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INFLUENCE OF CROSS-SECTIONAL CONFIGURATION OF CYLINDRICAL BODIES ON THE KARMAN VORTEX EXCITATION

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ABSTRACT It is well known that Kármán vortices shedding from a circular cylinder can synchronize with the cylinder oscillation (lock-in phenomenon) when the body is supported elastically, and can resonate with the vortex shedding (Kármán vortex excitation). In this work the influence of the cross sectional configuration on these phenomena was investigated experimentally and the results were compared with those of numerical calculations. Measurements on a semi-circular and a triangular cylinder under a controlled oscillation showed that the lock-in phenomenon occur for both cases in spite of the fact that the separation points for them are fixed at the edges. Differences among their oscillation behaviours in the range of Kármán vortex excitation were quite large in spite of the rather small differences of the behaviours in the lock-in phenomenon.

1. Introduction

It is well known that Kármán vortices shedding from cylindrical bodies can synchronize with the cylinder oscillation over a certain free stream velocity domain. In this domain the vortex shedding frequency f_v can be different from the natural vortex shedding frequency f_{v_0}, that is the vortex shedding frequency from the cylinder at rest, but it become equal to the cylinder oscillation frequency f_c [1]. This is called "lock-in phenomenon". When the cylinder is supported elastically and the free stream velocity U is around the value at which f_{v_0} is equal to the natural frequency f_n of the cylinder, Kármán vortices can induce a large cross-flow oscillation called "Kármán vortex excitation". Owing to its practical importance the influence of the cross sectional configuration on this phenomenon is being studied extensively by many researchers. Since the lock-in phenomenon can most clearly be observed for a circular cylinder the mechanism is explained as follows: the oscillatory motion of the cylinder makes the movement of the separation point in phase with the displacement, and therefore controls the shedding frequency. This mechanism, however, is still not verified since there are many factors affecting this phenomenon, such as Reynolds number, the frequency and amplitude of cylinder oscillation, etc. The specific aim of this work is to investigate the influence of the cross sectional configuration on the lock-in phenomenon and on the Kármán vortex excitation, based on experiments on cylinders with controlled oscillation and on elastically supported cylinders while keeping other conditions virtually identical.

2. Experiment

Measurements were carried out in a blow-down type wind tunnel with a 320x320mm measuring cross section and turbulence level less than 0.4%. Three cylinders with circular, semi-circular and triangular cross sections of practically equal characteristic length were used. In the case of the controlled oscillation experiment these cylinders were oscillated in the z-direction with a fixed frequency and amplitude smaller than the threshold value for lock-in reported so far. The z-axis is perpendicular both to the mainstream and to the axis of the cylinder. Conditions were chosen so as to ensure that the separation point at the triangular cylinder should be fixed to the edges. In the Kármán vortex excitation experiment the same cylinders were supported elastically so as to allow their displacements in the z-direction only. The natural frequencies and damping factors of the cylinders are almost identical. The experimental conditions are summarized in Table 1.

The velocity component u parallel to the main flow was measured at a point downstream of the cylinder where the fluctuation due to the Kármán vortex was most clearly detected. The vortex shedding frequency f_v was determined from the spectrum of u, S_u

3. Results and discussion

3.1 Controlled oscillation experiment

Results of forced oscillation experiment by frequency controlled device using are shown in Fig. 1. The lock-in phenomenon can be seen not only in case of the circular cylinder but also for the semi-circular and the triangular cylinders for which the location of the separation points are considered to be unaffected by the cylinder motion.

The lock-in phenomenon is most distinct for the circular cylinder, accompanied by a sharp increase in S_{up}, the peak value in the spectrum S_u. The lock-in region is widest for the circular cylinder, ranging over both sides of U_0 (the value of velocity at which the natural vortex shedding frequency f_{v_0} is equal to the frequency of cylinder oscillation f_c). The lock-in regions is smaller for the semi-circular and triangular cylinders, and are shifted towards $U > U_0$, and $U < U_0$, respectively.

The results on the lock-in region shown in Fig. 1 are converted into non-dimensional parameters, replotted in Fig. 2, and compared with earlier experimental results and numerical calculations done on circular cylinders. It can be seen in the figure that the lock-in phenomenon occurs also for semi-circular and triangular cylinders with amplitudes smaller than the threshold values reported in earlier papers.

3.2 Vortex excitation experiment using elastically supperted cylinders

The root mean square (rms) values of the displacements, Z_{rms} for the three elastically supported cylinders are shown in Fig. 3 for measurements carried out while increasing U. In spite of the fact that the natural frequencies and damping factors of the three cylinders are virtually equal, the oscillation amplitudes and ranges of velocity for the vortex excitation are very different. Compared with the rather small differences in the lock-in regions shown in Fig. 2, the differences in the oscillation behaviours of the three cylinders shown in Fig. 3 are unexpectedly large.

In Fig. 4 Z_{rms}, f_v, S_{up} for the circular and the triangular cylinder are plotted against U while measurements were done for both increasing and decreasing U values. Hysteresis behaviour can clearly be observed for the circular cylinder in Fig. 4 (a), while it is not discernible for the triangular cylinder. It can be seen in Fig. 4 (a) that S_{up} increases remarkably when the oscillation amplitude is large, which means that the regularity of the vortex shedding is enhanced by the cylinder oscillation. On the other hand the correlation between Z_{rms} and S_{up} is not clear for the triangular cylinder (see Fig. 4 (b)).

4. Concluding remarks

The configuration of the cross section largely affects the lock-in phenomenon and the Kármán vortex excitation. The lock-in phenomenon was observed for circular, semi-circular and triangular cylinders at oscillation amplitudes lower than threshold values reported so far. Compared with the difference in the lock-in behaviours under controlled oscillation, differences in the behaviours of vortex excitation were quite large among the three configurations. The results presented here implies that the lock-in phenomenon and the Kármán vortex excitation cannot solely be explained by two-dimensional effects such as the movement of the separation point, but that the effect of the cylinder motion on the spanwise structure of the vortices should also be investigated.

References

[1] Bearman, P. W., "Vortex shedding from oscillating bluff bodies", Fluid Mech., 1984, **16**,195-222

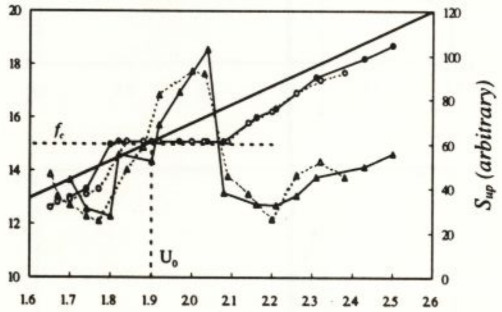
[2] Griffin, O. M. and Hall, M.S., "Review-Vortex shedding lock-on and flow control in bluff body wakes", J. Fluids Eng., Trans. ASME, Vol.113, pp. 526-536

[3] OOGANE, K., "Investigation on numerical analyses for problems concerning fluid-structure interaction", Doctoral thesis, Nagaoka University of Technology, Japan, 1993

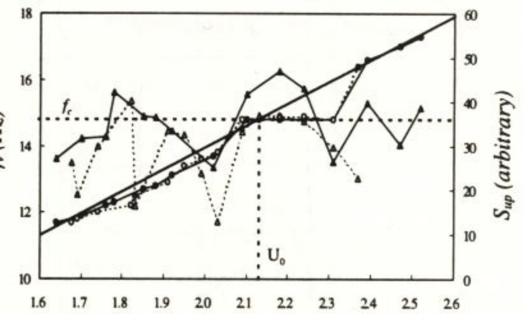
Table 1 Experimental conditions

Cross-section	Characteristic length d (mm)	Controlled oscillation experiment		Karman vortex excitation experiment	
		Frequency f_c (Hz)	Amplitude[(1)] a (mm)	Natural frequency f_n (Hz)	Logarithmic damping factor δ
Circular	 26	15.0	2.0	15.0	0.0136
Semi-circular	 31	14.8	2.0	15.0	0.0077
Triangular	 27	15.2	2.0	15.0	0.0081

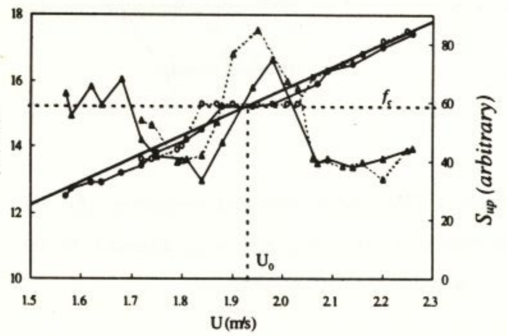
(1) Peak-to-Peak value



(a) Circular cylinder



(b) Semi-circular cylinder



(c) Triangular cylinder

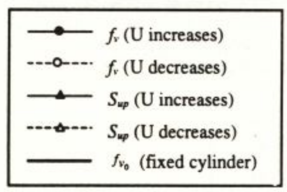


Figure 1 Variation of vortex shedding frequency f_v and the spectrum peak value S_{up} with U for controlled oscillation experiment.

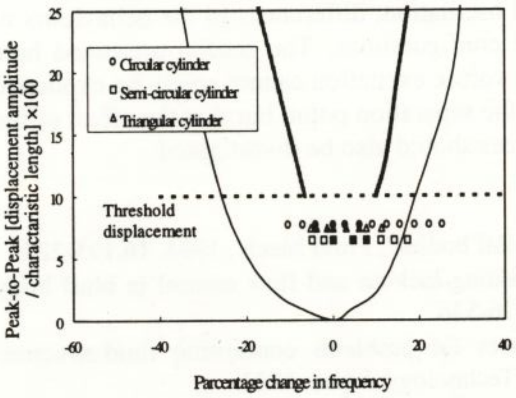


Figure 2 Lock-in region presented by non-dimensional parameters; solid symbol: lock-in, open symbol: non lock-in, ▬: lock-in region by Williamson and Roshko[2], —: lock-in region by numerical analysis[3]

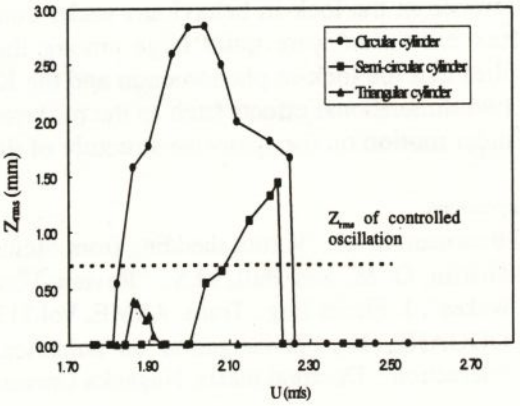
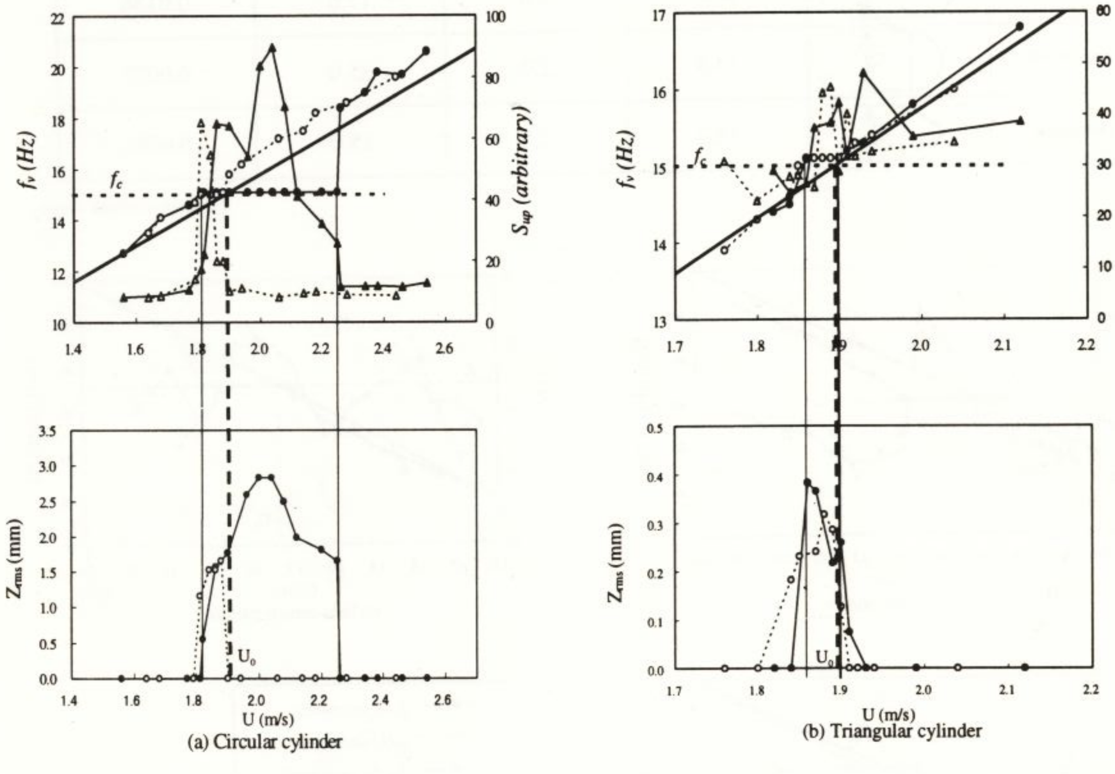


Figure 3 Oscillation behaviour of elastically supported cylinders (U increases).



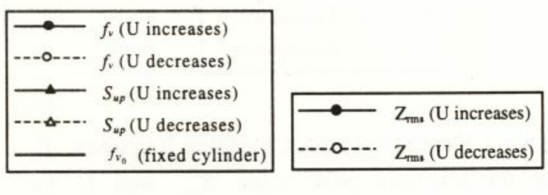


Figure 4 The vortex shedding frequency f_v, the spectrum peak value S_{up} and Z_{rms} against U for the circular and triangular cylinders.