Simulation of three-dimensional flow around a square cylinder at moderate Reynolds numbers

Ahmad Sohankar
Thermo and Fluid Dynamics, Chalmers University of Technology, S-412 96 Göteborg, Sweden

C. Norberg
Division of Heat Transfer, Lund Institute of Technology, Box 118, S-221 00 Lund, Sweden

L. Davidson[a)]
Thermo and Fluid Dynamics, Chalmers University of Technology, S-412 96 Göteborg, Sweden

(Received 22 December 1997; accepted 15 October 1998)

Direct numerical simulations of two-dimensional (2D) and 3-D unsteady flow around a square cylinder for moderate Reynolds numbers (Re=150–500) are performed, employing an implicit fractional step method finite-volume code with second-order accuracy in space and time. The simulations, which are carried out with a blockage ratio of 5.6%, indicate a transition from 2-D to 3-D shedding flow between Re=150 and Re=200. Both spanwise instability modes, A and B, are present in the wake transitional process, similar to the flow around a circular cylinder. However, seemingly in contrast to a circular cylinder, the transitional flow around a square cylinder exhibits a phenomenon of distinct low-frequency force pulsations (Re=200–300). For 3-D simulations, the Strouhal number and the mean drag coefficient are in general agreement with existing experiments. Between Re=300 and 500, an increase in the spanwise coupling of fluctuating forces is indicated. The influence of the spanwise aspect ratio using periodic boundary conditions, a finer grid, and a finer time step is also investigated. © *1999 American Institute of Physics.*
[S1070-6631(99)00902-2]

I. INTRODUCTION

Over the last 100 years, the flow around slender cylindrical bluff bodies has been the subject of intense research, mainly owing to the engineering significance of structural design, flow-induced vibration, and acoustic emissions. In recent years, such studies have received a great deal of attention as a result of increasing computer capabilities, improvements in experimental measurement techniques, and increasing awareness of some new phenomena such as transitional spanwise instability modes.[1] The vast majority of these investigations has been carried out for the flow around a circular cylinder, whereas, from an engineering point of view, it is also necessary to study flow around other bluff body shapes, such as sharp-edged rectangular cross-sectional cylinders. Structures that typically have rectangular or near-rectangular cross sections include architectural features on buildings, the buildings themselves, beams, fences and occasionally stays and supports in internal and external flow geometries. The main motivation for the present study is of a practical nature. Above some critical Reynolds number, the flow around cylindrical structures exhibits the well-known time periodic phenomenon of vortex shedding. Due to the associated fluctuating forces on the body, the alternate shedding of vortices may cause structural vibrations, acoustic noise emissions (Aeolian tones), or in some cases resonance, which can trigger the failure of structures. As for the square cylinder, there is a more or less complete absence of detailed data on, e.g., mean and fluctuating forces at moderate Reynolds numbers. For instance, the only available experimental data on the mean drag coefficient for Re⩽500 can be found in the work of Okajima and co-workers.[2] There is also an academic motivation. For instance, the influence of the actual cross section in question on the transitional scenario, leading to turbulence in the wake, is of fundamental importance.[3]

It may be called for here to draw attention to some characteristics in the flow around slender cylindrical bluff bodies, as the Reynolds number is increased from about unity to approximately 500, with Re based on the cross-stream dimension, the diameter. In general terms, the following short description applies to the flow around a circular cylinder (hereafter referred to as CC flow). At low Reynolds numbers, say less than about 100, the description is also believed to be valid for the case under consideration, i.e., the flow around a square cylinder at zero incidence (hereafter referred to as SC flow). However, at higher Re, the sharp corners may play a significant role in the development of flow instabilities and other flow characteristics.

At Reynolds numbers below about unity, the flow is fully attached with no separation. As Re is increased, the flow separates, and a pair of steady symmetric vortices forms behind the body. For the circular cylinder, this occurs at around Re≈3–5.[4] The recirculation region behind the body grows with increasing Re. At a critical onset Reynolds number ($Re=Re_{c1}$), the twin vortex arrangement becomes

[a)]Corresponding author. Electronic mail: lada@tfd.chalmers.se; telephone: +46 31 7721404; fax: +46 31 180976.

