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Influence of Amplitude Modulation on the Fluid Forces Acting on a Vibrating Cylinder in Cross-Flow

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ABSTRACT

This paper describes the results of experimental measurements of the fluid forces acting on a circular cylinder undergoing amplitude-modulated motion. Experiments were conducted in the Testing Tank Facility at the Massachusetts Institute of Technology, involving a circular aluminum cylinder towed through still water and forced to oscillate with a beating motion transverse to the direction of towing. Lift and drag forces were measured and analyzed for mean, rms, and spectral amplitude and phase information. The drag force results are presented here and compared with those from pure-sinusoidal excitation using the same apparatus. The principal conclusion is that the modulation reduces the mean drag coefficient and increases the oscillating drag coefficient. Hypotheses on the origins of this phenomenon are presented.

INTRODUCTION

A classic open-flow problem in fluid mechanics is the flow around a circular cylinder. This is because of both the rich physical phenomena that occur in the wake, as well as the cylinder's importance as an engineering element in manmade structures. At all but the lowest Reynolds numbers, the wake behind the cylinder is unstable: The boundary layers on either side of the cylinder separate and roll up into discrete vortices that form the celebrated Kárman vortex street. This vortex shedding, in turn, induces oscillating lift and drag forces on the cylinder, which may cause it to vibrate.

From a practical perspective, the study of these vortex-induced forces is very important because one would like to predict the responses of real-world structures exposed to fluid flow. The traditional method of investigating the problem has been through laboratory experiments, with important contributions including those of Bishop and Hassan (1964), Protos et al. (1968), Sarpkaya (1977) and Staubli (1983a, 1983b). From the efforts of all these researchers over the years, a fairly consistent picture has been built up of the vortex-induced forces on stationary as well as sinusoidally oscillating cylinders.

In addition to the experimental data, recent theoretical work has provided new insights into the phenomenon. Triantafyllou et al. (1986) have shown that the vortex street is a self oscillation of the cylinder wake, initiated and sustained by a hydrodynamic instability of the *time-averaged* flow behind the cylinder. The frequency of vortex shedding is set by the *absolute* nature of this instability. Karniadakis and Triantafyllou (1989) have further explored the concepts of wake instability and forcing. They found that the wake oscillation, due to the absolute instability, induces oscillatory forces on the cylinder, which may cause it to vibrate in response. The onset of the cylinder vibration considerably complicates the situation, as the motion could excite a second mode in the wake that competes with the first. As a result of the interaction between the two frequencies, the subsequent response state can be quasiperiodic, with a broad spectral content. The cylinder motion essentially corresponds to an external forcing of the wake. When the system is in lock-in, the response frequency in the wake is equal to the excitation frequency, and when the system is not in lock-in, the wake frequency is equal to the frequency of absolute instability. As the system goes from the lock-in to the nonlock-in state or vice versa, the response is quasiperiodic; at the boundary marking the separation between the two states, the response is chaotic.

Notwithstanding all of the above, it is clear that the problem of cylinder wakes and induced loads is far from solved. New evidence indicates that the bulk of the experimental and numerical results arrived at over the years for *pure-sinusoidal* oscillations cannot be directly applied to real situations. A recent, unique, full-scale experiment on the dynamics of long marine tow cables, reported by Yoerger et al. (1991), Grosenbaugh (1991) and Triantafyllou et al. (1988), illustrates that such cables sustain an amplitude-modulated, or beating response, rather than a pure-sinusoidal one. Due to a nonuniform current profile, as well as an inclination of the static configuration of the cable, the vortex-

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