Free-end effects on flow interference between two tandemly arranged circular cylinders.

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1. INTRODUCTION

It is well known that the presence of a free end can significantly affect the flow around one cylinder. Previous work by Okamoto(1973), Farivar(1981), Gerrard(1981), Kawamura(1984) and Zdravkovich(1989) shows that the presence of a free end introduces three dimensional flow particularly near the free end, on top of which the separated flow is deflected down towards the wake near the mid span of the cylinder. This downwash causes disruption of the regular vortex shedding along the span of the cylinder, which in turn affects the dynamic forces.

For flow around two cylinders, most of the previous studies have been concentrated on the interference between two dimensional cylinders, ie. cylinders without free ends, among which, Zhang and Melbourne(1991) demonstrated that vortex shedding plays a dominant role in determining various flow interference regimes. In comparison, the study of interference between two three-dimensional cylinders, which is of more practical interest, has not been well emphasised in the past, although the presence of the free ends is likely to alter the mechanisms of flow interference.

2. EXPERIMENTAL ARRANGEMENT

The model circular cylinders were aluminium tubes with an outside diameter of 100mm. The main cylinder, on which the measurements were made was cantilevered on a heavy steel plate bolted on a massive concrete block underneath the tunnel floor. Strain gauges were mounted near the base of the main cylinder. The dummy cylinder was simply bolted rigidly onto the tunnel floor.

The outputs from the strain gauge bridges were low pass filtered below the natural frequencies of the main cylinder, which were well above the Strouhal frequency. The Reynolds number was set at 1.1×10^5 and free stream turbulence intensity was 0.4%. The aspect ratio of the cylinders was 8. The outputs from the bridges were calibrated against the moments about the floor level and the results are presented in the form of interference moment coefficient $I_{\overline{m}}$ and interference factor I_{σ_m} which are defined as follows:

$$I_{\overline{m}} = C_{\overline{m}} - C_{\overline{m}_i}; \quad I_{\sigma_m} = C_{\sigma_m}/C_{\sigma_{m_i}}$$

where $C_{\overline{m}}$ and C_{σ_m} are the mean and standard deviation of moment coefficients on the cylinder suffering interference and the subscript i denotes the results obtained on an isolated cylinder under the same free stream conditions.

3. EXPERIMENTAL RESULTS

Figure 1 shows the cylinder coordinate system used for the presentation of the results. The cylinder coordinate system is fixed on the main cylinder. Figure 2 presents the variations of $I_{\overline{m}_c}$, $I_{\sigma_{m_a}}$ and $I_{\sigma_{m_c}}$ with cylinder spacings. The subscripts a and c denote alongwind and crosswind directions, respectively. For example, $I_{\overline{m}_c}$ represents the crosswind interference moment coefficient which is caused by the alongwind force. In addition, X denotes the x coordinate of the dummy cylinder. In the same figures, the corresponding two-dimensional results are also presented for the purpose of comparison.

Figure 2 indicates that the presence of free ends increases the $I_{\overline{m}_c}$ significantly towards zero for all spacings, compared with the two-dimensional case. The upstream cylinder cannot provide as

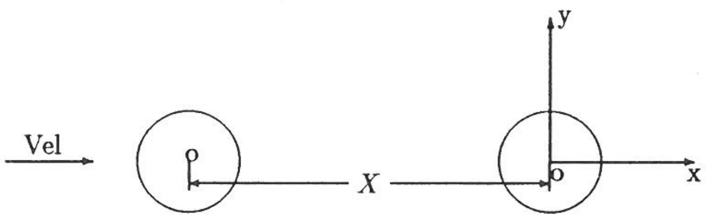

Figure 1: The cylinder coordinate system used for the presentation of the results.

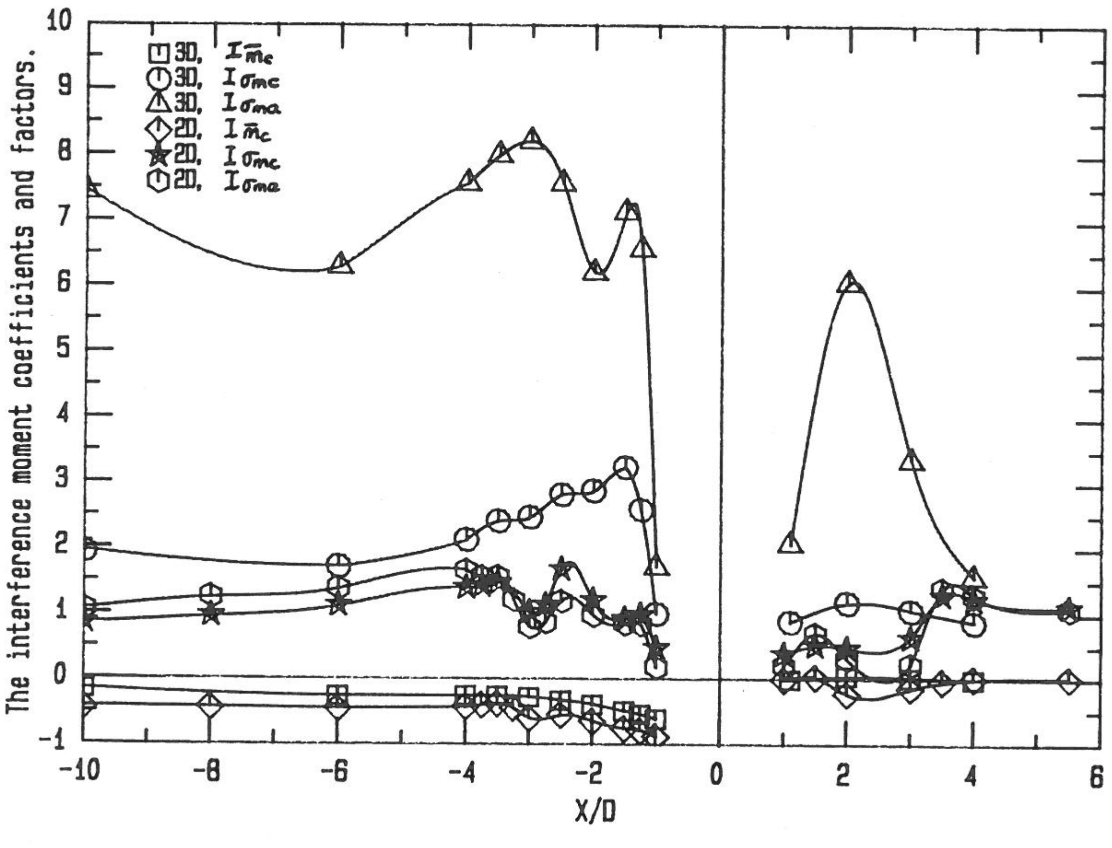

Figure 2: The variations of $I_{\overline{m}_c}$, $I_{\sigma_{m_a}}$ and $I_{\sigma_{m_c}}$ with cylinder spacings for both 2D and 3D cases.

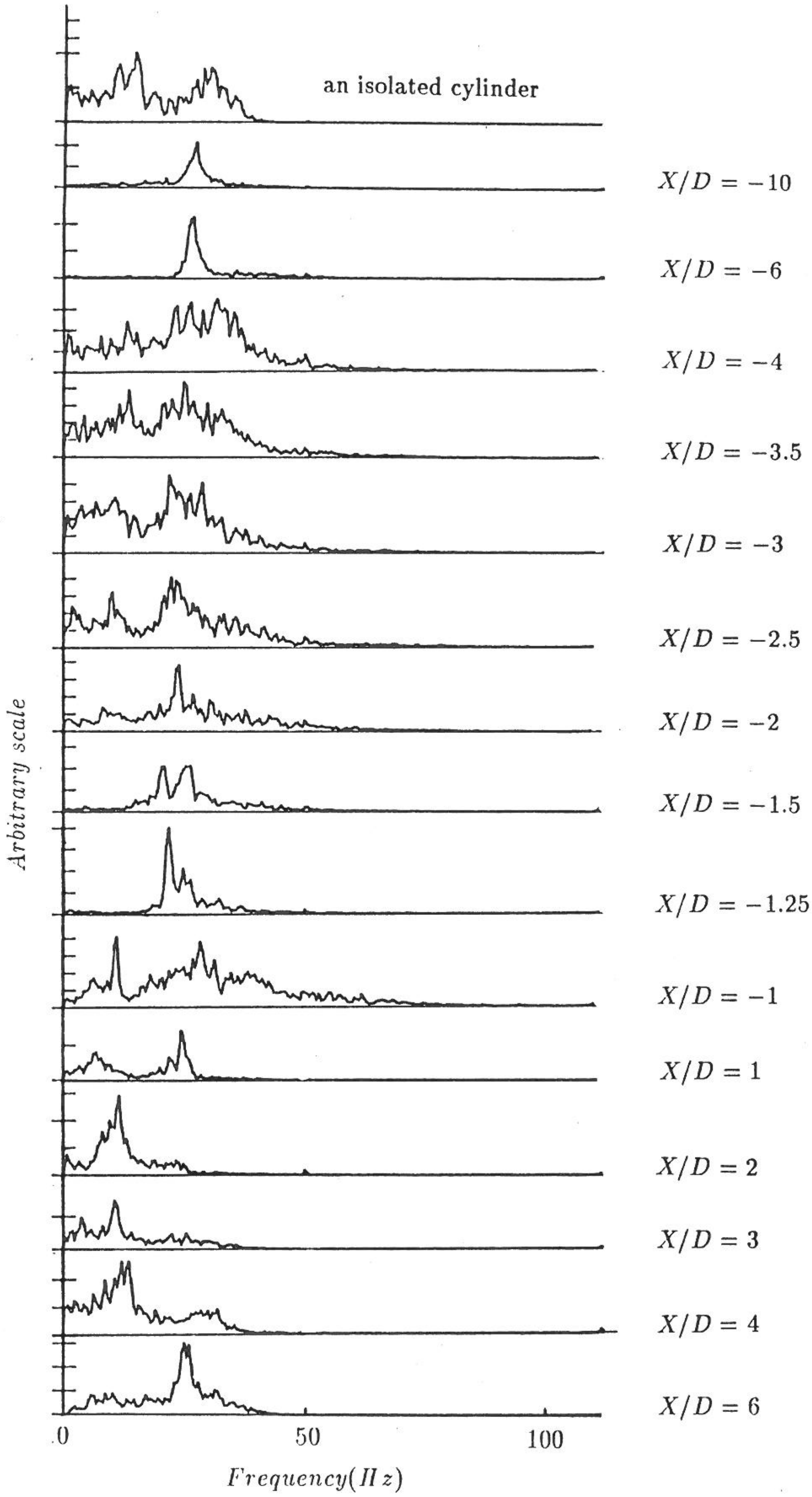

Figure 3: The variations of spectra for alongwind fluctuating moments with cylinder spacings.

much shielding as it would for the two-dimensional cylinders. Furthermore, the significant change in $I_{\overline{m}_c}$ observed on the two-dimensional cylinders are not prominent for the three-dimensional case.

As opposed to the mean moment, the magnitude of interference for fluctuating moments, in particular $I_{\sigma_{m_a}}$, is increased dramatically for the 3D case as shown in the same figure. Furthermore, the characteristic variations of moments on the 2D cylinders for various interference regime cannot be detected on the 3D cylinders.

Figure 3 gives the spectra of alongwind fluctuating moment for various cylinder spacings. It can be seen that the for $|X/D| \geq 6$, the spectra are narrow banded and centred at the Strouhal frequency. Although the presence of an upstream cylinder can greatly strengthen the vortex shedding on the downstream cylinder in both 2D and 3D cases, the impact for the 3D case is far more significant, which can be clearly seen from the drastic change in the spectra. (Compare the spectrum of an isolated cylinder with that of $|X/D| = 10$.) As X/D is reduced to 6 diameters, the fluctuating moments show a slight decrease, but nevertheless the Strouhal peak is still prominent. Hot wire measurements have shown that the presence of the upstream cylinder enlarges the region on the downstream cylinder where periodic vortex shedding takes place. The region expands towards the free end, which ultimately causes the large change in the fluctuating moments.

However, for $|X/D| < 6$, it can be seen that the spectra become very broad banded. This is very different from the 2D case, in which the downstream cylinder always experiences narrow banded excitation. The change in the spectra for $|X/D| < 6$ is caused by a disruption of vortex shedding along the span of the downstream cylinder. This is thought to be influenced by the separated shear layer from the free end of the upstream cylinder. The switch in the source of excitation for the downstream cylinder results in a significant increase in the fluctuating moments.

It should be mentioned that as the free stream turbulence intensity was increased, the effects of free ends on the flow interference were dramatically reduced.

4. CONCLUSIONS

The presence of the free ends can significantly influence the flow interference. In comparison with the two-dimensional cylinders, the magnitude of interference is reduced for the mean moment, but increased dramatically for the fluctuating moments. The presence of the upstream cylinder increases the region where periodic vortex shedding takes place on the downstream cylinder. Furthermore, for $|X/D| < 6$, the separated flow from the free end of the upstream cylinder is expected to be the main source of excitation for the downstream cylinder.

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