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Numerical Study on a Two-Dimensional Circular Cylinder with a Rigid and an Elastic Splitter Plate in Uniform Flow

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ABSTRACT

A two-dimensional incompressible viscous flow around a fixed or elastically supported circular cylinder with a splitter plate of attached rigid, hinged or elastic types, has been simulated by a finite difference method, to study the effect of splitter plate on the drag and vortex shedding frequency of the cylinder. The computation is carried out at R_e = 1000, and the results are in good accordance with the available experimental data. The relationship between the unsteady flow patterns and hydrodynamic force coefficients is also discussed.

INTRODUCTION

Drag force and flow-induced vibration are important considerations in the design of a riser pipe and a towing cable system (Myers et al., 1969). Field experiments (Griffin and Ramberg, 1982) show that when a cable undergoes resonant cross flow oscillations, the average drag is greatly increased. A splitter plate placed on the downstream side of the cylinder may reduce the vibration and drag force. A trailing splitter plate is often used in practice to suppress cable motions. In the Research Institute for Applied Mechanics, experiments were conducted on three types of cable fairing(Nakamura and Koterayama, 1992), to investigate the effect of fairing on the hydrodynamic forces acting on a cable.

Cable or pipe vibrations may be studied using a uniform flow past a two-dimensional elastically mounted cylinder. Numerous papers have been written on bare cylinders, and a review of these works was made by Chen (1987). For the wake interference problem, Roshko (1954) experimented with a splitter plate placed downstream of a cylinder and found that if the plate were sufficiently long, the drag force of the cylinder would be substantially reduced due to increasing the base pressure. The effect of the gap between cylinder and plate was also discussed. Gerrard (1965) and Apelt et al. (1973, 1975) studied the effects of the length of a splitter plate attached to a cylinder. Gerrard showed experimentally that as the plate length increases, the Strouhal number decreases and attains a minimum for a plate length of approximately D (where D is the diameter of the cylinder), and then increases as the length increases to $2D$. Apelt et al. found that a short splitter plate markedly reduces the drag by stabilizing the separation points, and for a splitter plate length of D, the reduction in drag reaches 68% of the bare cylinder value. Further changes in drag were relatively small when the plate length was increased up to $8D$.

Sallet (1970) showed in an experiment that the vortex-induced cross-flow vibration of a short cylinder (L/D = 5.15, where L is the cylinder length) can be suppressed by an attached splitter plate. The optimum plate dimensions were studied.

Another extensive experiment was made by King (1977), in which the in-line oscillation of a cylinder with an attached and a separate splitter was investigated. All the aforementioned experimental studies confirmed that the effect of a splitter plate on the vortex shedding from a cylinder is the main reason for the reduction in hydrodynamic force and the vibration, and that such an effect is both complicated and interesting.

In this paper, a two-dimensional incompressible viscous flow around an elastically supported circular cylinder with an attached splitter plate of different length L_S has been simulated by a finite difference method. The simulation is based on the solution of Navier-Stokes equations expressed in a generalized coordinate system. First, uniform flow past a fixed cylinder with a rigid plate of different length is studied. The variation of the vortex shedding with the plate length, and the effect on the drag and vortex shedding frequency are investigated. Two cases (L_S/D = 0 and 1), in which the cylinder is supported elastically and undergoes vortex-induced vibrations, are simulated. To simulate the problems with greater engineering reality, a rigid plate attached to a cylinder by a hinge, and an elastic plate attached to the cylinder are considered. Some simulation results are presented.

PROBLEM FORMULATION

The equations of a two-dimensional incompressible viscous flow are continuity and Navier-Stokes equations. These can be expressed in nondimensional form as:

$$\nabla \cdot \mathbf{u} = 0 \tag{1}$$

$$\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} = -\nabla p + \frac{1}{R_e} \nabla^2 \mathbf{u} \tag{2}$$

where $\mathbf{u}$ stands for the velocity vector, and p, the pressure. The velocity is normalized by a reference velocity U (such as the velocity of a uniform flow),the pressure by ρU^2, the length by the cylinder diameter D, and the time by D/U. Here ρ denotes the density of the fluid. The equations in this paper are normalized in such a way.

The Poisson equation for pressure p is (Harlow and Weich, 1965):

$$\nabla^2 p = -\nabla \cdot (\mathbf{u} \cdot \nabla)\mathbf{u} + R \tag{3}$$

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KEY WORDS: Splitter plate, vortex-induced vibration, numerical simulation.