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EXPERIMENTAL STUDY OF A TETHERED CYLINDER IN A FREE STREAM

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Results of an experimental investigation into the motion of a tethered cylinder are presented. The tethered cylinder is located in a free-stream and the flow velocity increased from rest up to a reduced velocity of $U^* = 16.8$. For a cylinder mass ratio of $m^* = 0.79$ periodic cylinder oscillations were observed for U^* above 11.9. The response of the cylinder is presented in terms of the mean tether layover angle and the oscillation amplitude of the cylinder, and at higher velocities the cylinder response indicates that there are two different states.

INTRODUCTION

The instabilities generated by fluid flow over a body can result in large scale motion of the body. A number of previous investigations have considered the flow induced motion of elastically mounted cylindrical bodies where the cylinder was constrained to move transverse to the flow, Govardhan and Williamson (2000), or was able to move in both the transverse and in-line directions, Jauvtis & Williamson (2002). A closely related problem is that of a tethered rigid cylinder; where the cylinder is free to move in an arc about the tether point. Despite the relevance of this case to the response of tethered bodies submerged in a steady current, this problem had received almost no attention until the recent numerical investigations of Ryan *et al.* (2002) and Pregnalato (2002). In this experimental investigation the response of a tethered cylinder to a range of flow velocities are presented and compared to the numerical results.

The cylinder, 30 mm in diameter and 594 mm long, is tethered using two 151.5 mm carbon fiber rods. The tether is located at the pivot point with precision bearings such that the tethered cylinder is free to rotate about the pivot point as shown in Figure 1. The cylinder is positioned in a free-stream flow and the flow velocity, U increased from zero to 0.46 ms^{-1}, giving a maximum Reynolds number of 13,700. The reduced velocity is given by $U^* = U/f_N D$, where f_N, the natural frequency of the tethered body varies with the tension in the tether. The cylinder mass normalised by the mass of the displaced fluid resulted in a mass ratio of $m^* = 0.79$ and a positive buoyancy force on the cylinder. The position of the cylinder was measured using PAL video tracking and the mean layover angle, θ_{mean} and the cylinder's oscillation amplitude, A_{std} were calculated from 16,384 data points.

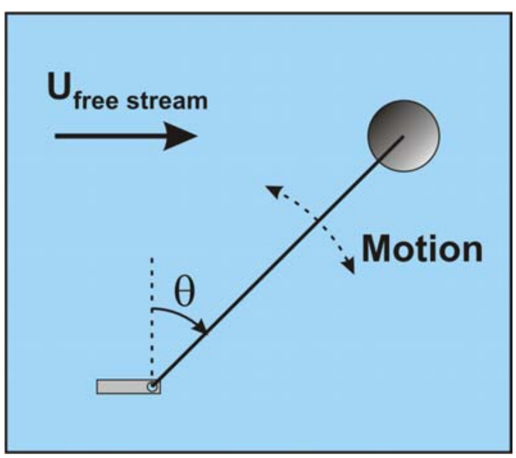

Figure 1 Schematic showing the tethered cylinder in the free-stream.

RESULTS AND DISCUSSION

As the flow velocity increases from rest, Figure 2(a) shows a steady increase in the mean layover angle, θ_{mean}, but at low flow velocities the cylinder does not oscillate. The onset of cylinder oscillations occurred at $U^* \approx 11.9$, corresponding to $Re = 7100$, which interestingly is well beyond the point at which the vortex shedding frequency passes through the natural structural frequency, $U^* \approx 5$. The onset of cylinder oscillations does not appear to alter the variation of θ_{mean} with U^*. As the velocity increases beyond $U^* = 11.9$ Figure 2(a) & (b) show that both θ_{mean} and the normalised oscillation amplitude, A_{std}/D increase with increasing U^*. The displacement traces indicate that the cylinder's motion is periodic but there is significant variation in the oscillation amplitude. Spectral analysis of the traces show two peaks, occurring at frequencies quite close to each other, and between $U^* = 11.9$ and 16.1 the variation in the oscillation amplitude appears to be a beating phenomena. The oscillation amplitude is represented by the standard deviation of the displacement trace which is significantly less than the largest peak-to-peak value.

Between $U = 0.38\ ms^{-1}$, corresponding to $U^* = 16.1$, and the maximum flow velocity of $U = 0.46\ ms^{-1}$ the cylinder demonstrates two different types of motion and the motion can be described as "dual state". For the first of these states the oscillation amplitude remains relatively small and appears to be consistent with the motion observed at lower flow velocity. The second state exhibits much larger amplitude oscillations and there is also an increase in the mean tether layover angle. At $U = 0.38\ \mathrm{ms}^{-1}$ the larger oscillation amplitudes are observed intermittently for relatively short periods of time, but as U^* increases the amount of time the cylinder spends in the large amplitude state increases. The displacement traces were split into segments representing the small and large amplitude oscillations using a mean layover threshold. The values of θ_{mean} and A_{std}/D corresponding to these segments, plotted as dual state points in Figure 2, clearly show the cylinders position and motion for these two states. In particular, Figure 2 clearly shows the link between the increase in θ_{mean} and the increase in A_{std}/D for the large amplitude state. The increase θ_{mean} as the cylinder moves to the large amplitude state corresponds to an increase in the tension in the tether, resulting in a decrease in the value of U^*. Thus, in Figure 2 the squares, corresponding to the large amplitude oscillations, occur at lower reduced velocities than the small oscillation points represented by the triangular symbols.

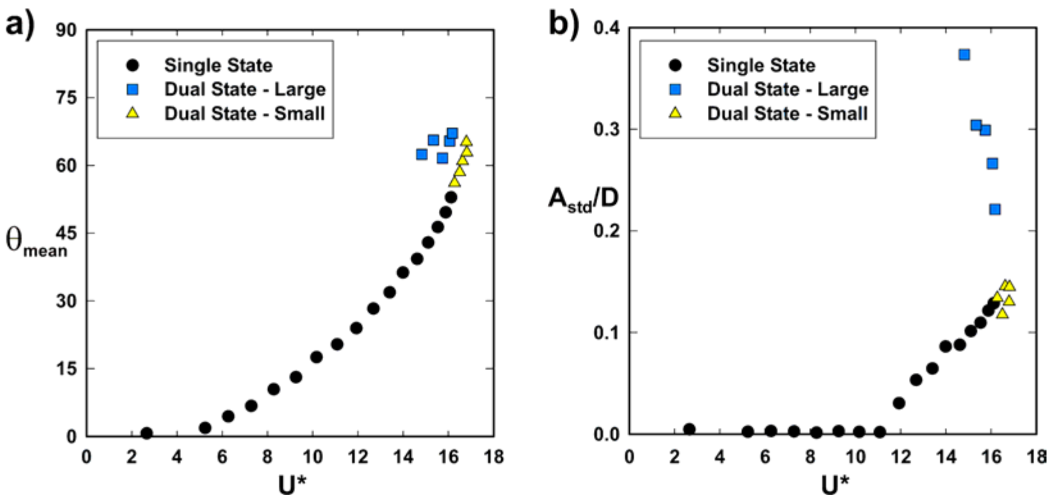

Figure 2 Variation of a) mean layover angle, θ_{mean} and b) normalised oscillation amplitude, A_{std}/D, with reduced velocity U*, $Re_{max} = 13{,}700$, $m^* = 0.79$, $L^* = 5.05$.

The variation of θ_{mean} with U^* at lower flow velocities is consistent with the two-dimensional numerical simulations of Ryan *et al.* (2002) at $Re = 200$, however the larger amplitude state was not observed in the numerical simulations at similar m^* values. Additionally, at low values of U^* the numerical simulations found very small oscillations which were not observed experimentally. The differences between the experimental and numerical results indicate that three dimensional effects, and possibly also Reynolds number, are important in determining the response of the cylinder.

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