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INVESTIGATING THE MOTION OF TETHERED BLUFF BODIES IN STEADY FLUID FLOW

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ABSTRACT

The motion of tethered bluff bodies subject to steady fluid flow has been investigated experimentally using a video motion-capturing technique. Both tethered spheres and cylinders were investigated in this study; tethered spheres were investigated to verify the motion-capturing method, and tethered cylinders as part of a new area of research. Comparisons are made not only between the two types of tethered bluff bodies, but also between elastically mounted cylinders and those constrained by tethers. Additional work is being undertaken to further understand the oscillation characteristics of the tethered cylinder.

1. INTRODUCTION

There have been a number of studies that investigated tethered bodies subject to free surface waves, but little has been done on tethered bodies below a free surface in steady fluid flow. Govardhan & Williamson (1997) investigated the oscillation amplitude and frequency of tethered spheres at different mass ratios (the ratio of body mass to the mass of the displaced fluid), $m^* = 0.01 - 0.9$, and tether length ratios (where the tether length is nondimensionalised by body diameter), $L^* = 3 - 9$, in a water tunnel. They found that the direction of motion of largest amplitude of the tethered sphere is normal to the flow, with transverse oscillations being up to four times larger than those in the streamwise direction, so this direction was the focus of their observations. Figure 1 below shows the oscillation amplitude for two different tether lengths compared to Reynolds number, *Re*, and reduced velocity, U^* (the inverse of Strohaul number, St). Figure 1(b) shows that the data for different tether length ratios actually collapse onto a single curve for the same mass ratio ($m^* = 0.76$). For the range of flow speeds investigated, it can be seen that there are two significant peaks of oscillation amplitude – a local peak at $U^* \approx 5$ (defined as mode I) and then a higher peak at $U^* \approx 10$ that continues through to the highest value of *Re* tested in these experiments (mode II). The authors comment that as the oscillation amplitude remains constant, mode II appears to be the saturation amplitude of the system.

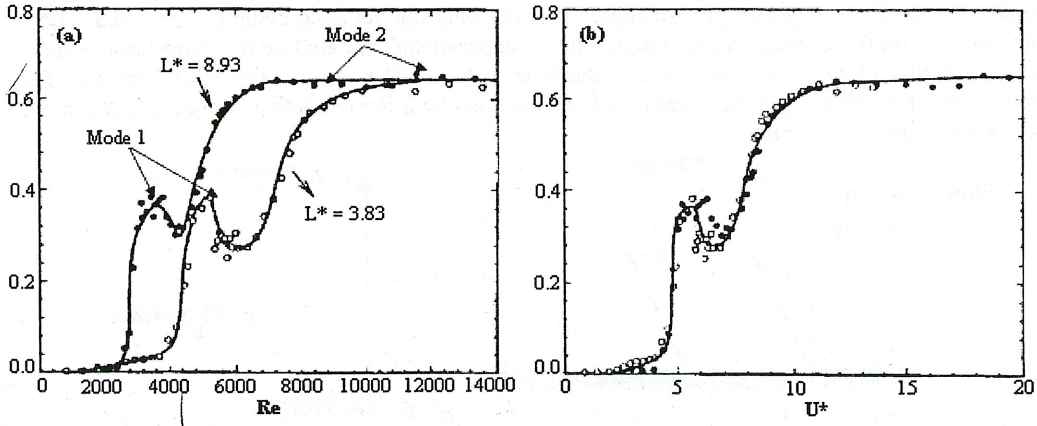

Figure 1 : Transverse oscillation of tethered spheres

Jauvtis et al. (2000) investigated the motion of tethered spheres with higher mass ratios ($m^* = 75 - 940$) in wind tunnels, which allowed the range of U^* to be increased substantially compared to the earlier studies by Govardhan & Williamson. Modes I and II were again observed for this high mass ratio case, although it was found that there is a sharp drop in oscillation response after the mode II peak, and a third oscillation peak (mode III) is found at larger U^*. No explanation for this third mode has been given at this stage.

Figure 1 shows that a change in tether length does not affect the amplitudes of oscillation of the system, although it does change the Reynolds numbers at which the modes of oscillation occur. The oscillation data collapses onto the same curve when plotted against U^*. Figure 2 (Govardhan & Williamson, 1997) shows the transition of sphere motion for constant tether length and mass ratio ($m^* = 0.082$ and $L^* = 9.3$). The pattern of the sphere oscillations show that as the Reynolds number increases, the phase between the streamwise and transverse motions changes, and the phase plot transforms from a 'crescent' shape (a) to a 'figure-8' shape (c). In each of these cases, although the streamwise and transverse frequencies are increasing with Re, they remain at a ratio of 2:1. Williamson & Govardhan (1997) suggest that this is because streamwise oscillations become phase-locked with the transverse oscillations and vibrate at twice the frequency of the transverse.

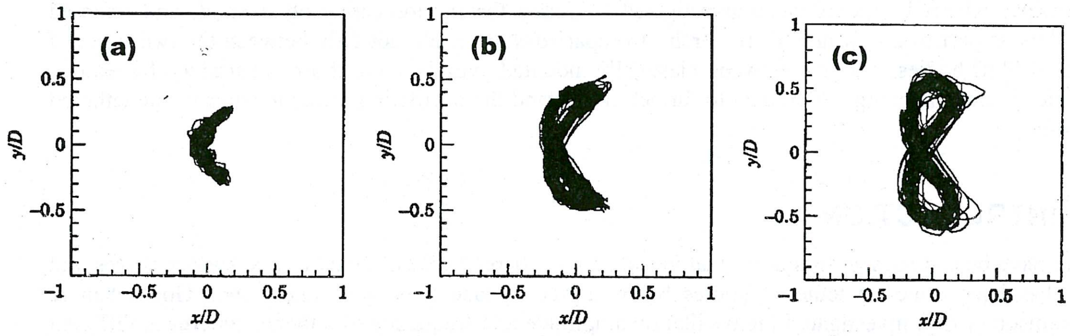

Figure 2 : Tethered sphere oscillations for (a) $Re = 5{,}132$, (b) $Re = 9{,}176$ and (c) $Re = 11{,}310$.

The other tethered bluff body investigated in this paper, the cylinder, does not appear to have been previously investigated under these flow conditions.

2. EXPERIMENTAL METHOD

Experiments were performed on tethered spheres and cylinders in order to observe the dynamics of these bluff bodies when they are subjected to uniform flow conditions in a water channel of cross-section 304 mm x 310 mm.

Tethered spheres of two different mass ratios ($m^* = 0.22, 0.82$) with the same diameter ($D = 35$ mm) and tether length ($L^* = 3.5$) were investigated. To date, only one tethered cylinder ($m^* = 0.87$, $L^* = 3.5$, and $D = 40$ mm) has been tested, although future experiments will analyse this bluff body in more depth. The tether in each case was fixed to the base of the bluff body and the water channel. The tethered cylinder for this experiment was simply constrained by a flexible tether connected at each end of the body as illustrated in Figure 3.

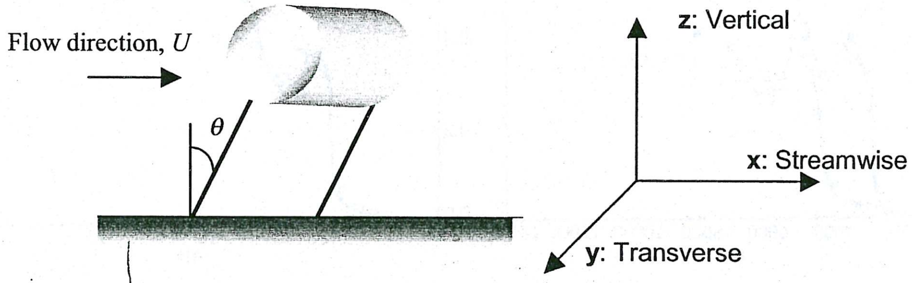

Figure 3 : Experimental apparatus for tethered cylinder experiment.

The bluff body displacement was recorded by a digital video camera mounted next to the working section, in the significant plane of oscillation. For the case of the tethered sphere the camera was set up to record in the x-y plane (refer to axes shown in Figure 3), while the tethered cylinder was measured in the x-z plane. The motion data collected from the camera is then transferred to a computer where the frames were digitally processed. Using a computer package, each frame of information from the video camera was analysed and the position of the body recorded. A sample set of results using this technique is shown in Figure 6 in Section 3.2 of this paper.

3. RESULTS AND DISCUSSION

3.1 TETHERED SPHERE EXPERIMENTS

For low values of m^* there was found to be a strong relationship between the oscillation results of the two sets of experiments, although water tunnel restrictions prevented testing at higher U^*. Figure 5 shows that the experimental results follow the trend of the data presented by Govardhan & Williamson (1997), although the expected initial peak (mode I) was not noticeable when comparing y_{RMS} to either Re or U^*. Figure 5 also shows different y_{RMS} values for the same values of flow speeds. This is believed to be a result of the fluctuating flow speed in the water channel used for these experiments.

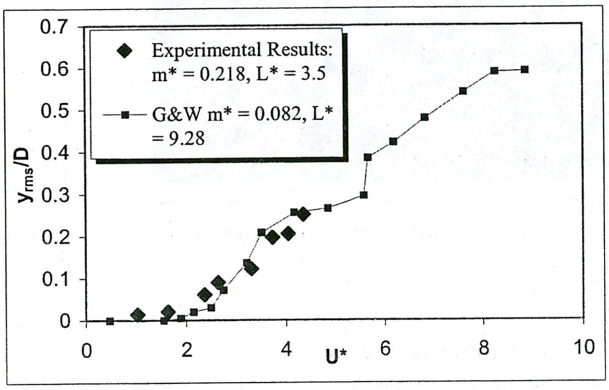

Figure 4 : Tethered sphere oscillation values at low m*.

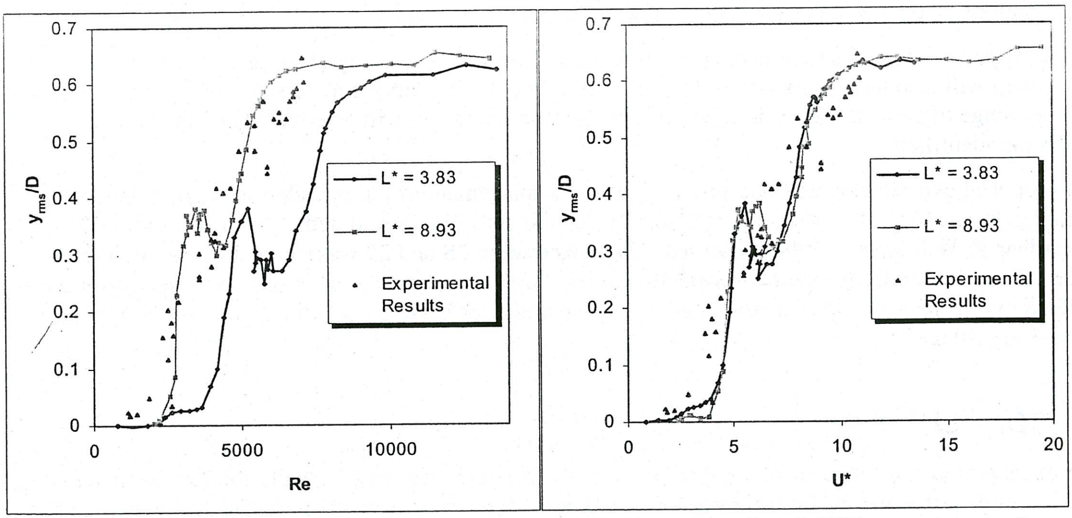

Figure 5 : Tethered sphere oscillation values compared to Re and U^*. Govardhan & Williamson data at $m^* = 0.76$, experimental data $m^* = 0.82$.

Although these results did not clearly show the modes of oscillation found in the results of Govardhan & Williamson, they did demonstrate that precise experimental conditions are required to get reliable results from the oscillating bluff body, which was not achievable with the water channel used for these initial experiments. Further experiments (discussed in Section 3.3) will be performed in a water channel where these variations in flow conditions will not be present.

3.2 TETHERED CYLINDER EXPERIMENTS

Figure 6 shows the oscillation pattern for the tethered sphere at one of the flow velocities investigated. These results show that the cylinder motion is in the shape of an arc, and that the streamwise (x) oscillation is most significant for this bluff body, unlike the transverse oscillations of the tethered sphere. Despite the flexible tether used in these experiments, the tether remained constantly in tension (mainly due to the buoyant effects of the cylinder), and very little bending or movement of the cylinder in the transverse direction was present, despite the varying flow conditions present in the water channel.

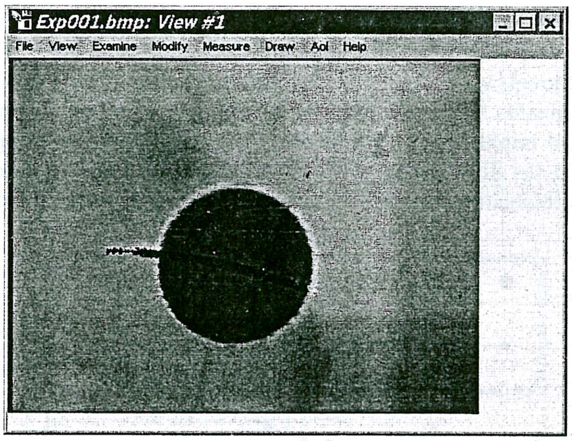

Figure 6 : Computer display of tethered cylinder motion at $U^* = 14.2$.

3.3 FURTHER WORK

The initial experiments described in this paper established a reliable means for recording position data with respect to time, and also identified significant directions of oscillation for tethered spheres and cylinders. Despite the fact that the primary direction of motion is different for spheres and cylinders, future experiments will compare the motion of tethered spheres and tethered cylinders at the same mass ratios and tether lengths in the x-z plane to see if a relationship exists.

Further experiments will be conducted in a new water channel of working cross-section 600 mm x 600 mm, which will also have more controllable flow conditions. By varying m^* and L^* within the reduced velocity range of $U^* = 0 - 20$, it is expected that the area of interest will be covered and the branches of oscillation identified.

The proposed experiments will not only look at the displacement of the cylinder but also at the vortex shedding in the cylinder wake and the forces on the bluff body and tether with respect to time. Govardhan & Williamson (2000) observed a change between 2S and 2P wake vortex modes at different values of oscillation frequency for elastically mounted cylinders, whether a similar result occurs for the tethered cylinder case will be investigated. The apparatus for these proposed experiments is currently in the design stage.

4. CONCLUSION

The experiments described in this paper provide some interesting initial results for the dynamics of tethered bodies that justify further research in this area. A series of much more detailed experiments involving tethered cylinders will be performed to further this study.

5. REFERENCES

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