Study of vortex induced vibrations in two degrees of freedom on a spring-mounted circular cylinder with PIV.

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Introduction Vortex Induced Vibrations (VIV) phenomena cause problems in many areas related to offshore engineering. Large structures such as a Spar platform may experience VIV. Most often this problem area is related to risers and pipelines in free spans, as well as with vibrations of tubular members in flare booms. The important of *streamwise* vibrations have recently been appreciated, e.g. in model tests on free spanning pipelines made for the Ormen Lange development project. Although the dynamic response of an spring-mounted cylinder allowed to move transverse to the flow only has received much attention during the past 30 years (see e.g Williamson & Govardhan (2004)), few studies can be found on the extension in two degrees of freedom (transverse and streamwise). The system motion at resonance can then be described by the following equation, indicating that the forcing in the x-direction will have twice the shedding frequency.

$$x(t) = A_x sin(2\omega t + \theta), \quad y(t) = A_y sin(\omega t) \tag{1}$$

The following non-dimensional variables are used to decribe the problem: m^*: ratio of the oscillating system mass over the displaced mass, ξ: structural damping in air, $U^* = \frac{U}{f_n.d}$: reduced velocity, where f_n is the natural frequency of the system in water and d is the cylinder diameter.

Controlled PIV experiments on VIV with combined wave and forward speed effect are undertaken in complement to modelling efforts. The forward speed effect only is focused herein. The present work departs notably from other studies in one or two degrees of freedom (see e.g. Jauvtis & Williamson (2004), Khalak & Williamson (1999)) by the very peculiar choice of parameters used, namely a low mass ratio and high subcritical structural damping. In addition, flow visualizations were obtained at notably higher Reynolds numbers than other investigators and shed light on an interesting question: how do the flow patterns identified at low turbulent Reynolds evolve in the subcritical range ($Re = 1 \times 10^4$ to 10^5)?

Experimental set-up Experiments were carried out at the hydrodynamic laboratory of Oslo in a water towing tank of section 51 cm (width) and 81 cm (depth). A wavemaker can be operated to study the effect of a periodic current on the vibrating system. The vibrating system consists in a circular opened cylinder made of plexiglas (span L=47.5 cm, diameter d=8 cm or 4 cm), supported on both ends by three torsion springs, star-mounted on 10 mm-thick plates (see figure 1).

The cylinder is attached to the springs by inextensible nylon wires of length 35 cm. It is filled with water in the tank, yielding a mass ratio m^* very close to one and equal in both the

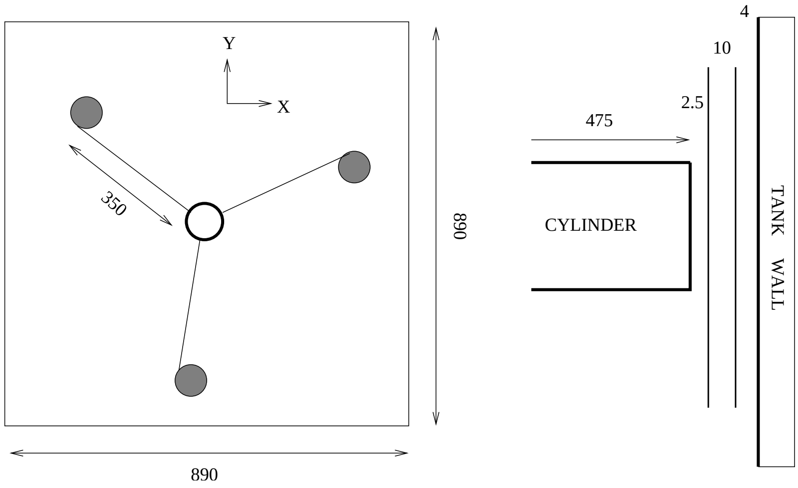

Figure 1: Side (left) and front (right) views of the mounting.

x-(horizontal) and y-(vertical) directions. On the other hand, the structural damping of this system is relatively high, so that the combined mass-damping parameter $m^*\xi$ usually used to predict the response of a system is around 0.1.
Reduced velocities U^*=4.5, 4.8, 5.1 and 6.7 have been investigated. A total of 90 runs were performed with both cylinders. In all runs, a two-dimensional PIV technique was used to extract the velocity field in a vertical plane (x,y) situated at mid-span. Images were obtained with a Photron APX CCD camera coupled with a pulsed NY-Ag laser, at 10 miliseconds of interval. The MatPiv software used a window-offset algorithm to cross-correlate the images, ending with 32×32 pixels subwindows. An accuracy of 3% is expected for the velocity.
The spatial resolution of the vector field was $d/10$ for both cylinders. The vorticity field was computed using a centered three-points scheme.
An important aspect of this set-up is that the PIV system is fixed, while the trailer is being towed in the tank. However, in the following description of the flow, data are presented in a frame of reference fixed with respect to the trailer, reproducing the more common situation of a water flume. 75% only of the trailer speed was substracted from the real velocity, in order to visualize the vortical structures in the wake.

Results Figure 2 presents the trajectory of the cylinder center for five cycles of motions, along with the approximation introduced in equation 1, justifying *a posteriori* the assumption of sinusoidal motion at resonance. The periodicity of the motion was found excellent for this speed (5% standard deviation in the peak amplitude). Comparison of the peak amplitudes obtained for the two cylinders with the widely used "Griffin" plot is shown in figure 3. The agreement is good, despite the dramatically different mass ratios involved (most results at high values of $m^*\xi$ were obtained in air, with $m^* = O(100)$).

Figures 4 and 5 show two instantaneous views of the flow field when the cylinder is at the top of its trajectory, for reduced velocities U^*=4.8 and U^*=6.7. Different vortex patterns can be easily identified despite the high Reynolds number: in figure 4, subsequent vortices are aligned on the wake centerline. The positive concentration of vorticity emanating from the upper shoulder of the cylinder is about to be shed during the future half-cycle. These features

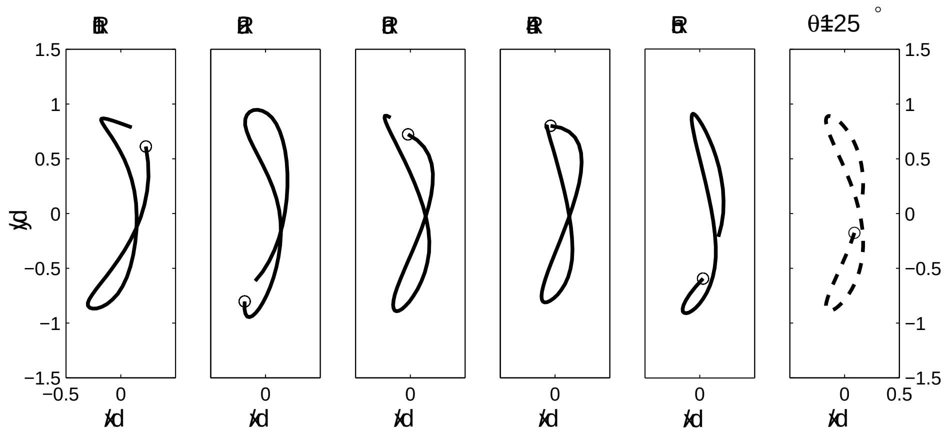

Figure 2: Trajectories obtained for one cycle at reduced speed $U^* = 6.7$ ($Re = 9500$), the circle indicating the starting point. Dotted-line: equation 1 plotted with $\theta = 125°$.

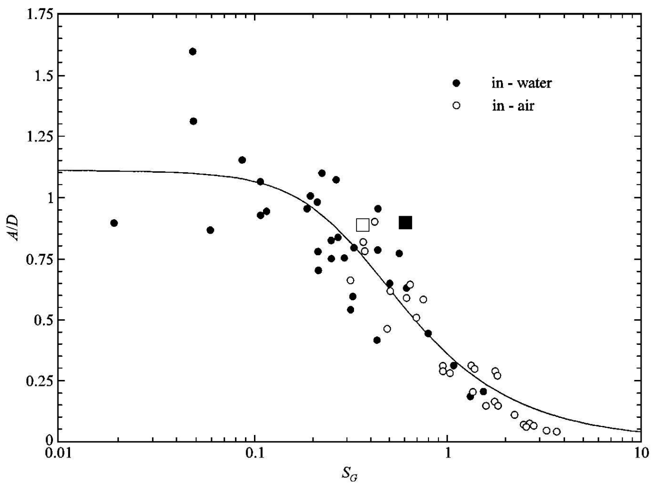

Figure 3: "Griffin" plot showing peak amplitude A^* versus S_G, linear y-axis. $\circ, \bullet$: data compiled from 1975. Curve fit: recent updtate by Skop & Balsabramanian (1997). $\blacksquare$: d=8 cm. $\square$: d=4 cm.

are characteristic from a "2S" pattern (following the classical denomination by Williamson & Roshko (1988)).

On the contrary, a second vortex is visible on the lower side of the cylinder on figure 5, forming with the original one a "mushroom" of two counter-rotating structures. The new one is actually formed as the cylinder accelerates upwards, in agreement with the description by Govardhan & Williamson (2000), at Reynolds numbers three times lower, so that two *pairs* of vortices are emitted in one cycle ("2P" pattern). However, this additional contribution is not visible in the wake, where single structures only are to be seen, widely spread apart from the wake centerline. The enhanced mixing corresponding to the high Reynolds number involved in these experiments is probably responsible for the quick decay of the weaker part of each "mushroom". This is supported from experiments made with the bigger cylinder, at Reynolds numbers up to 19000.

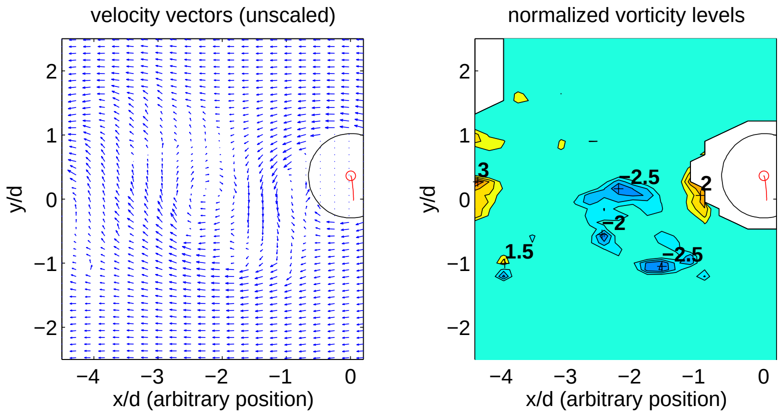

Figure 4: Instantaneous flow field obtained at $U^* = 4.8$ (2S pattern).

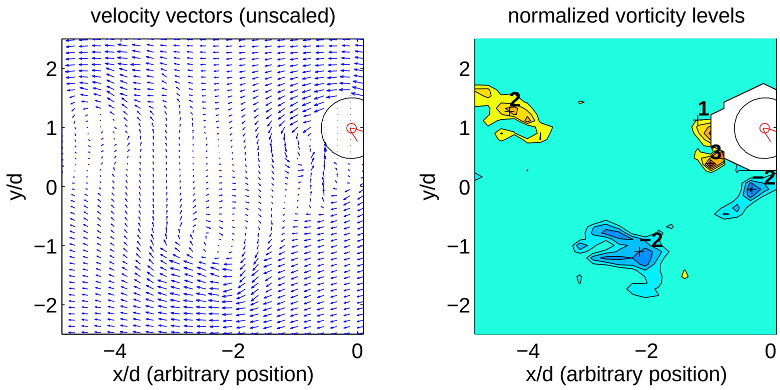

Figure 5: Instantaneous flow field obtained at $U^* = 6.7$ (2P pattern).

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