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Communications in Nonlinear Science and Numerical Simulation 11 (2006) 391–412
Communications in Nonlinear Science and Numerical Simulation
www.elsevier.com/locate/cnsns

Coherent structure in flow over a slitted bluff body

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Received 2 June 2004; received in revised form 9 July 2004; accepted 15 July 2004
Available online 8 December 2004

Abstract

The focus of the present investigation is resolution of the coherent structure in the near wake behind a slitted bluff body. The bluff body is two-dimensional with gap ratio from 0.12 to 0.48. The evolution of the structure was numerically investigated using the renormalization group (RNG) k–ε model at Reynolds number of 470,000. Two types of coherent structure are identified: At low gap ratio 0.12, the structure is characterized by a flip–flopping gap flow; at high ratio 0.22–0.48, the gap flow deflects to one side with an asymmetrical wake. The coherent structure is divided by the gap flow into two zones called the primary recirculation zone and the secondary recirculation zone. The coherent structure is intimately related to the gap ratio, and the structure of small gap ratio is different from that of large gap ratio because the interaction between two zones relates to the gap ratio. To explain the vortex shedding, a mechanism that single vortex of large size suddenly immerses between two shear layers was proposed. Experimental results using point-to-point method and particle-image velocimetry (PIV) measurements in a close wind tunnel were also carried out to confirm the observation from the numerical study. The evidence shows that the numerical results are of good agreement with the experiments. The comparison between the RNG k–ε model and the large eddy simulation also indicates that the RNG k–ε model is adequate in computing the bluff body flow.

PACS: 47.20.Ky; 47.27.Eq; 47.27.Vf
Keywords: Bluff body; Near wake; Coherent structure; Vortex shedding

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1007-5704/$ - see front matter
doi:10.1016/j.cnsns.2004.07.003

1. Introduction

The nature of the flow over a bluff body has received considerable research interest both experimentally and numerically for many years. Especially the flow over a circular cylinder has been regarded as the canonical subject. Roshko [1] has observed bluff bodies with different geometries that the flow goes through a progression of regimes. At low Reynolds number the flow is steady and laminar. With increasing Reynolds number the flow becomes unsteady in a two-dimensional periodic manner with regular vortex shedding forming the well-known Karman vortex street in the wake. With further increasing Reynolds number the flow becomes chaotic and turbulent. Development of experimental techniques, like particle-image velocimetry (PIV), has provided valuable insight into the shedding processes. Increasing computational capabilities has helped to reproduce and isolate many experimental findings in the laminar and transitional Reynolds number regime. However, the complexity of the vortex shedding process has eluded an analytical description of the subject. Von Karman celebrated model describes the vortex street as a staggered periodic chain of vortices with alternating rotational direction and where the spacing is derived from a stability consideration. This model inspired numerous modifications. The assumed vorticity distribution of the point vortices is far from realistic and predicted transverse spacing is too large. Von Karman combined his geometrical model of the vortex street with a momentum consideration to derive a drag relationship. Consequently, numerous drag models have been proposed to describe the role of physical and geometric parameters of the mean recirculation zone. However, the Reynolds-number dependency and coherent structures have not been explicitly incorporated. Coherent structures are intimately related to fluctuation amplitudes of drag and lift and also to the mean flow quantities.

Most of the fundamental work on bluff body flows has been focused on the flow over a single bluff body. Many applications, however, involve the flow past two or more bluff bodies in close proximity to one another. Examples of such applications are porous media flow, fluidized beds, compact heat exchangers, and flame holders.

Flow behind two circular cylinders of equal diameter has been investigated by Zdravkovich [2]. One of the features is the occurrence of asymmetric flow patterns at the critical spacings of cylinders of $1.5 < G/D < 2.0$ in side-by-side arrangement, where G is the transverse distance between the cylinder centers and D the cylinder diameter. Within the asymmetric flow regime, narrow and wide wakes are found and are divided by the biased gap flow. The gap flow is bistable and switches are irregular intervals. The narrow wake corresponds to lower base pressure, higher vortex frequency and higher drag force, while the wide wake is the opposite [3]. However, the exact mechanism for the irregular switching was not explained.

Bluff body flame holders are widely used to make flames stable in industry, especially for combustors with high velocity flows. Many research conducted during the past four decades indicates that the wake flow structure behind the bluff body is directly related to the flame-holding performance. The wake flow contains the complexities of separation and recirculation, mass and momentum transport across the shear layers, and the vortex shedding. However, the study of the flow structure has not been thoroughly explored. Yang and Tsai [4] have experimentally investigated the effects of the width of gap on the recirculation zone and the drag in the near wake of a slitted bluff body (v-gutter) in a confined tunnel at $Re = 120{,}000$. According to their experimental evidence, a asymmetric wake structure is developed behind the symmetric slit ($G/D = 0.2$ and 0.4).