FLOW STRUCTURE ON THE SYMMETRY PLANE OF THE WAKE OF A FINITE-HEIGHT SQUARE CYLINDER BASED ON LES

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Abstract The current paper reports an analysis of the flow structure on the symmetry plane of the near wake behind a finite-height square cylinder mounted normal to a ground plane. The cylinder aspect ratio is AR = 3 and the Reynolds number based on the cylinder width and inlet velocity is Re = 500. The flow field is obtained from a large eddy simulation using a dynamic Smagorinsky subgrid-scale model. Phase averaging is used to study the quasi-periodic motions in the wake, specifically the signature of the vortex structures on the symmetry plane.

INTRODUCTION

Large eddy simulation (LES) is a popular computational approach for solving complex turbulent flows that are characterized by large-scale unsteady motions. LES relies on a subgrid-scale (SGS) model to capture the effect of small-scale motions which are not resolved in the simulation. The present paper uses LES to study the wake of a finite-height square cylinder mounted on a ground plane. Recent studies of these flows have focused on trying to better understand the vortical structures in the near wake, in particular the mechanism whereby the vertically oriented vortex tubes being shed from the downstream corners of the cylinder become aligned in the streamwise direction. Wang and Zhou [1] performed an experimental study of flow over finite square cylinders with different aspect ratios ($3 \leq AR \leq 7$, where the aspect ratio AR is defined as the ratio of the cylinder height, H, to the cylinder width, D) and proposed a three-dimensional vortex model consisting of two vertical legs which connect across the wake near the free end of the cylinder. Bourgeois *et al.* [2] argued that the flow structure in the wake was better understood in terms of the phase-averaged structure. They used particle image velocimetry (PIV) measurements to reconstruct phase-averaged velocity fields which evidenced a so called half-loop structure. The present paper uses LES to study a low Reynolds number flow over a square cylinder of aspect ratio AR = 3. An ensemble of three-dimensional velocity fields is used to examine the phase-averaged structure. Of special interest is the periodic behavior of the flow on the symmetry plane, and its relation to the three-dimensional structures developing in the wake.

MATHEMATICAL FORMULATION

The mathematical model consisting of the filtered Navier-Stokes equations was discretized using the finite-volume method. A localized dynamic Smagorinsky model was used for the SGS stress. The discrete equation set was solved using a fractional step method, where the convective and diffusive terms were advanced in time using the Crank-Nicolson method. After establishing a realistic flow, instantaneous velocity data were collected and processed to obtain the phase- and time-averaged values.

SKETCH & GEOMETRY

Figure 1 shows the solution domain and identifies the boundary conditions. Note that given the short upstream extent of the solution domain, the boundary layer developed on the ground place was laminar and relatively thin.

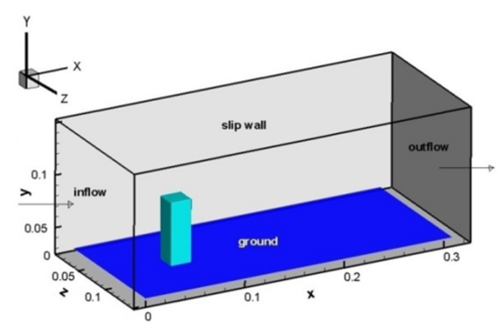

Figure 1. Sketch of the flow domain showing coordinate directions and boundary conditions.

PRELIMINARY RESULTS AND DISCUSSION

The summary results are presented for the case of a finite square cylinder with AR = 3 at a Reynolds number (based on the freestream velocity and cylinder width) of Re = 500. The period inferred from the value of the Strouhal number (Str = 0.128) was used to phase-average the velocity field. Five different phases (N = 1 to 5) were used to characterize the periodic variation of the flow behind the cylinder.

Figure 2a) shows the mean structure in terms of streamlines and contours of the transverse (z) vorticity. The mean flow in the wake is characterized by a large vortex just behind and below the trailing edge of the free end of the cylinder and a much smaller vortex immediately behind the cylinder at the wall. Figures 2b) - 2f) show the streamlines and transverse vorticity for the five different phases. Note that unlike the case of the mean flow, for the phase-averaged flow the velocity field on the symmetry plane is not necessarily two-dimensional. The number and location of vortices in the near wake changes for each period, as vortices are generated behind the cylinder and then convected downstream. The vorticity patterns correlate with the three-dimensional vortex structures (not shown), in particular the upstream segment of a half-loop which crosses the symmetry plane to connect to the vortex structures on the other side of the wake.

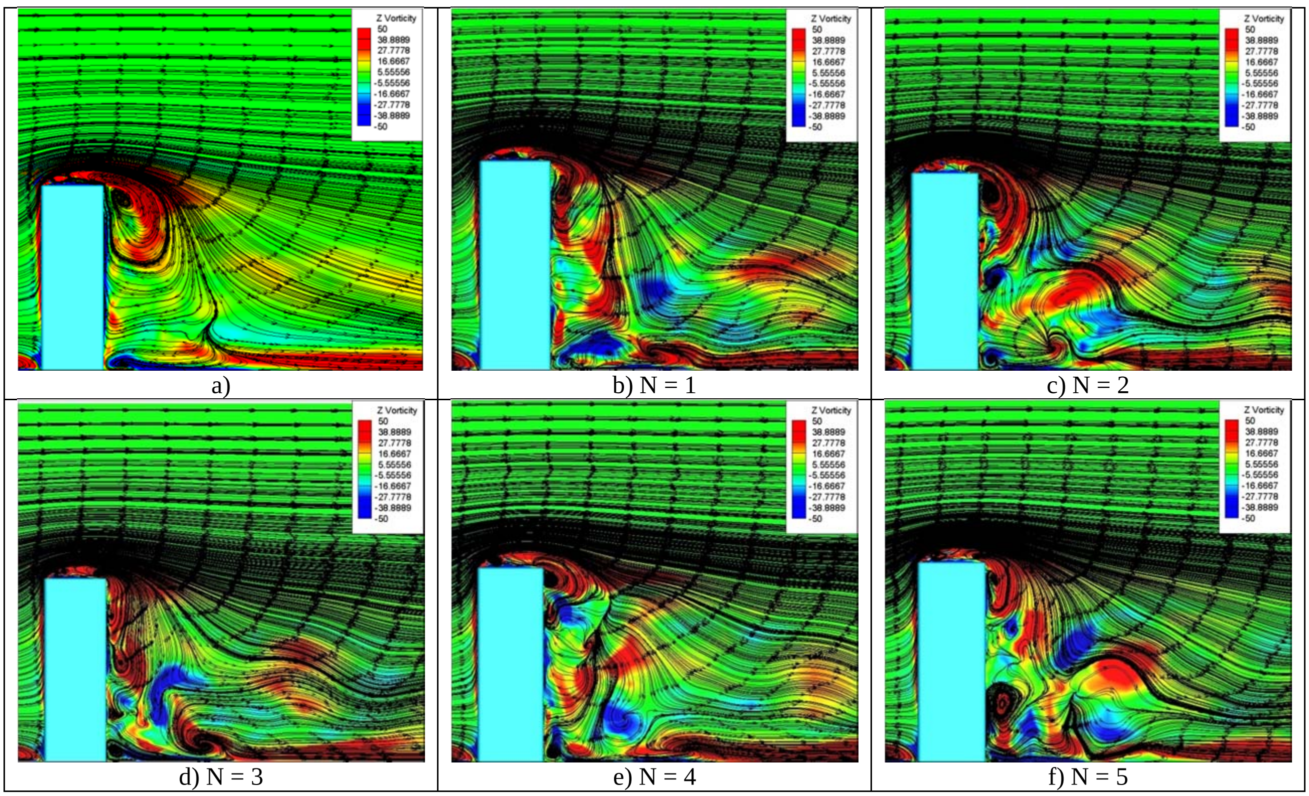

Figure 2. Streamlines and transverse vorticity in the symmetry plane: a) mean flow; b) – f) phase-averaged flow.

The full paper will provide a comprehensive analysis of the phase-averaged velocity field on the symmetry plane making reference to the three-dimensional vortex structures of the wake as visualized by the second invariant of the velocity field.

References

[1] H. F. Wang and Y. Zhou, The finite-length square cylinder near wake, *Journal of Fluid Mechanics*, 638, 453–490, 2009.

[2] J. A. Bourgeois, P. Sattari, and R. J. Martinuzzi, Alternating half-loop shedding in the turbulent wake of a finite surface-mounted square cylinder with a thin boundary layer, *Physics of Fluids*, 23, 1–15, 2011.