UNSTEADY FORCES ON A CIRCULAR CYLINDER AT CRITICAL REYNOLDS NUMBERS

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Abstract The flow past a circular cylinder is associated with various instabilities which involve the wake, separated shear layer and boundary layer. It is well known that when Reynolds numbers is about 2×10^5 the boundary layer undergoes a transition from laminar to turbulent regime. The range of critical Reynolds numbers up to $\sim 5 \times 10^5$ is characterised by a rapid decrease of the drag coefficient with the Reynolds numbers. Another feature which characterise this regime is the presence of asymmetric forces during the transition regime as reported experimentally. This work aims at shed some light into the complex physics present at these critical Reynolds numbers by means of large-eddy simulations of the flow.

DESCRIPTION OF NUMERICAL MODEL

The governing equations have been discretised on a collocated unstructured grid arrangement by means of second-order spectro-consistent schemes [13]. Such schemes are conservative, i.e. they preserve the symmetry properties of the continuous differential operators and ensure both, stability and conservation of the kinetic-energy balance on any grid and even at high Reynolds numbers and with coarse grids. For the temporal discretisation of the momentum equation, a two-step linear explicit scheme on a fractional-step method has been used for the convective and diffusive terms, while for the pressure gradient term an implicit first-order scheme has been used. This methodology has been previously used with accurate results for solving the flow over bluff bodies with massive separation [8, 10]. By filtering the Navier-Stokes system of differential equations, the subgrid-scale (SGS) stress term appears in the momentum equations which must be modelled in order to close the formulation. In this work, the wall-adapting local-eddy viscosity model within a variational multi-scale formulation (VMS-WALE) [9, 7] has been used. The meshes used for solving the domain considered have been generated by a constant step extrusion of a two-dimensional (2D) unstructured grid. The algorithm used for solving the resulting Poisson equation is explained in detail in [3].

RESULTS

We consider here the flow past a circular cylinder at critical Reynolds numbers of $Re_D = 1.44 \times 10^5$, 2.6×10^5, 3.8×10^5 and 5.3×10^5. The cases have been solved in a computational domain of dimensions [-16D,16D];[-10D,10D];[0,0.5πD] in the stream-, cross- and span-wise directions, respectively, with a circular cylinder of diameter D at (0,0,0). The boundary conditions at the inflow consist of a uniform velocity (u,v,w)=(1,0,0), slip conditions in the top and bottom boundaries of the domain, while at the outlet a pressure-based condition is used. At the cylinder surface, no-slip conditions are prescribed. As for the span-wise direction, periodic boundary conditions are imposed. As mentioned before, the governing equations are discretised on an unstructured mesh generated by the constant-step extrusion of a two-dimensional unstructured grid. Different grids up to 387492×128 ($\sim$ 50MCV) have been used, depending on the Reynolds number. Figure 1(left) shows the isocontours of second invariant of the velocity gradient tensor coloured by the velocity magnitude at Reynolds numbers $Re = 1.44 \times 10^5$ and $Re = 5.3 \times 10^5$. While the lower Reynolds numbers exhibits a flow topology similar to that observed in the sub-critical regime, i.e. laminar flow separation and transition to turbulence in the separated shear layers, the flow at $Re = 5.3 \times 10^5$ shows a narrow wake with separation point moving towards the rear end of the cylinder.

The variation of the drag coefficient with the Reynolds number is plotted in figure 1(right) together with reference data from the literature. At these Reynolds numbers, the measured data of the drag coefficient present a large scattering because of the difficulties associated with the measurements, the flow is very sensitive to the different turbulence intensities, end conditions, surface roughness, etc. Even though this scattering in the reference data, results obtained with the present simulations shows a fair agreement. Furthermore, when comparing the pressure distribution on the cylinder at $Re = 1.44 \times 10^5$ with that measured by Cantwell and Coles [5] at the same Reynolds number, a good agreement is observed (see figure 2). One interesting feature observed in the present computations is the presence of asymmetric forces on the cylinder in the regime transition (in the present computations at $Re = 2.5 \times 10^5$). This behaviour, which causes large fluctuations in the cylinder forces and yields average lift $C_l > 0$, was also observed experimentally by Bearman [2] and Schewe [11]. At the larger Reynolds, forces on the cylinder recover their symmetry (see figure 2). In the final version of the manuscript, results of the different flow configurations observed at the different Reynolds numbers will be given, together with measurements of the local forces and characteristics frequencies of the flow.

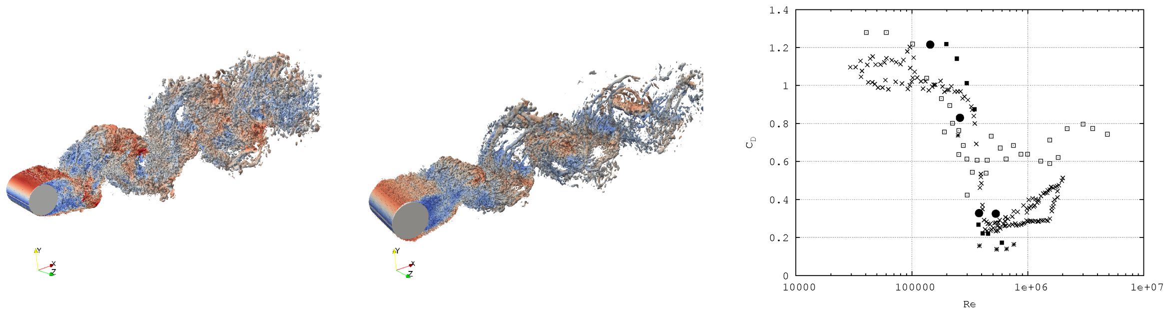

Figure 1. (left) Vortical structures at different Reynolds numbers (left) $Re = 1.44 \times 10^5$; (right) $Re = 5.3 \times 10^5$.(right) Variation of the drag coefficient with the Reynolds number. Comparison with the literature. (Solid dots) Present results, (squares) Achenbach [1], (solid squares) Bursnall and Loftin [4], (stars) Spitzer [12], (crosses) Delany and Sorensen [6]

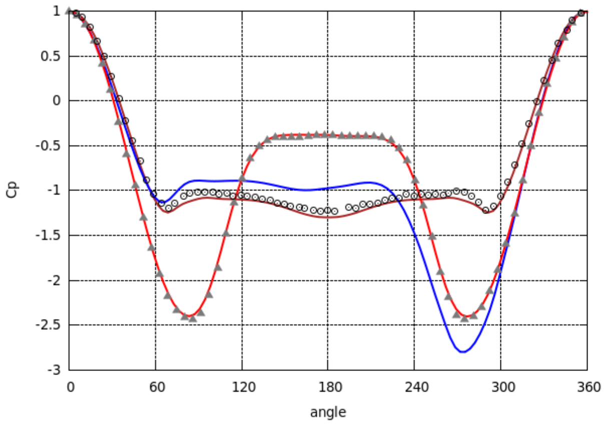

Figure 2. Asymmetries in the pressure distribution at critical Reynolds number. (brown) $Re = 1.44 \times 10^5$; (blue) $Re = 2.6 \times 10^5$; (red) $Re = 3.8 \times 10^5$; (gray triangles) $Re = 5.3 \times 10^5$; (circles) Cantwell and Coles $Re = 1.44 \times 10^5$ [5].

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