

The Effect of Changed Mass Ratio on the Motion of a Tethered Cylinder

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Introduction

To date, few studies on the uniform flow past a tethered body exist, most of these concentrating on the flow past a tethered sphere. This is despite tethered cylinders having practical applications in sub-sea pipelines, tethered lighter-than-air-craft, and tethered spars just to name a few examples.

A significant body of research exists in the related field of freely oscillating cylinders, both with high- and low- mass damping. For both cases, several parameter studies have been performed, including studies regarding the effect of mass ratio on the modes of oscillation observed. In particular, Govardhan and Williamson (2000) observed that for low mass damped hydro-elastically mounted cylinders three modes of oscillation exist, namely the initial, upper and lower branch, and a critical mass ratio exists below which oscillations continue up to an indefinite reduced velocity along the upper branch. Recent studies by Govardhan and Williamson (2002) have confirmed that this phenomenon occurs up to an infinite reduced velocity.

Only the two-dimensional studies of Pregalato *et al.*(2002), and Ryan *et al.*(2002) have reported studies on the flow past a tethered cylinder. In these related papers, only one cylinder mass ratio and tether length ratio was studied ($m^* = 0.833$, $L^* = 5.05$), however, at large layover angles, θ (where the tethered cylinder experiences dominantly transverse oscillations), oscillations similar to that of a freely oscillating cylinder were reported, and it may be assumed that a tethered cylinder may have a critical mass ratio similar to that found for a freely oscillating cylinder.

In this paper two-dimensional simulations of a tethered cylinder with various mass ratios ($m^* = 0.1-0.98$) and a tether length, $L^* = 5$, are reported (see Figure:1). The reduced velocity $u^* = \frac{U}{f_n D}$ was chosen as the controlling flow parameter, with all simulations performed at a Reynolds number, $Re = 200$. Simulations were carried out with a highly accurate spectral element method coupled with a predictor corrector method, detail of which may be found in Pregalato *et al.*(2002).

Results

The results of the mean layover angle are presented in figure 2 for each mass ratio investigated over a range of reduced velocities. In general, as u^* is increased, there is a corresponding increase in the mean layover angle, θ . For $m^* > 0.2$ this increase is monotonic and continuous for increasing u^* . For $m^* \leq 0.2$ a discontinuous jump in the mean layover angle is observed, as the mean layover angle passes through 45° ; two mean layover angle states may be defined: the low mean layover state (θ_{Low}) and the high mean layover state (θ_{High}). Three reduced velocity regimes were observed. For low u^* , corresponding to $\theta \lesssim 30^\circ$ the mean layover angle for $m^* \leq 0.2$ corresponds closely to that found for $m^* > 0.2$. For slightly higher u^* , an intermittent mode is found for $m^* \leq 0.2$ where the cylinder oscillates about either θ_{Low} or θ_{High} . This occurs as the mean layover angle passes through 45° . For higher u^* , and for $m^* \leq 0.2$, the cylinder oscillates about θ_{High} . For $m^* > 0.2$, the cylinder oscillates about the low mean layover angle state for all reduced velocities investigated. For very high u^* , a further jump in θ is found for $m^* \leq 0.3$.

Figure 3 shows the amplitude of cylinder oscillation about the mean layover angle in the direction of motion. As may be seen, at the same reduced velocity (where θ passes 45°) there is a significant increase in the amplitude of oscillation for cylinders with $m^* \leq 0.3$ which is maintained up to the highest reduced velocity investigated. No significant oscillations were observed for cylinder with higher m^* up to the limit of u^* investigated.

Both Figure 2 and Figure 3 indicate a critical mass ratio exists for the tethered cylinder of $m^* \simeq 0.2-0.3$. Below which high amplitude oscillations are sustained as the mean layover angle passes 45° . This is similar to the $m^*_{crit} = 0.25$ found in the two-dimensional simulations of a hydro-elastically mounted cylinder performed

by Shiels (1998) and reported by Govardhan and Williamson (2002).

Conclusion

A critical mass ratio, $m^* = 0.2 - 0.3$ has been found for the uniform flow past a tethered cylinder, below which sustained large amplitude oscillations are observed up to the highest reduced velocity simulated in this study. The critical mass ratio is found to coincide closely with that found for a hydro-elastically mounted cylinder using two-dimensional simulations in previous studies. However, for a tethered cylinder, the critical mass ratio affects both the mean layover angle as well as the amplitude of oscillation.

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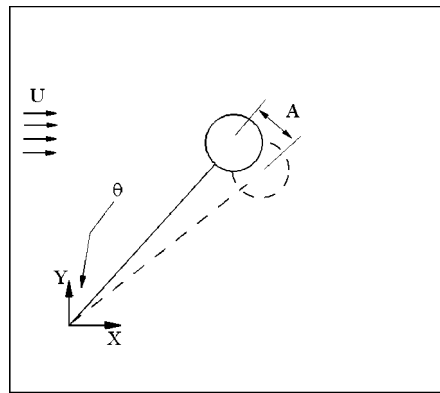


Figure1: Schematic of the tethered cylinder system

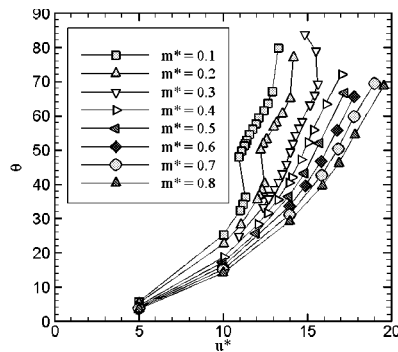


Figure2: Mean layover angle as a function of u^*

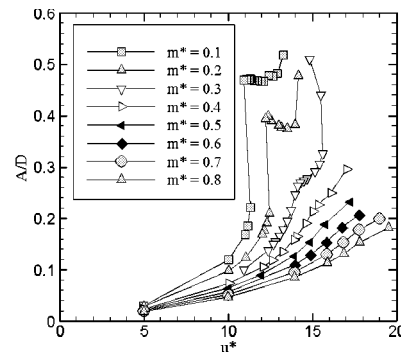


Figure3: Normalised amplitude of oscillation as a function of u^*