 (2003) 467–510.

[2] KATIC, I., HØJSTRUP, J., JENSEN, N.O. "A SIMPLE MODEL FOR CLUSTER EFFICIENCY." EWEC PROCEEDINGS, 7-9 OCTOBER 1986, ROME, ITALY.

[3] LARSEN, C. G. "A SIMPLE WAKE CALCULATION PROCEDURE." RISØ-M-2760, 1988.

[4] ISHIHARA, T., YAMAGUCHI, A., FUJINO, Y. "DEVELOPMENT OF A NEW WAKE MODEL BASED ON A WIND TUNNEL EXPERIMENT." GLOBAL WIND POWER 2004.

CONCLUSIONS

An actuator disc concept is applied to model a wind turbine in RANS simulations of a single WECS wake. A uniform pressure drop is applied on the disc; the value of the pressure drop is calculated from the thrust coefficient and axial induction factor. From comparison with WT [1] tests the wind deficit predicted by the CFD simulations is the under predicted in the near wake (2D diameters downstream), the level of wind deficit is instead correctly predicted at 6D downstream while in the far wake the wind deficit is overestimated. When comparing the presented actuator disc to some analytical models the best match is found to the Larsen [3].