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Abstract. In the present work, the in-house UnSteady Double Wake Model (USDWM) is used to simulate flows past a cylinder at subcritical, supercritical, and transcritical Reynolds numbers. The flow model is a two-dimensional panel method which uses the unsteady double wake technique to model flow separation and its dynamics. In the present work the separation location is obtained from experimental data and fixed in time. The highly unsteady flow field behind the cylinder is analyzed in detail, comparing the vortex shedding charactericts under the different flow conditions.

Keywords: cylinder, unsteady flow, panel method, vortex method, double wake

INTRODUCTION

With the future generation of 10MW and even larger wind turbines, new challenges arise for scientists and engineers in the wind energy community. Due to, mainly, structural reasons, the new designs demand longer and more slender blades which require thick and innovative airfoils designs, relatively new for the sector. This new generation of thick airfoil designs has become one of the main obstacles that aerodynamicists face nowadays. Besides, the existence of flow separation, which has been one of the main difficulties in the field of fluid mechanics for the last decades, becomes critical in the case of thick airfoil profiles. It is well-known that even for highly sophisticated Navier-Stokes solvers with complicated turbulence models is a hard task to predict the correct behavior of the complex vortex shedding behind thick bodies. This type of codes requires a fine mesh and a high amount of computational power.

With the aim of capturing the overall physics of separated flows over airfoils using panel methods, Maskew and Dvorak [1] developed a simplified model based on an inviscid flow solver, which could accurately simulate steady flows around airfoils at high angles of attack. Following this idea, Ramos-García [2] developed a double wake model (DWM) and Marion [3] extended it to focus on the deep stall region. Later on, the model was modified to account for the dynamics of vortex shedding by Cayron [4] and Ramos-García [5]. In the present study the unsteady version of the solver is employed to simulate subcritical, supercritical and transcritical flows around a cylinder, with the aim to assess the capability of the flow solver to capture the changes in vortex shedding frequencies associated with the different flow states.

NUMERICAL MODEL

A body in a fluid is considered, with the fluid moving with the free stream velocity, U_∞, and the velocity induced by the body, u. Considering a point in the domain surrounding the solid body, the total velocity can be defined,

$$U = U_\infty + u \tag{1}$$

Assuming that the flow is incompressible, inviscid and irrotational, u can be expressed as the gradient of the potential field, $\nabla\Phi$, where Φ satisfies the Laplace equation. The general solution to the Laplace equation can be obtained through a source and vorticity distribution around the body. Moreover, the shed vorticity behind the solid body can be modelled with downstream converging point vortices. The velocity induced at any point in the domain can therefore be written using the superposition principle as follows,

$$u = u_\sigma + u_\gamma + u_{\gamma W\,USEP} + u_{\gamma W\,LSEP} + u_{\Gamma\,USEP} + u_{\Gamma\,LSEP} \tag{2}$$

Where u_σ, u_γ, are the velocities induced by the airfoil distributed sources and vortices, $u_{\gamma W\ USEP}$, $u_{\gamma W\ LSEP}$, the velocities induced by the upper and lower separation vortex panels and $u_{\Gamma\ USEP}$, $u_{\Gamma\ LSEP}$, the velocities induced by the upper and lower wake vortices.

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In the USDWM, the cylinder is discretized in N panels following the sketch in Figure 1, with each of the panels represented by a linear distribution of vorticity, $\boldsymbol{\gamma_1}$ to $\boldsymbol{\gamma_{N+1}}$. Here, $\boldsymbol{\gamma_1}$ is the trailing vorticity of the first panel and $\boldsymbol{\gamma_{N+1}}$ is the leading vorticity of the last panel. The vorticity released at the upper and lower separation points are initially taken into account as two uniform panel distributions, γw_{USEP} and γw_{LSEP}, which later are convected into the wake region as point vortices. Finally a constant source distribution is applied over the cylinder, σ.

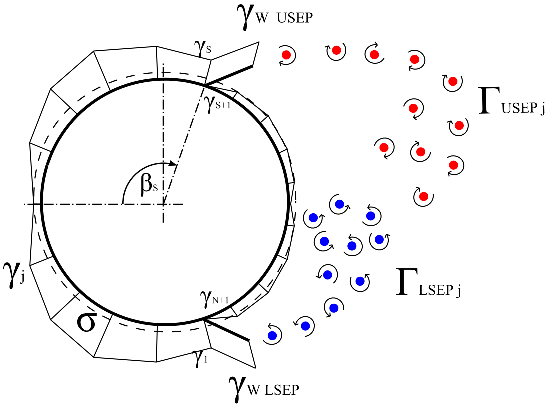


FIGURE 1. Sketch of the singularity distributions used in the USDWM to simulate the flow around a cylinder.

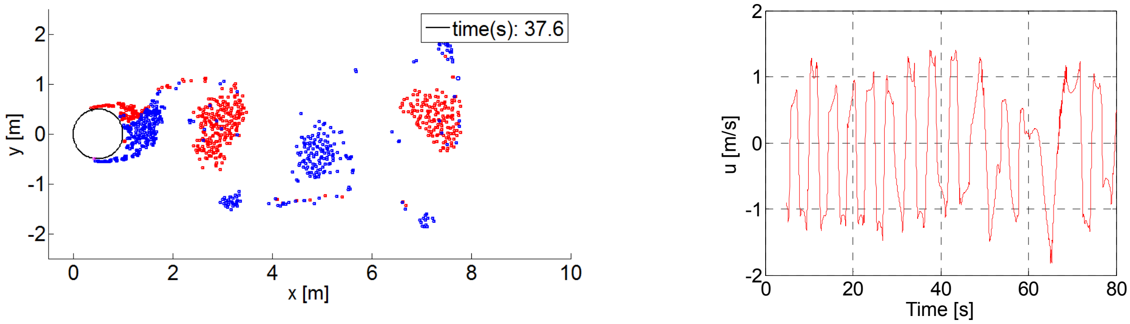
A total of N+4 unknowns have to be determined: γ_1 to γ_{N+1}, γw_{USEP}, γw_{LSEP} and σ to define the flow around the cylinder. The system of equations that defines the flow around the cylinder modeled by the chosen distribution of flow singularities can be written as follows,

- Eq. 1-N: Neumann non-penetration condition $$U_i \cdot n_i = 0 \tag{3}$$
- Eq. N+1: "Kutta" condition $$\gamma_1 + \gamma_{N+1} = \gamma_{W\ LSEP} \tag{4}$$
- Eq. N+2: vortex strength at the upper separation panel $$\gamma_{W\ USEP} = \gamma_S \tag{5}$$
- Eq. N+3: Kelvin's theorem $$\gamma_{W\ USEP}{}^t \Delta_{W\ USEP}{}^t + \gamma_{W\ LSEP}{}^t \Delta_{W\ LSEP}{}^t = \Gamma_B^t - \Gamma_B^{t-1} \tag{6}$$
- Eq. N+4: zero vortex strength at N+1 $$\gamma_{N+1} = 0 \tag{7}$$

This system of equations is closed and the unknowns can be determined. Once the system is solved, the length and angle of the separation panels is updated. The wake vortices are also updated and the new right hand side is calculated by accounting for the influence of the new set of point vortices in the wake. Convergence at a given time step is obtained once the variation of the length and angle of the separation panels, as well as that of the total cylinder circulation is lower than a threshold.

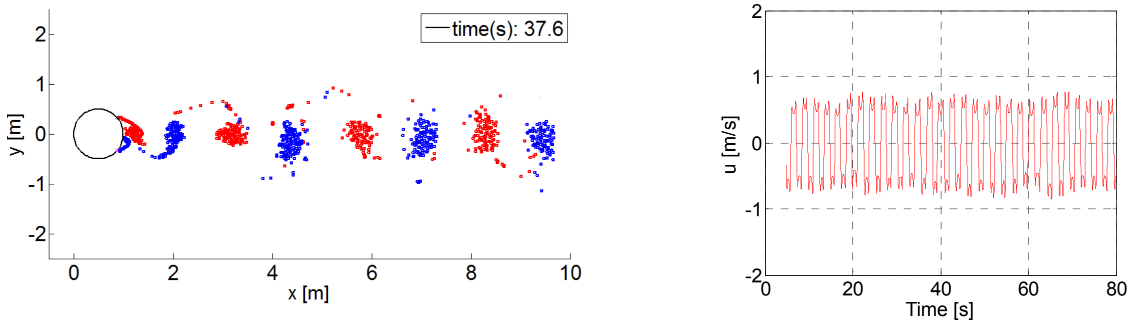
SIMULATIONS

In all simulations 70 panels have been used to represent the cylinder's surface, the time step is set to 0.02 s, the free-stream velocity is 1 m/s and the diameter is fixed to 1 m. Moreover, the maximum number of point vortices in the wake has been fixed to 1000 and a coalescence criterion has been used in order to reduce the number of point vortices in the far wake. The coalescence radius between particles is fixed to 0.04 and all vortices located more than four diameters downstream of the trailing edge are candidates for the merging. The flow past the cylinder has been simulated for 80 seconds. The separation point at the surface of the cylinder, β_s, is obtained from the experimental data of Schewe [5]. β_s is fixed in the USDWM simulations to 80, 140 and 110 degrees for the subcritical, supercritical and transcritical cases respectively.



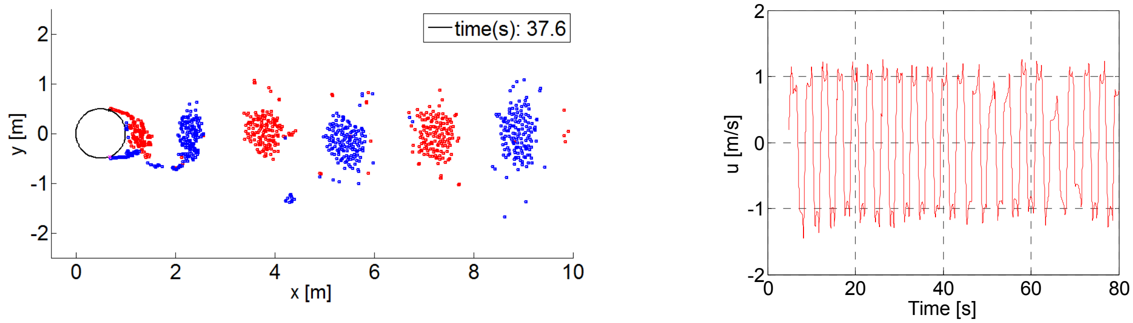
(a) (b)

FIGURE 2. USDWM simulation of the subcritical flow past a cylinder (a) instantaneous flow visualization at t = 37,6 s. (b) time series of the vertical velocity signal 0.6D downstream the cylinder.



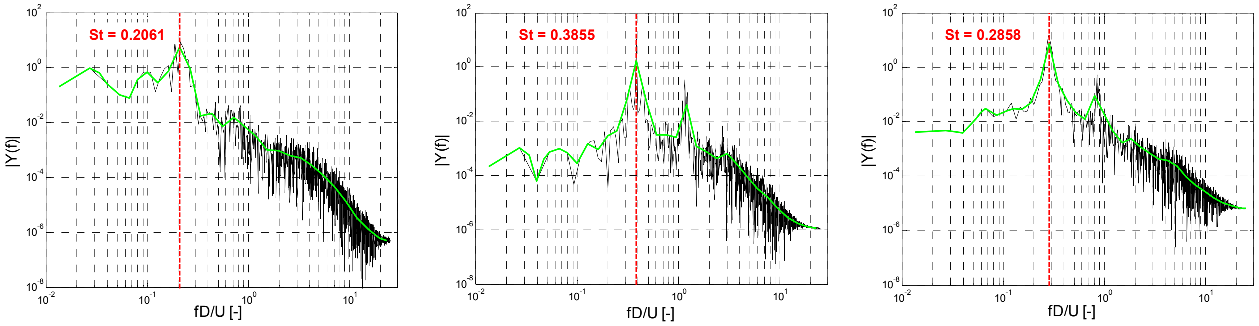
(a) (b)

FIGURE 3. USDWM simulation of the supercritical flow past a cylinder (a) instantaneous flow visualization at t = 37,6 s. (b) time series of the vertical velocity signal 0.6D downstream the cylinder.



(a) (b)

FIGURE 4. USDWM simulation of the transcritical flow past a cylinder (a) instantaneous flow visualization at t = 37,6 s. (b) time series of the vertical velocity signal 0.6D downstream the cylinder.



(a) (b) (c)

FIGURE 5. Filtered and non-filtered energy spectra of the vertical fluctuating velocity at a location 0.6D downstream the cylinder along its center line (a) subcritical Reynolds (b) supercritical Reynolds (c) transcritical Reynolds

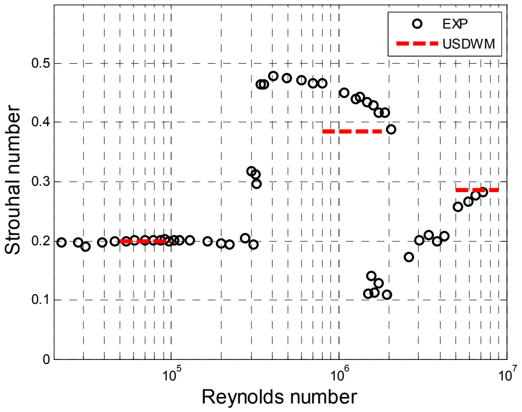


FIGURE 6. Comparison of the USDWM computed Strouhal frequency against experimental data from Schewe [6].

The instantaneous flow visualization at the final simulated time of 40 seconds is shown in Figures 2(a), 3(a) and 4(a). The vertical component of the velocity 0.6 diameters downstream the cylinder is presented in Figures 2(b), 3(b) and 4(b). As expected, it can be seen in the figures how as the distance between the vortex sheets increases, the frequency of the velocity oscillation decreases. For a more detailed analysis of this phenomenon, the energy spectra of the vertical velocity signal has been calculated and shown in Figure 5, where one can observe the peak Strouhal frequency at different flow regimes. As shown in Figure 6, the Strouhal frequency has been identified for each one of the flow cases and compared with experimental data. The USDWM is capable of accurately capturing changes in the Strouhal frequency, especially in the subcritical and transcritical Reynolds regime. However, an underprediction of the shedding frequency is obtained for the supercritical case. This discrepancy could be explained from the two-dimensionality of the simulations. The three-dimensional nature of the vortex shedding in the experiments acts by generating vortex structures in the spanwise direction, which promotes the interaction between the vortex sheets, increasing the shedding frequency, especially when the vortex sheets are close to each other.

CONCLUSION

The flow past a cylinder under subcritical, supercritical and transcritical conditions has been simulated with the in-house USDWM. Experimental results have been used to prove that the solver is capable to accurately predict the changes in the shedding frequency for the three different regimes.

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REFERENCES

1. B. Maskew and F.A. Dvorak, "The Prediction of $C_{l\,max}$ Using a Separated Flow Model". Journal of the American Helicopter Society. 1978.
2. Ramos-García N., Unsteady Viscous-Inviscid Interaction Technique for Wind Turbine Airfoils. Phd thesis. DTU, Department of Mechanical Engineering. ISBN 978-87-90416-53-9. April 2011.
3. L. Marion, N. Ramos-García and J.N. Sørensen "Inviscid Double Wake Model for Stalled Airfoils" The Science of Making Torque from Wind. IOP Publishing. Journal of Physics: Conference Series 524 (2014) 012132. August 2014.
4. A. Cayron, "Unsteady Inviscid Double-Wake Model for Two-Dimensional Stalled Airfoils". MSc. Project report. Technical University of Denmark, February 2015.
5. N. Ramos-García, A. Cayron and J. N. Sørensen, "Unsteady Double Wake Model for the Simulation of Stalled Airfoils". Journal of Power and Energy Engineering, Proceedings of the 5th Conference on New Energy and Sustainable Development, July 2015.
6. G. Schewe, "On the Force Fluctuations Acting on a Circular Cylinder in Crossflow from Subcritical to Transcritical Reynolds Numbers". J. Fluid Mech. 133, 265.