Forces and Wake Modes of an Oscillating Cylinder

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Introduction

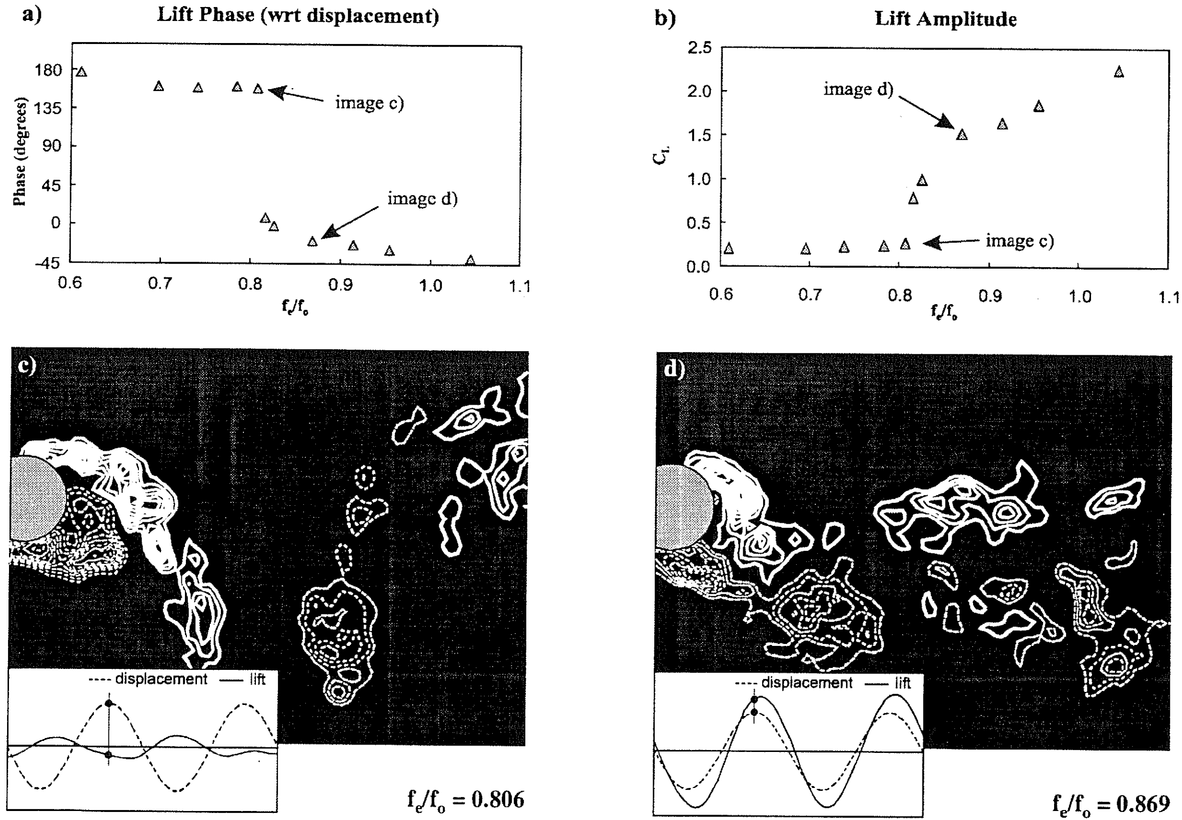
Oscillating cylinders in steady currents have been widely studied. For frequencies of oscillation near the natural Kármán frequency, significant changes in both the wake structure and the forces on the cylinder are observed. Generally speaking, studies have focused on either the forces experienced by the cylinder or the structure of the near wake. However, a full understanding requires simultaneous knowledge of both the forces and the wake state. The present study is an experimental investigation of the link between quantitative changes in the instantaneous structure of the near wake and the forces on the cylinder. In particular, we focus on frequencies of oscillation immediately surrounding these changes.

Experimental Method

The cylinder was oscillated transverse to the free stream such that its vertical motion was given by $A \sin(2\pi f_e t)$. For all experiments described $A/D = 0.5$. The frequency of oscillation, f_e, is normalised by the Kármán frequency f_o. For the frequency range studied, $0.5 < f_e/f_o < 1.4$, the wake was "locked on" to the cylinder oscillations. The Reynolds number, $Re = U_\infty D/\nu$, was 2300. For each frequency of oscillation the cylinder was started from rest at time, $t = 0$. The velocity field of the near wake of the cylinder was measured using a laser scanning version of high-image density PIV. The vorticity fields reported here were calculated from velocity fields containing 3500-5220 velocity vectors. The time varying lift and drag forces on the cylinder were measured by four strain gauges mounted on a support sting.

Results and Discussion

Previous investigations by Bishop & Hassan (1963) and Sarpkaya (1995) have found that as f_e/f_o is increased through unity there is a change of order 180 degrees in the lift phase, θ_{lift}, and a simultaneous jump in the lift amplitude, C_L. Our results, shown in Figure 1 a & b, agree well with previous work. The lift phase is calculated relative to the vertical displacement of the cylinder. The jump in the lift amplitude and phase suggests that the mode of vortex shedding may have changed.



$f_e/f_o = 0.806$

$f_e/f_o = 0.869$

Figure 1 $A/D = 0.5$, $Re = 2300$. a) variation of C_L with f_e/f_o, b) variation of θ_{lift} with f_e/f_o. Instantaneous vorticity fields with displacement and lift force are shown at c) $f_e/f_o = 0.806$ and d) fe/fo = 0.869. The timing of the images (top of the oscillation) is indicated by the small circles on the lift-displacement inserts. Both inserts use the same amplitude scale.

This observation is related to the previous work of Ongoren & Rockwell (1988), who observed a "switch" in the timing of the initially formed vortex from one side of the cylinder to the other. As the images in Figure 1 c & d are at the same displacement phase we can compare the relative position of the vortex structures. The sign of the vortex structures about to be shed into the wake are opposite: at the top of the oscillation for $f_e/f_o = 0.806$, a negative vortex structure is separating from the attached shear layer and positive vorticity is forming close to the back of the cylinder. For the higher frequency state, however, the structure being shed into the wake is positive and the vorticity forming around the back of the cylinder is negative. The opposite sign of the relative vortex structures is indicative of the approximately 180° phase difference in the lift. The results also show some agreement with those of Williamson & Roshko (1988), who observed that the vortex shedding changes from a "2P mode" to a "2S mode" around $f_e/f_o = 1$.

To test the link between forces and wake modes we examined wake states either side of the phase jump. The two instantaneous vortex fields in Figure 1 c & d are typical of the lower and higher frequency wake states respectively. The images, both taken at the top of the oscillation cycle, show two distinctly different modes of vortex shedding. The wake state before the jump, Figure 1c, has two vortex pairs of opposite sign shed per oscillation. This is similar to the 2P mode described by Williamson & Roshko (1988). The pairs are of unequal strength and cross annihilation makes the pairing unclear further downstream. The wake state after the jump, Figure 1d, is the traditional Kármán shedding or 2S mode, with two single vortex structures of each sign shed per oscillation. The vertical extent of the wake prior to the jump, $f_e/f_o = 0.806$, is clearly greater than after the jump, $f_e/f_o = 0.869$. The greater length of the attached shear layers at low f_e/f_o generates two shedding events per shear layer per oscillation, resulting in the formation of two vortex pairs.

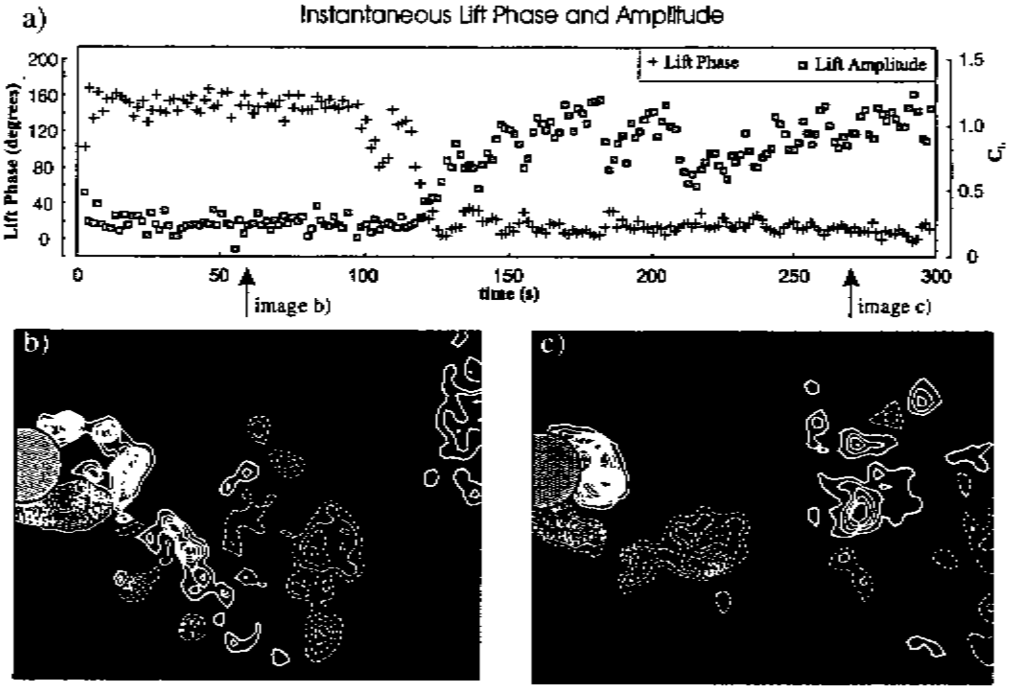


Figure 2 Transition between low and high frequency states can occur at a single oscillation frequency. a) The time variation of instantaneous lift phase (+) and lift amplitude (□) are shown on the same axis. The corresponding instantaneous vorticity fields at b) t = 60 sec and c) t = 270 sec are consistent with the lower and higher frequency wake states respectively. Both images were taken at the top of the oscillation.

Examination of the time history for frequencies around transition showed that changes in the lift properties could actually occur within an experimental run. The transition between the two wake states, at fe/fo = 0.815, is shown in the time series of lift force of Figure 2a. In this example, the transition occurs after more then 150 oscillations of the cylinder. The low frequency state is characterised by relatively low lift amplitude and high lift phase angle. The high frequency state has relatively large lift amplitude and small or negative lift phase angle. The wake modes either side of the transition are represented by the instantaneous vorticity fields in Figure 2 b & c. The wake modes are clearly different despite the fact that the cylinder oscillation frequency is the same. The wake states before and after the transition correspond to the low and high frequency states of Figure 1 c &d.

References

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