FLOW BEHIND A CYLINDER FORCED BY A COMBINATION OF OSCILLATORY TRANSLATIONAL AND ROTATIONAL MOTIONS

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Summary   This paper presents experimental results for flow behind a cylinder undergoing forced motion. The motion consists of two independent oscillations: cross-stream translation and rotation. Previous studies have extensively investigated the effect of these motions individually on cylinder wakes; however, the investigation of their combined effect is new. The motivation for studying such a flow lies in its application to vortex-induced vibration (VIV), and its suppression, and biomimetic motion. The results presented here focus only on the effect of the phase difference between the two motions. The results show that there is an unexpected loss of lock-on between the vortex shedding and the translational motion for a finite range of phase differences. The possible causes of this are discussed.

INTRODUCTION

The primary goal of this research is to understand the physical mechanisms behind the response of the wake behind a cylinder to the combined forcing mechanism of cross-stream translation and rotational oscillations. With an in-depth understanding the flow physics it may be possible to propose a novel means of actively or passively suppressing the lock-on between vortex shedding and transverse oscillation. Also, we are interested in application to biomimetic motions and in particular carangiform motions, as originally proposed by Blackburn *et al.*[1]. There has been considerable research on the effect of either transverse or rotational oscillations on cylinder wakes, as discussed in the extensive reviews [2, 3] Primarily, these have focused on the translational oscillation due to their focus on VIV. There have also been studies of the effect of rotational oscillation on wakes [4, 5]. Research has also been done on the effect of the combined motions in quiescent fluids[6] and for the case of flow[7] but this latter study was for a limited parameter space. From the intriguing results of Elston[6] and Leontini *et al.*[8] it would seem that an important variable for consideration is the phase difference between the two motions and this has been the focus of our initial research, which is discussed here. This work is part of a more extensive set of experiments that will look at the full range of independent variables.

EXPERIMENTAL APPARATUS

The experiments were conducted in the FLAIR free-surface closed-loop water channel in the Mechanical Engineering Department at Monash University. The cylinder used was 800mm length and with an outer diameter of $D = 20$mm, giving an aspect ratio of 40. The experiments were performed for a fixed upstream velocity $U_\infty = 0.0606$m/s giving $Re = U_\infty D/\nu = 1322$. Two sinusoidal motions were imposed namely: translational (cross-stream) given by $y = A_t \sin(2\pi f_t t)/D$ and rotational given by $\theta = A_\theta \sin(2\pi f_\theta t + \Phi)$. The experiments presented are for fixed amplitudes of oscillation, $A_t = D/2$ and $A_\theta = 1$. This set of amplitudes provides equal maximum velocities from the translational motion and the rotational motion. The frequencies are fixed close to that of the natural frequency ($T^{-1} = f_t = f_\theta \approx f_N$). As mentioned earlier, we present results of the phase difference (Φ) effect on the wake of the cylinder.
The method used here to characterise the wake of this forced cylinder is via particle image velocimetry (PIV). The flow was seeded with round granular shaped polyamide particles having a mean diameter of 50μm and specific gravity of 1.016. The particles were illuminated using two mini-YAG laser sources. The plane of interest for these experiments was cross-wise (y-direction) and down-stream (x-direction) of the cylinder (xy-plane). The given setup provided a field of view of roughly $6D \times 6D$.

RESULTS AND DISCUSSION

Figure (1) presents motion phase-locked vorticity iso-contours taken at $t = T$ for different phase differences. Starting at the top-left hand side of the figure, with the two motions being at opposite phase ($\Phi = \pi$), we observe a $2S$ mode (2 single vortices shed per period) in a single row aligned in the medial plane. The field of view does not allow us to see the double row that should occur further downstream [10]. As the phase difference is reduced towards close to in-phase, $\Phi = \pi/6$, the vortices are arranged closer to each other and less aligned with the medial plane, suggesting an earlier double row transition. The in-phase case, $\Phi = 0$, presents the signature of a $P + S$ mode (a single vortex and a vortex pair formed per cycle), this observation will be confirmed by future experiments with a larger field of view and with numerical simulations. For this in-phase case, the vortices are shed widely apart (nearly $4D$) readily explained by the rotational oscillation adding momentum to the translational motion. This strain favours the transition to the $P + S$ wake[9]. Reducing the phase difference to $\Phi = -\pi/6$ and $\Phi = -\pi/3$, the vorticity pattern returns to a $2S$ mode in a double row configuration. It should be noted that the spacing between the two rows reduces (from $2.5D$ to $2D$) as we decrease Φ. The cases of $\Phi = -\pi/2$ and $\Phi = -2\pi/3$ are of particular interest: contrary to all the other experimental cases, these two cases were not synchronised with the translational motion beyond $2D$ downstream. Indeed, near the cylinder the two strong vortices are still synchronised but not further downstream. This *a priori* surprising phenomenon

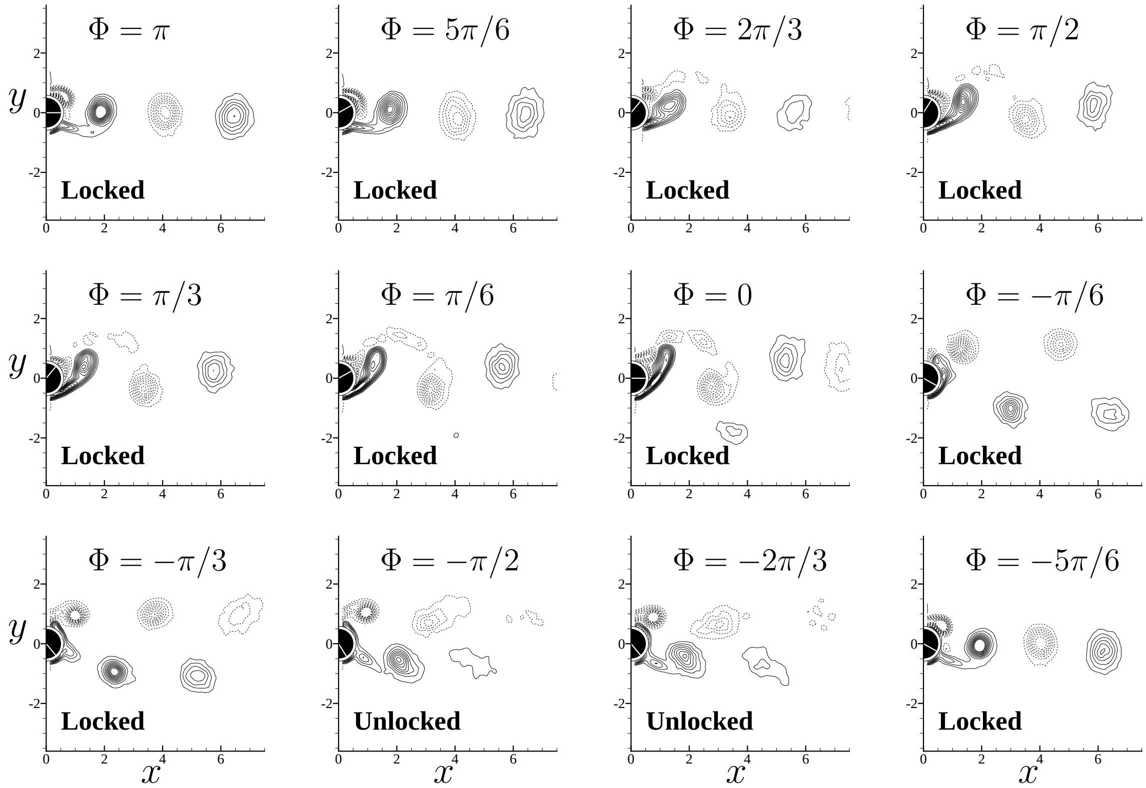

Figure 1. Motion phased-locked vorticity iso-contours taken at the motion-phase $t = T$. The near wake vorticity is shown for different phase differences between the two imposed oscillatory motions. Of interest is the asynchronous wake (unlock) with the imposed translational motion for the phase $\Phi = -\pi/3$ and $\Phi = -\pi/2$.

could be explained by the fact that the separation between the two rows of vortices is smaller and that this arrangement of vortices is not stable. Similar behaviour can be found behind elliptical cylinders[9]. The last case $\Phi = -5\pi/6$ (and necessarily the first case, $\Phi = \pm\pi$) displays vortices in a single row.

Further investigations are required to pinpoint the physical mechanism of the suppression of synchronisation for the two above mentioned particular phase differences. Experiments (not shown here) suggest that the suppression mechanism also holds for smaller amplitudes of motion (A_θ and A_t).

CONCLUSIONS

For the first time experiments have been carried put on a cylinder wake then the cylinder is experiencing combined rotary and translational oscillation. Preliminary results on the effect of the phase differences between the two forced motions, reveal that regular shedding can be suppressed for particular phase difference. This study raises further questions to be answered. Is the range of unlocked vortices continuous? What is the extent of the observed phenomenon with respect to other parameters? Can we envisage an application to suppress regular shedding with this additional rotation motion?

References

[1] Blackburn, H.M., Elston, J.R., Sheridan, J.: Bluff-body propulsion by combined rotary and translational oscillation *Phys. Fluids* **11**:4–6, 1999.

[2] Willamson, C.H.K., Govardhan, R., Vortex-induced vibration *Ann. Rev. Fluid Mech.* **36**:413–455, 2004.

[3] Sarpkaya, T.: A critical review of the intrinsic nature of vortex-induced vibrations *J. Fluids and Structures* **19**:389–447, 2004.

[4] Tokumaru, P.T., Dimotakis, P.E.: Rotary oscillation control of a cylinder wake *J. Fluid Mech.* **224**:77–90, 1991.

[5] Filler, J.R., Marston,P.L., Mih, W.C.: Response of the shear layers separating from a circular cylinder to small amplitude rotational oscillations *J. Fluid Mech.* **231**:481–499, 1991.

[6] Elston, J.R.: The structures and instabilities of flow generated by an oscillating circular cylinder. *PhD Thesis*, Monash University, Dept. Mech. Eng., Australia, 2006.

[7] Kocabiyik S., Al-Mdallal Q.M.: Bluff-body flow created by combined rotary and translational oscillation *Fluid Structure Interaction and Moving Boundary Problems* **84**:195–203, 2005.

[8] Leontini, J.S., Stewart, B.E., Thompson, M.C., Hourigan, K.: Predicting vortex-induced vibration from driven oscillation results *App. Math. Modelling* **30**:1096–1102, 2006.

[9] Leontini, J.S., Stewart, B.E., Thompson, M.C., Hourigan, K.: Wake state and energy transitions of an oscillating cylinder at low Reynolds number *Phys. Fluids* **18**(3):067101, 2006.

[10] Lamb H.: Hydrodynamics. Dover, NY 1932.