

Large Eddy Simulations of Flow around a 3D Cylinder at Subcritical Reynolds Number

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ABSTRACT

The three dimensional simulations of the flow around cylinder at $Re = 3900$ by using the large eddy simulation solver in OpenFOAM are presented in this paper. Extensive analysis of characteristics and properties of the turbulent wake flow behind the cylinder is also given. The presented numerical results show that the large eddy simulation employed could capture the subtle structure in the flow field. All of the presented numerical results are in good agreement with the experimental ones, which could help us to understand the complicated 3D turbulent wake flow around a 3D cylinder.

KEY WORDS: Large-eddy simulation; turbulent flow around cylinder; subcritical Reynolds number; wake analysis.

INTRODUCTION

Flow around a cylinder is a classical problem in hydrodynamics, since it includes complex phenomena such as separation, reattachment, or vortex shedding. Therefore, it is of significant importance in engineering applications in the cases of offshore platform, bridge pier, oil pipeline in the seabed, etc. In the case of oil pipelines lying on the seabed, the cylinder is also subjected to an oscillatory flow induced by sea waves. Many researchers, such as Justesen (1991), Scandura, (2009), Lin (1996), have contributed a lot excellent works. There are many parameters influencing flow around a cylinder. Reynolds number is the critical parameter among them, because it decides the evolution of wake flow. For low Reynolds number, the viscous force plays a major role and the flow is laminar. The laminar flow is steady and the laminar vortex shedding is very regular. At Re below around 150, the flow field can be simplified to two-dimensional flow and this laminar steady regime can be further divided as follows. At Re below around 5, there is no separation of shear layer. In the range of Reynolds numbers between 5 and 40, there is a pair of symmetric counter-rotating vortices forming behind the cylinder. In the range of Reynolds number between 40 and 150, vortex periodic shed from alternate sides of the cylinder. As the Reynolds number increasing, the flow experiences transition to finer scale three dimensionality. And the laminar flow gradually transform to turbulent over a range of Re from 150 to 300.

All of the above is the summary of many researchers about laminar

flow around a cylinder. Cao et al.(2009) studied the numerical simulations of the flows around two cylinders in tandem and side-by-side arrangements by the OpenFOAM solver. Wu (2011) studied the flow past a circular cylinder at low Reynolds up to 300. Rajani (2009) analyzed two- and three-dimensional flow past a circular cylinder in different laminar flow regimes. Williamson (1996) carried out a serious of experiments of flow around cylinder and got conclusions of wake vortex at different low Reynolds number. Many researchers pay attention on the flow transition from laminar to turbulent. And the change of vortex structure in this Reynolds number regime is their most interesting question. Williamson (1988) did experimental study on wake flow around cylinder in the laminar-turbulent transition. This transition regime is associated with changes in the wake formation as Re is increasing. In the range of Re from 180 to 230, the spanwise length of streamline vortices is around four cylinder diameters (it is called Mode A). When Re is greater than 260, the spanwise length of streamline vortices is around one cylinder diameter (it is called Mode B). In the range of Re from 230 to 260, the two modes exist together, and with the increase of Re , the vortex energy transform from Mode A to Mode B. Zhang (1995) and Brede (1996) had similar discovers from their experiments. Mittal (1995), Thompson (1996), Persilon (1998) carried on numerical simulations of laminar-turbulence transition. And Thompson(1996) successfully simulated Mode A and Mode B which were discovered by Williamson experiments. The numerical simulation results indicated that the vortex shedding of Mode A is periodic, and the curl of vortex is ordered arrangement. The vortex shedding of Mode B is irregular, and the curl of vortex is disorder. Leweke & Williamson (1998) found out the reason of two modes vortex in the transition regime. Huang(2008) successfully simulated the three-dimensional vortex of Mode A and Mode B based on DNS method. Besides of flow around circular cylinder, Soha (2003) presented the wake flow around square pillar at low Reynolds number. The two-dimensional Karmen vortex converts to three-dimensional in the Re regime of $150 < Re < 175$.

As the Reynolds number increases, $Re > 300$, the flow has transformed to purely turbulence. Under such circumstance, the fluid flow is unstable though the wake vortex still shed at a certain frequency. This is because the effect of inertia force is greater than the viscous force. Any small disturbance could easily develop the flow to turbulence flow. The turbulence is characterized by irregular, multi-scale and non-linear. Therefore, how to describe the features of