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INTERFERENCE BETWEEN TWO TWO-DIMENSIONAL CIRCULAR CYLINDERS IN TURBULENT FLOW

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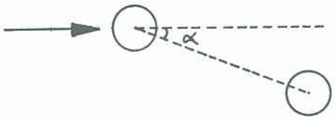
ABSTRACT

This paper presents some of the results of the wind tunnel studies on the interference between two-dimensional smooth circular cylinders for tandem and side by side arrangements in turbulent flow. Both alongwind and crosswind interference factors on one of the cylinders are presented for different cylinder arrangements. The effects of cylinder arrangement and turbulence intensity on interference factors and force spectra are examined. Also the influence of turbulence intensity on critical spacings is discussed.

INTRODUCTION

The topic of flow interference between two circular cylinders has been studied by a number of researchers in the last two decades. The common approach to the subject is to measure interference forces and flow fields for different cylinder arrangements by means of wind tunnel experiments. The cylinder arrangements are usually classified into three groups: tandem, side by side and staggered arrangement as shown in Figure 1.



$\alpha=0$: Tandem Arrangement;

$\alpha=90$: Side By Side Arrangement;

$\alpha\neq0$ and $\alpha\neq90$: Staggered Arrangement.

Fig.1. Different Cylinder Arrangements.

For the side by side configuration, the work of Williamson (1985), Kiya (1980), Zdravkovich (1982), Bearman (1973) et al. has shown that there exist three regimes based on the spacing ratio L/D, where L is the distance between the centres of the two cylinders and D is the cylinder diameter. For $1 < L/D < 1.2$, the two cylinders behave as a single bluff body with a single vortex street downstream. The vortex shedding frequency is associated with a body width of about two diameters. For $1.2 < L/D < 2.2$, narrow and wide wakes are formed, divided by a biased flow through the gap. The biased flow is bistable and the narrow and wide wakes can intermittently interchange between the two cylinders. When the spacing is further increased, two vortex streets are formed behind the two cylinders and they have the same frequency but coupled in and out of phase mode.

For tandem arrangement, two distinct regimes were classified by Zdravkovich (1977). For spacings up to a critical range, after separation from the upstream cylinder, the flow reattaches to the rear cylinder. The critical spacing at which the separating flow starts to reattach at the downstream cylinder is generally about 3.5 cylinder diameters for smooth flow. Therefore, within the range of $1 < L/D < 3.5$ the interference forces and flow pattern are distinctively different from those for $L/D > 3.5$.

It should be mentioned that the above results were all obtained in very low turbulence flow. In fact, there is very little information available for turbulent flow in the critical Reynolds number regimes. Thus, to understand the interference mechanisms, especially in turbulent flow, a series of investigations is being conducted at Monash University. This paper deals with some of the force measurements in turbulent flow for tandem and side by side arrangements.

EXPERIMENTAL ARRANGEMENT

The experiments were performed in the insertable 2m x 1m working section in the 450kw wind tunnel in the Department of Mechanical Engineering, Monash University.

The turbulent flows with different turbulence intensities were achieved using grid turbulence generators at various locations in the wind tunnel. A TSI hot wire anemometer together with a Perkin-Elmer minicomputer and a Data 6000 waveform analyzer were used to get the free stream velocity, turbulence intensity and longitudinal integral scale. Temperature compensation to the hot wire measurement has been made. The turbulence intensities I_u used were 4.9% and 11.5% respectively; the integral scale was 0.14m for both.

Cylinders of 800mm length, with diameters of 100mm, were used for the investigation. The relative surface roughness was estimated to be about $K/D = 10^{-6}$, where K is the average size of the surface roughness.

While one cylinder was treated as a dummy cylinder, the other, or the principle cylinder, was mounted horizontally on a two-dimensional strain gauge force balance which measured alongwind and crosswind forces. The first modal frequencies of the force balance were 137Hz for the alongwind and 127Hz for the crosswind. The signal was amplified and filtered at a cut-off frequency of 100Hz with an 8th order filter and collected by the Perkin-Elmer computer at a sampling frequency of 1000Hz. The computer reduced the time mean and standard deviation of the signals for a preset averaging time of 50 seconds. This averaging period gave a probability of more than 95% for the repeatability of the fluctuating forces to within 3%.

At the position where the principle cylinder was mounted, the thickness of the boundary layer generated on the wind tunnel side walls was estimated to be about 100mm. In order to minimise the influence of the tunnel side wall boundary layer on the flow field, a pair of rectangular end plates were fixed 100mm away from the wind tunnel side walls. The thickness of the boundary layer introduced by the end plates at the principle cylinder was about 20mm.

The highest blockage ratio for two cylinders in side by side arrangement was 10%, and no blockage corrections have been made to the results presented in this paper.

EXPERIMENTAL RESULTS

In order to compare the interference results with those of one cylinder, the interference factor is introduced. This is defined as the ratio of force coefficient on the cylinder in the presence of the interference cylinder to that when the cylinder is isolated for the same free stream conditions.

1. Tandem Arrangements

Figure 2 gives the interference factors for time mean drag, the standard deviations of drag and lift forces on the downstream cylinder for different turbulence intensities at a Reynolds number of 1.1×10^5. It can be seen that the interference factors were closer to one at higher turbulence intensity than those at lower turbulence intensity for all the alongwind spacings. For crosswind fluctuating force, the interference factor at the higher turbulence intensity I_u = 4.9% was smaller and closer to one when the spacing was above three. As the spacing is further decreased, the interference factor for the low turbulence flow decreased very rapidly while for the flow with a higher turbulence intensity it started to drop at the same rate but a smaller spacing. The interference factor for the lower turbulence flow was closer to one in this case.

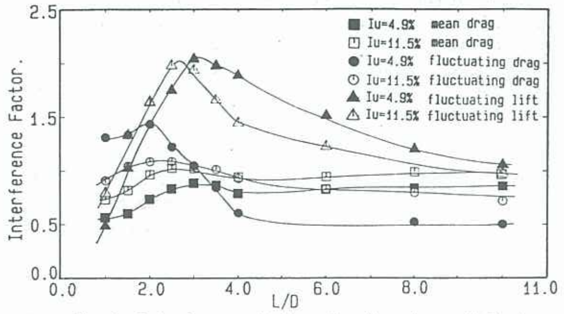


Fig.2. Interference Factors For Downstream Cylinder In Tandem Arrangements.

To compare with the results obtained from smooth flow. Figure 3 shows the interference drag coefficient from the work by both Biermann et al. (1933) and the authors. The interference drag coefficient is defined as the difference between the drag coefficient measured on one of the cylinders in tandem and the drag coefficient of the single cylinder under the same free stream conditions. As can be seen from the figure, that turbulence intensity can reduce the absolute interference drag coefficient quite significantly. Apart from this, as turbulence intensity increases, the length of the region in which strong interference occurs decreases. In Figure 3 it can be seen that for smooth flow the absolute interference drag coefficient starts to increase at L/D = 4.0. When the turbulence intensity increases to 4.9%, L/D drops to about 3.5 and continues to decrease to 3.0 as the turbulence intensity increases to 11.5%.

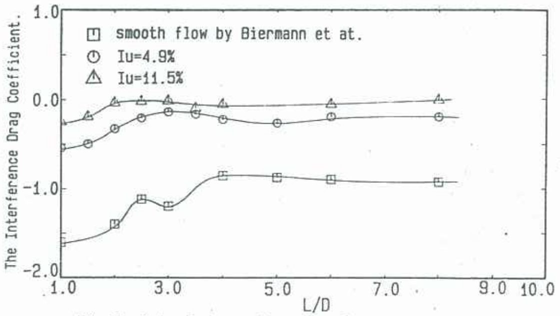


Fig.3. Interference Drag For Downstream Cylinder In Tandem Arrangements.

As observed by Zdravkovich (1977), for tandem arrangement in smooth flow, the change of the base pressure of the rear cylinder and the pressure at the gap between the cylinders is responsible for the change of drag. Therefore, the drop of drag as I_u increases could be caused by the decrease of the difference between the base pressure and gap pressure. Figure 3 also shows that in high turbulence flow, the upstream cylinder has a less shielding effect on the downstream cylinder as indicated by the increase of drag on the rear cylinder. In addition, for the case of I_u = 4.9%, when L/D was above four, the fluctuating drag coefficient on the downstream cylinder was only half of that on an isolated cylinder under the same free stream conditions. However, as the spacing was decreased to below four diameters, there was a rapid increase in the fluctuating drag. The rate of increase was slowed down as the turbulence intensity was increased to 11.5%.

2. Side by Side Arrangement

Figure 4 presents the interference factors for time mean drag and fluctuating lift coefficient at the Reynolds number Re = 1.1×10^5. It can be seen that there is not much interference when the spacing is above 1.25 diameters and which also gives some indication of the blockage effects, i.e. 10% to 20% on mean drag, and very small to negligible amount on fluctuating lift. As the distance between the cylinders was reduced to below 1.25 diameters, the interference factors jumped suddenly. This could be caused by the switch to different flow regime and hence the start of the unsteadiness of the wakes behind the two cylinders.

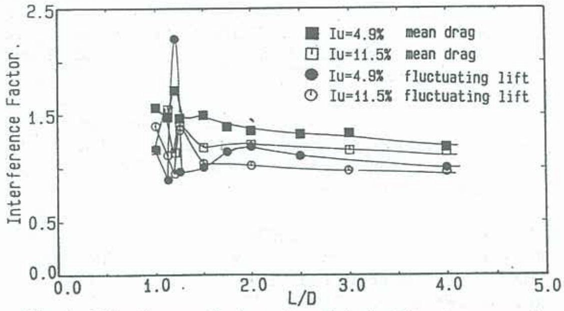


Fig.4. Interference Factors For Side by Side Arrangements.

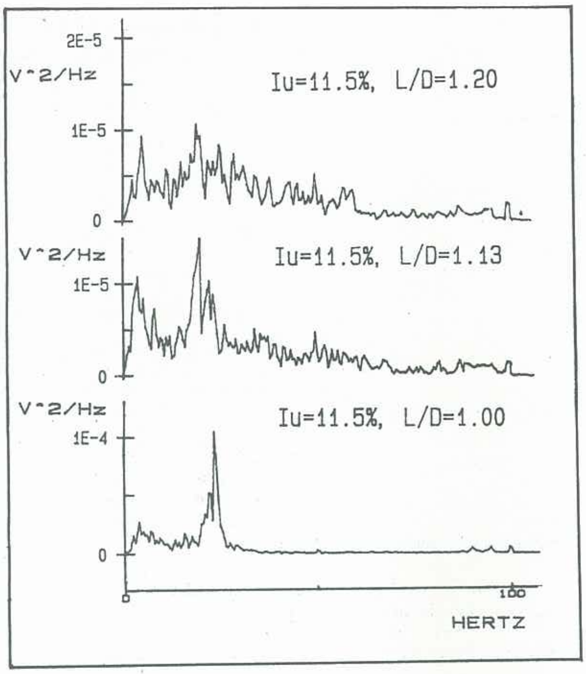


Fig.5. Lift Force Spectra For Some Side By Side Arrangements.

Figures 5 and 6 give the power spectra of the lift force for both turbulence intensities. For the lower turbulence case, starting from L/D = 1.25, a clear low frequency component can be detected in the crosswind power spectrum. This component becomes more dominant as the two cylinders are moved closer together, indicating the formation of a single vortex street behind the two cylinders. However, as the turbulence intensity increases to 11.5%, this low frequency component could not be detected until L/D = 1.13 and the peak in the spectrum is much broader than that for the low turbulence case. Outside the bistable regime as L/D increases, the interference factors are slightly smaller at the higher turbulence intensity for both forces.

In Figure 7, mean lift coefficient is presented, showing the existence of a large lift force as L/D decreases. The lift force is in the direction of separating the cylinders. It is interesting to note that there is also a sudden change of the mean lift. The spacing ratio at which this sudden change occurs is approximately 1.2 for the lower turbulence case and 1.13 for the high turbulence case. This sudden change could be caused by the formation of the single vortex street behind the cylinders.

Figure 7 also shows that the mean lift force increases as turbulence intensity is increased.

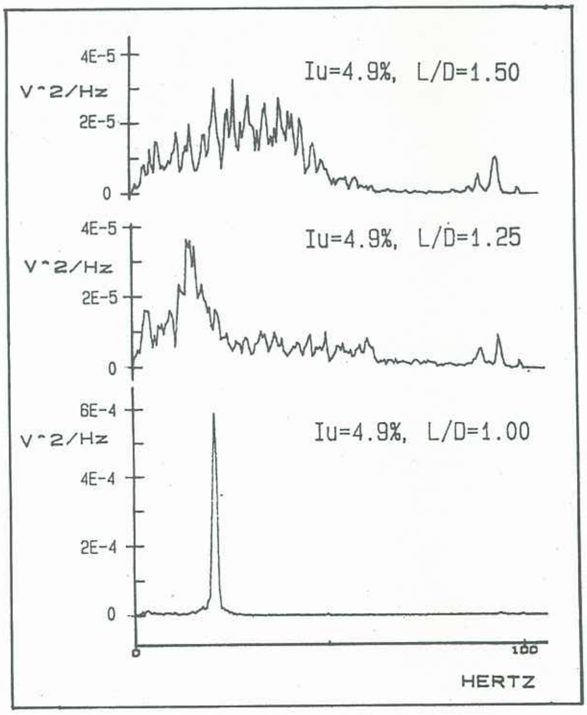


Fig.6. Lift Force Spectra For Some Side By Side Arrangements.

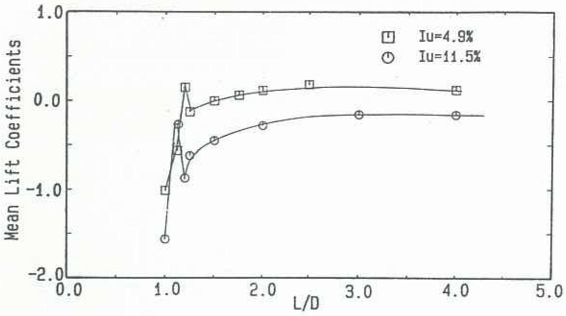


Fig.7. Mean Lift Coefficients For Side By Side Arrangements.

CONCLUSION

Some investigations have been carried out on the interference between two two-dimensional circular cylinders in turbulent flow at the Reynolds number of 1.1×10^5 and the results obtained have shown that:

The increase of turbulence intensity generally leads to a reduction in interference factor for alongwind force. For crosswind fluctuating force, the trend is similar to that of alongwind when L/D is above three. However, as L/D is decreased to below three, there is more interference for the high turbulence case. As the turbulence intensity is increased, the regions where intense interference occurs for both alongwind and crosswind become smaller. For the tandem arrangement, no sudden changes can be observed on the drag curve in turbulent flow. However, for side by side arrangement, sudden changes can be observed for both alongwind and crosswind curves. The cause of this phenomenon needs further investigation. Furthermore, a large lift force could be observed for side by side arrangement as L/D approaches one and this lift force increases with increase of turbulence intensity.

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