

Experimental Observation of Swinging Motion of a Suspended Circular Cylinder near a Vertical Heated Plate

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1. INTRODUCTION

Flow-Induced Vibration (FIV) of a circular cylinder has been an attractive research topic for many years due to its relevance to engineering applications. A typical FIV configuration includes a circular cylinder of a certain mass elastically mounted on a spring-damper system. When a flow passes the cylinder, lock-on or resonance occurs when the vortex shedding frequency behind the cylinder matches the natural frequency of the mass-spring-damper system, which may result in abnormally strong periodic oscillations [1]. Most existing studies in the literature have considered FIV of a spring-mounted circular cylinder system in non-thermal flows, and a significant research gap exists in understanding thermal effects on FIV. In this study, we experimentally observe FIV of a suspended circular cylinder (i.e., pendulum setting) in a buoyancy driven flow.

2. EXPERIMENTAL SETUP

Figure 1 shows a schematic of the experimental system with a suspended cylinder. In the schematic, θ , L and D are the angular position of the cylinder, string length and the cylinder diameter, respectively. We conducted a shadowgraph flow visualisation in a water tank previously adopted in [2], in which a vertical plate is maintained at a constant temperature of $T_w = 32$ °C. The temperature of the ambient water is approximately at $T_a = 20$ °C. A circular cylinder with a mass ratio $m^* = 1.12$ (the ratio between the density of the cylinder to the density of water) is suspended by two non-stretchable strings and positioned next to the heated plate without an initial gap. The global and local Rayleigh numbers based on the full height of the heated plate and the cylinder position are $Ra = 3.72 \times 10^{10}$ and 5.81×10^8 , respectively.

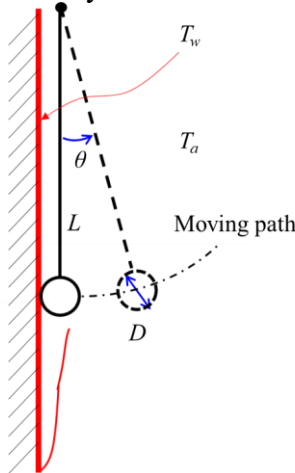


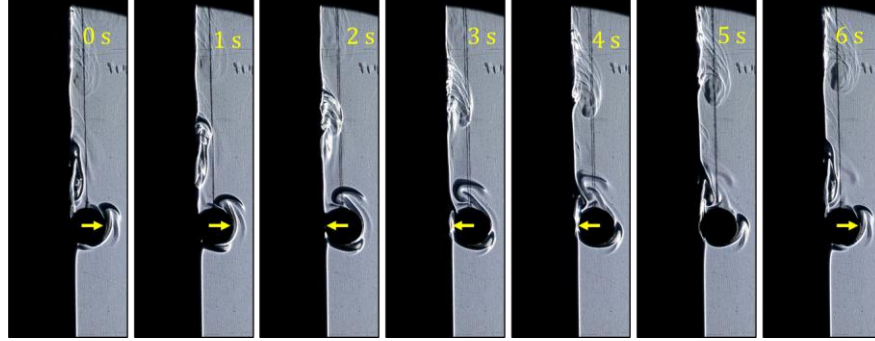
Figure 1. Schematic of the experimental system.

3. RESULTS

Figure 2 shows a series of shadowgraph images and the corresponding response amplitude of the cylinder at $m^* = 1.12$ over approximately one swinging cycle. The arrows in Figure 2(a) indicate the swinging direction of the cylinder. In Figure 2(b), the amplitude of response is made dimensionless by $\psi = \theta L/D$. A periodic swinging motion around a mean position of $\psi \sim 0.10$ is

clearly observable in the figure. From 0 s to 1 s, the cylinder is moving away from the heated plate, and the amplitude of response increases from $\psi = 0.104$ to 0.17. The cylinder is reversing its swinging direction from 2 s to 4 s with a decrease of the response amplitude. At 5 s, the cylinder reaches the lowest position without colliding with the heated plate (where $\psi > 0$). Subsequently, it moves away from the heated plate. A new swinging cycle starts from approximately 6 s onwards.

(a)



(b)

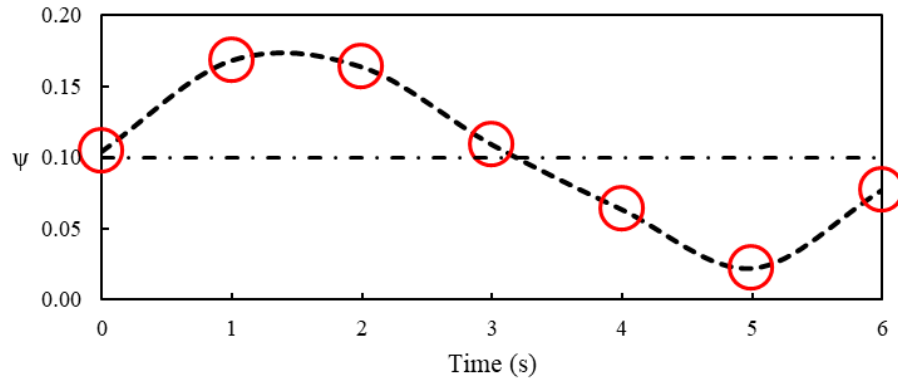


Figure 2. (a) Shadowgraph images of the wake dynamics and (b) the corresponding dimensionless amplitude of response for $m^* = 1.12$.

The dynamics of the wake behind the swinging cylinder (refer to Figure 2a) appear distinctly different from those observed by Chen et al., [3] for a cylinder undergoing FIV near a flat plate in non-thermal flows. Chen et al., [3] reported that, when the cylinder is initially in contact with the plate (i.e., without an initial gap), no oscillation of the cylinder is observed, and an irregular vortex street is present in the wake. In contrast, the wake appears quite regular in the present experiment, and a distinct oscillating frequency is detected (not reported here for brevity). This periodic motion may be beneficial for enhancing heat transfer through the heated surface.

4. CONCLUSIONS

The present study experimentally examines the dynamics of a suspended circular cylinder near a vertical heated plate. It is observed that the buoyancy driven flow can induce and sustain a periodic motion of a suspended circular cylinder with a mass ratio of $m^* = 1.12$. The swinging motion may be utilised for heat transfer enhancement. Further investigations are required to examine the phenomenon in greater detail.

REFERENCES

- [1] Williamson, C.H.K. and R. Govardhan, *Vortex-Induced Vibrations*. Annual Review of Fluid Mechanics, 2004. **36**(1): p. 413-455.
- [2] Zhao, Y., C. Lei, and J.C. Patterson, *A PIV measurement of the natural transition of a natural convection boundary layer*. Experiments in Fluids, 2015. **56**(1).
- [3] Chen, W., Wang H., and C., Chen, *Experimental investigation of the vortex-induced vibration of a circular cylinder near a flat plate*, Ocean Engineering, 2023. **272**.