Numerical Simulation for Shear Effect on Vortex Shedding
Behind a Square Cylinder

Robert R. Hwang
Institute of Physics, Academia Sinica
Taiwan, China

Y.C. Sue
National Taiwan University
Taiwan, China

SUMMARY

This paper is concerned with the numerical simulation of the flow-structure around a square cylinder in a uniform shear flow. The calculations were conducted by solving the unsteady 2D Navier-Stokes equations with a finite difference method. The effect of the shear parameter K of the approaching flow on the vortex-shedding Strouhal number and force coefficients acting on a square cylinder is investigated in the range of K = 0.0 to 0.25 through various Reynolds numbers from 500 to 1500. Computational results are compared with some existing experimental data and previous studies. The effect of shear rate on the Strouhal number and the force acting on the cylinder has a tendency to reduce the oscillation. The Strouhal number, mean drag and amplitudes of the fluctuating force tend to decrease as the shear rate increases but no significant change in the small shear rate. Increase the Reynolds number decreases the Strouhal number and increases the force acting on the cylinder. At high shear rate, shedding frequencies of the fluctuating drag and lift coefficients are identical.

keywords : Vortex shedding, Shear flow, Strouhal number, Square cylinder

INTRODUCTION

The flow past bluff structures is a classic and important problem in fluid mechanics. It is frequently associated with periodic vortex shedding causing dynamic forces on the structures. The velocity of the approaching stream may vary in the direction normal to a generator of the body. A typical relevant case can be that of a long-span structure such as a suspension bridge or a pipeline system which is parallel to the ground or water surface, presents in the planetary boundary layer. In the consideration of the shearing effect, an important variation of the basic flow is the situation when the incoming free-stream is a uniform-shear flow. It is obviously implied that a constant vorticity and energy production are embedded in the free-stream, and this gives rise to complicated interactions associated with the flow separations. Therefore, it is important to understand the mechanism of the vortex shedding behind the bluff body under the effect of the presence of shear in the approaching stream.

The problem of vortex shedding behind a rectangular cylinder in uniform flows has recently been investigated both numerically and experimentally by many researchers (Davis and Moore, 1982; Franke et al., 1990; Okajima, 1982). Patankar and Kelkar (1992) also investigated the onset of the vortex shedding by means of a linear stability analysis of the steady flow. The structure of vortex shedding behind a square cylinder in a channel was recently investigated numerically by Davis et al. (1984) and Biswas et al. (1992) to study the effect of wall on the flow characteristics of the vortex shedding. Leonard and Kounoutsakos (1993) advanced the vortex method to simulate the bluff body flows.

The effect of the free-stream shear on the formation of wake, shedding mechanism of the vortices, etc., on the other hand, is a topic of recent origin. Kiya et al. (1980) and Sung and Hgun (1992) investigated experimentally the vortex shedding from a circular cylinder in moderate-Reynolds-number shear flows. Ayukawa et al. (1993) conducted a study theoretically and experimentally on the effect of the shear rate on the Strouhal number for a square cylinder in a uniform shear flow. In Ayukawa et al.'s simulation, the flow is assumed to be the superposition of a potential flow which consists of a system of vortex filaments representing approximately the square cylinder. No Reynolds number variation was considered in their study.

It is expected that the shear rate influences not only vortex shedding but also the flow pattern in the wake of the cylinder which causes environmental disturbance in the downstream of a large structure. The purpose of this study is to investigate the effects of various shear strength and Reynolds numbers on the periodic shedding motion behind a square cylinder by solving the full Navier-Stokes equations with numerical techniques. The advantage of a numerical simulation is the accessibility of a detailed analysis and nuances of flow development. Two parameters usually govern the uniform flow — one is the shear strength and the other is the Reynolds number. The aim of the present study is to investigate the influence of these parameters on the frequency of the vortex shedding and the aerodynamic forces acting on the square cylinder.

STATEMENT OF THE PROBLEM

The physical problem considered in this study is a two-dimensional, viscous, incompressible flow around a square cylinder placed in a uniform shear flow. Figure 1 shows the geometry and coordinates of the flow problem. Far upstream of the cylinder, the approaching stream is assumed to have a linear shear velocity as

\[ u = U_0 + Gy \]  

in which \( U_0 \) is the speed of the undisturbed stream at the center of the