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The effect of two degrees of freedom on vortex-induced vibration at low mass and damping.

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Summary: Although there are a great many papers dedicated to the problem of a cylinder vibrating transverse to a fluid flow (Y-motion), there are almost no papers on the more practical case of vortex-induced vibration in two degrees of freedom (X,Y motion) where the mass and natural frequencies are precisely the same in both X- and Y-directions. We have designed the present pendulum apparatus to achieve both of these criteria. Even down to the low mass ratios, where $m^*=6$, it is remarkable that the freedom to oscillate in-line with the flow affects the transverse vibration surprisingly little. The same response branches, peak amplitudes, and vortex wake modes are found for both Y-only and X,Y motion. There is, however, a dramatic change in the fluid-structure interactions when mass ratios are reduced below $m^*=6$. A new amplitude response branch with significant streamwise motion appears, in what we call the 'super-upper' branch, yielding massive amplitudes of 3 diameters peak-to-peak ($A_Y^*\sim 1.5$). We discover a corresponding periodic vortex wake mode, comprising a triplet of vortices being formed in each half-cycle, in what we define as a '2T' mode. We qualitatively interpret the principal vortex dynamics and vortex forces which yield a positive rate of energy transfer (e_V) causing the body vibration, using the following simple equation:

$$e_V = 2\Gamma^* U_V^* Y$$

where Γ^* is vortex strength, U_V^* is the speed downstream of the dominant near-wake vorticity, and Y is the transverse velocity of the body. This simple approach suggests that the massive amplitude of vibration for the 2T mode is principally attributed to the energy transfer from the 'third' vortex of each triplet, which is not present in the lower-amplitude 2P mode. We also find two low-speed streamwise vibration modes, which is not unexpected, since they correspond to the first and second excitation modes of vibration for flexible cantilevers. By considering equations of motion for the two degrees of freedom, we find a critical mass, m^*_{crit}=0.52, similar to recent Y-only studies, below which the large-amplitude vibrations persist to infinite flow velocity. We show that the critical mass m^*_{crit} is the same for the X- and Y-directions, which ensures that the shapes of X,Y trajectories can retain their form as the velocity becomes large. The extensive studies of vortex-induced vibration for Y-only body motions, built up over the last 35 years, remain of strong relevance to the case of two degrees of freedom, for $m^*>6$. It is only for 'small' mass ratios, $m^*<6$, that one observes a rather dramatic departure from previous results, which would suggest a possible modification to offshore design codes.

MSC:

76D25	Wakes and jets
76D17	Viscous vortex flows
76-05	Experimental work for problems pertaining to fluid mechanics

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