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A Numerical Procedure for Predicting Transverse Forces on a Body Submitted to Lock-In Motion

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ABSTRACT

An explicit computational procedure is developed to solve the coupled motion of a rigid body and a viscous incompressible fluid. In this study, the investigated body is a rigid 2-D cylinder conducting forced sinusoidal motion in a viscous fluid flow. The arbitrary Lagrangian-Eulerian (ALE) formulation is employed in order to incorporate the interface conditions between the body and the fluid. The Galerkin finite element method is used for the spatial discretization of the fluid domain, and a velocity correction projection method is used to solve the Navier-Stokes equations. The fluid boundary motion is determined from the forced cylinder motion. The method is applied to predict the so-called transverse added mass and added damping of a circular cylinder under vortex shedding vibrations. The computed results are compared with experimental data reported in the literature, and the agreement appears to be quite good.

INTRODUCTION

Extensive experimental studies have been performed on spring-supported cylinders in steady, uniform flow, and it has been found that the drag force is quite regular, while the transverse force exhibits a large degree of variability. However, such experiments also show that the transverse motion is nearly regular (sinusoidal), and its amplitude is usually related to certain dimensionless parameters, such as reduced velocity, Reynolds number and some version of a stability parameter. Utilizing these dimensionless parameters one has been quite successful in fitting the experimental results onto a single curve, e.g. Griffin (1975) or Sarpkaya (1979). In this approach, the transverse force, which presumably is driving the motion, is not paid much attention to. As a matter in fact, it is usually not reported, and in many cases probably not measured.

For more general applications it is of interest to know more about the exciting force. For example, some parts of a long flexible offshore riser will at a given vibration mode exhibit larger (and some parts smaller) amplitudes than a spring-supported segment at the same reduced velocity. It is then the total energy transmitted from the flow to the riser over its entire length which is of interest. This energy must balance the internally dissipated energy (with a possible adjustment for other contributors to the energy balance). A natural approach is then to perform forced vibration tests, and vary parameters such as reduced velocity and motion amplitude-to-diameter ratio, while measuring the lift force. Several experimental tests on forced vibrations of this kind have already been reported, e.g. Sarpkaya (1995) or Moe and Wu (1990).

In the present paper a numerical procedure for performing such forced vibrations tests is presented. The fluid domain is described by the finite element method, and the cylinder motion is given as a prescribed boundary condition to the flow field. Computationally, one needs to treat the problems with a moving interface between the fluid and the rigid body. In the present study the ALE formulation is employed because of two considerations. First, it is convenient to describe the fluid motion on the moving interface by the Lagrangian description in order to treat the compatibility conditions and the equilibrium between the fluid and the rigid body. Secondly, it is apparently impossible to employ the Lagrangian description for the entire fluid domain because of severe mesh distortion due to vortex shedding and flow through outer boundaries. Therefore a mixed Lagrangian and Eulerian formulation seems a natural choice.

The remainder of this paper may be outlined as follows: The ALE method is briefly reviewed; the basic equations of motion of a fluid and solid are stated; the discretized equations are presented; the computational procedure including the force coefficient averaging is described; some numerical results are presented and compared to reported experimental results; and finally some concluding remarks are presented.

THE ALE CONCEPT

The ALE description is based on a general kinematical theory described by Hughes (1981) among others, where three domains and the mapping among them are defined as follows:

- **Spatial** domain is where the fluid mechanics is posed. It is regarded as generally in motion because of the moving interface to the adjoining structures.
- **Material** domain is to be thought of as the domain occupied at time $t = 0$ by the material particles which occupy the spatial domain at t (which is the time of interest). Hence, the material domain is also generally in motion.
- **Referential** domain is defined as fixed for all t, and its image at time t under a prescribed mapping is the spatial domain.

In the context of finite element analysis, the spatial domain is represented by a moving mesh and the referential domain by a reference state of the moving mesh. If the spatial domain is fixed throughout, the formulation can be regarded as a Eulerian description. Likewise, a Lagrangian description is obtained when the spatial domain always coincides with the material domain. The

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