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FEEDBACK CONTROL OF VORTEX SHEDDING FROM A CIRCULAR CYLINDER

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ABSTRACT

It is observed that vortex shedding from a circular cylinder can be suppressed sequentially for a short duration by imposing an excitation upstream using acoustic speakers. A sensor hot wire, which responds to the velocity fluctuations associated with vortex shedding, provides the feedback signal to drive the speakers. Once suppression is achieved, in the absence of a feedback signal to excite the speakers, vortex shedding reappears which is followed by a short duration of suppression and the process is repeated. Suppression of vortex shedding was achieved when the control hot wire was placed nearly 6.5 cylinder diameters downstream. When the control wire was placed close to the cylinder, suppression was also successful. The present investigation suggests that continuous suppression of vortex shedding using a feedback mechanism cannot be easily realised.

INTRODUCTION

Periodic vortex shedding behind a bluff body like a circular cylinder is associated with a fluctuating pressure disturbance which can lead to structural instability of tall chimney stacks and buildings. From an engineering point of view, it is desirable to exert some control over the vortex shedding phenomenon. Generally the term "control" refers to techniques that can change or even suppress the shedding of vortices. Several techniques have been employed to modify or even suppress vortex shedding behind circular cylinders by different investigators. Passive devices like tabs and thin spiral elements can reduce the undesirable consequences of vortex shedding. Small diameter control cylinders placed normal to the main cylinder have been shown to delay the onset of vortex shedding (Strykowski and Sreenivasan 1990). The location of the control cylinders with respect to the main cylinder appears to be a critical factor in this technique. Active techniques like imposing a periodic fluctuation on the flow using acoustic drivers have also been employed for flow control, (e.g. Ffowcs Williams and Zhao (1989) and Roussopoulos (1993).

Ffowcs Williams and Zhao employed a feedback control mechanism using acoustic speakers to control vortex shedding behind circular cylinders in a wind tunnel over a range of Reynolds number $400 < Re_D < 12000$ ($Re_D = U_0D/\nu$ where U_o is the free stream velocity, D is the cylinder diameter and ν is the kinematic viscosity of air). A fixed control hot wire in the shear layer placed at a distance of $x/D = 1.5$ downstream and $y/D = 0.8$ above the centre-line provided the feedback signal which was used to drive the speakers placed upstream of the cylinder. A movable sensor hot wire was used to examine the velocity fluctuations in the wake. Under excitation, the amplitudes of the fundamental as well as harmonics in the velocity fluctuations were reduced. They concluded that vortex shedding from a smooth circular cylinder can be controlled by using an acoustic feedback mechanism. By employing a similar technique, Roussopoulos recently investigated the feedback control of vortex shedding in more detail. By using two speakers directly above and below the cylinder, Roussopoulos was able to achieve complete suppression of vortex shedding at $Re_D = 53$. Roussopoulos also observed that a single speaker was as effective in suppressing vortex shedding as two speakers which were excited in opposite phase. At larger Reynolds numbers, Roussopoulos observed that the results of Ffowcs Williams and Zhao could not be reproduced. Roussopoulos also observed that this type of excitation has a larger influence in the mid-span region of the cylinder compared to the influence near the two ends which yielded only localised control. Other methods like excitation of fluid issuing out of a narrow axial slit of a hollow cylinder (Huang 1996), vibrating cylinders (Warui and Fujisawa, 1996) have been also employed.

The main aim of the present study is to employ feedback control by using acoustic speakers to investigate the possibility of suppression of vortex shedding. The cylinder was placed in the potential core of a plane jet and speakers placed upstream in the settling chamber of the wind tunnel provided the excitation which could be considered to be uniform over the entire length of the cylinder and reduce (or avoid) the mid-span localisation effect.

EXPERIMENTAL CONDITIONS

The experimental set-up is shown schematically in Figures 1 and 2. The experiments were conducted in the potential core of a 340 x 34.0mm plane jet facility. The speakers used for pulsing the flow were mounted on both sides of the jet settling chamber. When the speakers were operated, it was noticed that the walls of the jet were subject to small amplitude vibrations. To isolate the cylinders from these vibrations, the cylinders were mounted on a separate frame. Cylinders of diameter

15.6mm, 9.65mm and 5.63mm were used in the experiments and were fitted with end plates at approximately ±150mm from the jet centre-line to isolate the vortex shedding from the effects of cylinder end conditions (Williamson 1989).

Two single 5μm diameter hot-wires (one as the control hot-wire and the other as a sensor hot-wire), operated in constant temperature mode were used in the experiments. Signals from both the hot-wires were monitored on an oscilloscope. The sensor hot wire signals were digitised by a 12 bit a/d converter, stored and subsequently processed on a PC. The signal from the control hot-wire was passed through a Krone-Hite band-pass filter, an analogue phase shifter and a 100W Sony amplifier before feeding to two 100W(rms) loud speakers which could be connected either in phase or out of phase, or operated individually.

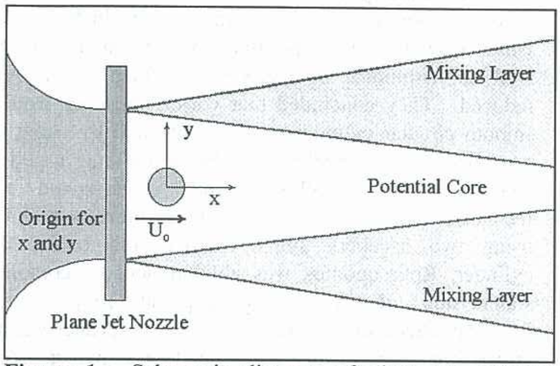


Figure 1 : Schematic diagram of plane jet, cylinder location and the origin, (z-coordinate is along cylinder axis).

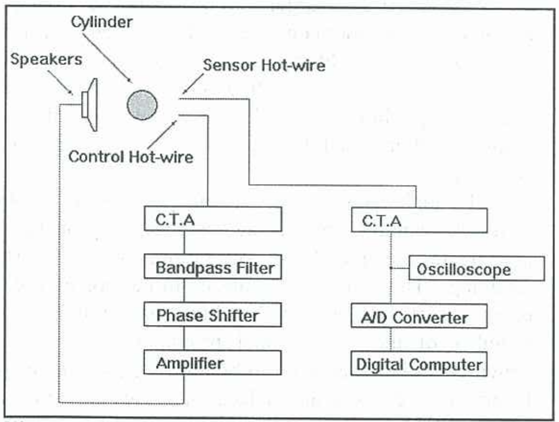


Figure 2 : Schematic diagram of the experimental set-up.

RESULTS AND DISCUSSION

A relatively large diameter cylinder (D = 15.6mm) compared to the width of the nozzle was mounted in the potential core of the plane jet. The free stream velocity (U_o) was set at 0.56m/s which for this cylinder which gave a Reynolds number ($Re_D = U_oD/\nu$ where ν is kinematic viscosity) of 585, well outside the laminar vortex shedding regime ($Re_D \approx 170$).

Initially, the control hot wire and the sensor wire were positioned at x/D = 6.45 and y/D = 0.5, 50mm on opposite sides of the jet nozzle centre-line. It was found by trial and error that the optimum range of low and high pass frequencies for the control hot-wire signal were 25Hz and 3Hz respectively. Figure 3 shows that the effect of feedback from the control hot-wire at this location is to significantly suppress vortex shedding. This duration of suppression extended only to a few seconds before the signal began to momentarily increase in amplitude. This may be due to the fact that while the control hot wire was not experiencing a fluctuating velocity, the amplitude of the suppressed signal driving the speakers was not sufficient to pulse the flow effectively to achieve an indefinite suppression of the flow. The effect of moving the control hot wire towards the cylinder along the line of y/D = 0.5 whilst leaving the sensor hot wire at (x/D = 6.45, y/D = 0.5 and z/D = 3.12) was to continuously decrease the level of suppression of vortex shedding. The worst sensor hot wire response is shown in Figure 4 with the control wire located at x/D = 1.5, y/D = 0.5 and z/D = -3.12).

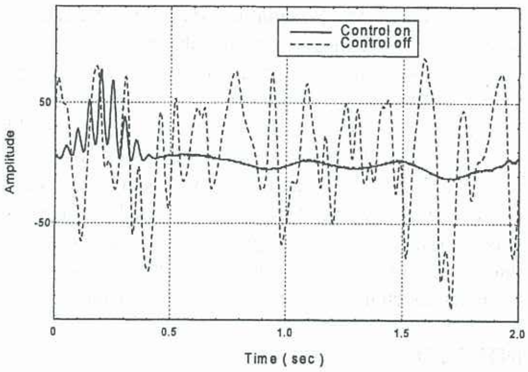


Figure 3 : Sensor hot wire signal with the control and sensor hot wires located at (x/D = 6.45, y/D = 0.5 and z/D = ± 3.12).

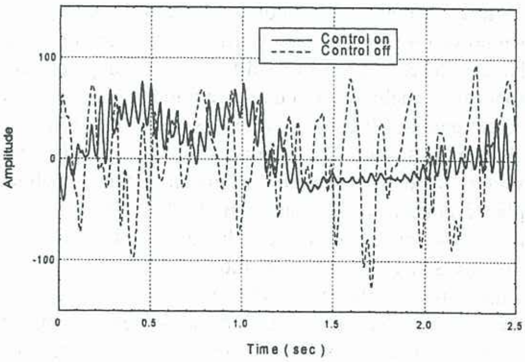


Figure 4 : Sensor hot wire signal with the control hot wire located at (x/D = 1.5, y/D = 0.5 and z/D = -3.12) and the sensor hot wire located at (x/D = 6.45, y/D = 0.5 and z/D = +3.12).

In a different set of experiments the position of the control hot wire was fixed at the location (x/D = 0.6, y/D = 0.5 and z/D = -3.12), and the sensor hot wire was moved to different locations closer to the cylinder. It was found that with the sensor hot wire located at (x/D = 6.45, y/D = 0.5 and z/D = 3.12), vortex shedding was suppressed as shown in Figure 5. Greater suppression of vortex shedding was observed closer to the cylinder. Since the experiments were carried out in a plane jet the size of the jet potential core prohibited us from examining the flow conditions in the far wake.

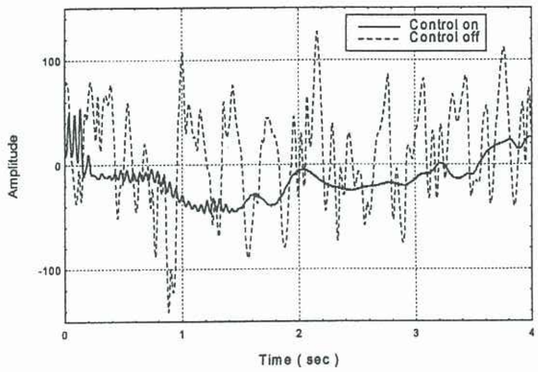


Figure 5 : Sensor hot wire signal with the control hot wire located at (x/D = 0.6, y/D = 0.5 and z/D = -3.12) and the sensor hot wire located at (x/D = 6.45, y/D = 0.5 and z/D = +3.12).

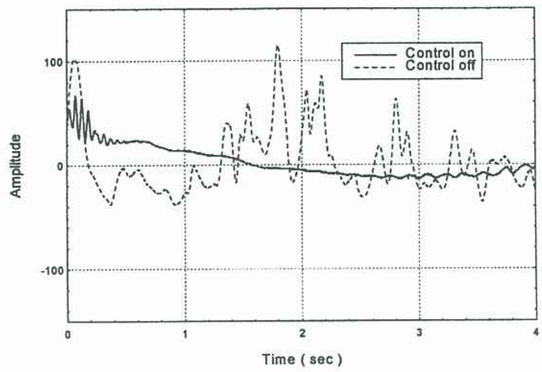


Figure 6 : Sensor hot wire signal with the control hot wire located at (x/D = 0.6, y/D = 0.5 and z/D = -3.12) and the sensor hot wire located at (x/D = 1.3, y/D = 0.5 and z/D = +3.12).

To illustrate the effect of feed-back control of vortex suppression, spectra of the sensor hot wire signals taken from experiments done using a 9.96mm diameter cylinder are presented in Figure 7. The spectra clearly show that the peak associated with vortex shedding at 11.2Hz were not present with the control turned on. Similar spectra were observed when the sensor hot wire was moved closer to the cylinder.

For the smallest diameter cylinder (5.63mm) which was used in the experiments, the low pass filter was set at 30Hz and the high pass filter remained at 3Hz. It was found that vortex shedding was never completely suppressed, although the amplitude of the fluctuations was significantly reduced. This seems to indicate that vortex control can be more easily realised for a larger diameter cylinder.

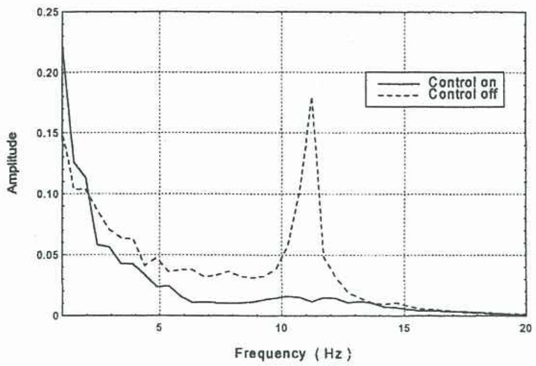


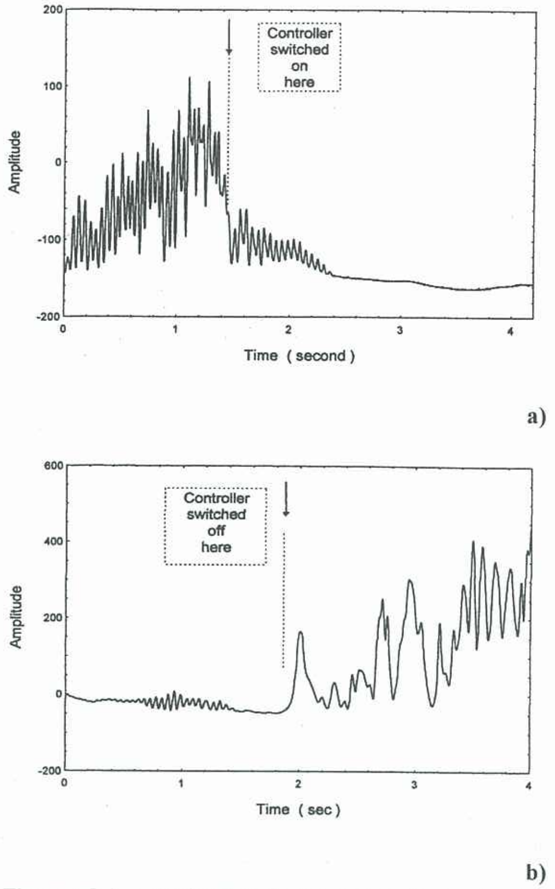
Figure 7 : Spectra of sensor hot wire signal with the control hot wire located at (x/D = 3.1, y/D = 0.5 and z/D = -3.12) and the sensor hot wire located at (x/D = 10.0, y/D = 0.5 and z/D = +3.12).

The effect of transient response is shown in Figure 8a) when the control is turned on and Figure 8b) when the control is turned off. With the control turned on, vortex shedding was not suppressed immediately, but the amplitude reduced gradually over a period of less than one second. When the control was turned off, the large fluctuations reappeared almost immediately.

An analogue phase shifter was tried in some of the experiments since previous work has suggested that a phase shifter has significant influence, as part of the overall feedback loop. In our experiments there was little evidence to indicate that the use of a phase shifter is effective in vortex suppression.

CONCLUSION

The control of vortex shedding from a circular cylinder mounted in the potential core of a plane jet has been shown to be possible for $Re_D = 585$. The suppression of vortex shedding for a *limited duration of time* was found when the control hot wire and sensor hot wires were located at (x/D = 6.45, y/D = 0.5 and z/D = ± 3.12). For this position of the sensor hot wire, suppression of vortex shedding steadily decreased as the control wire was moved closer to the cylinder. When the control hot wire was located at (x/D = 0.6, y/D = 0.5 and z/D = -3.12) and the sensor hot wire located at (x/D = 1.3, y/D = 0.5 and z/D = +3.12), vortex shedding was also suppressed. Generally the vortex shedding suppression was better at this control hot wire location, since as the sensor probe was moved downstream within the bounds of the jet potential core, the signal still indicated considerable suppression of vortex shedding. Spectra confirm the effect of the feed-back control technique on the suppression of vortex shedding. Finally it was found that suppression of vortex shedding from smaller cylinders (D



Figures 8a) and b) :Transient response from when the control is turn from off to on and from on to off.

= 5.63mm) was not as effective with this control technique.

It is believed that by fine tuning the feedback control circuit, whilst the vortex shedding may not be entirely eliminated for indefinite periods of time, fluctuations associated with vortex shedding may be reduced significantly.

REFERENCES

FFOWCS WILLIAMS, J. E. and ZHAO, B. E., 1989, “The active control of vortex shedding”, *J. Fluids and Structures*, vol 3, pp115-122.

HUANG, X. Y., 1996, “Feedback control of vortex shedding from a circular cylinder”, *Experiments in Fluids,* vol 20, pp218-244.

ROUSSOPOULOS, K., 1993 “Feedback control of vortex shedding at low Reynolds numbers”, *J. Fluid Mech*, vol 248, pp267-296.

STRYKOWSKI, P. J and SREENIVASAN, K. R. 1990, "On the formation and suppression of vortex 'shedding' at low Reynolds numbers", *J. Fluid Mech*, vol 218, pp71-107.

WARUI, H. M. and FUJISAWA, N., 1996, "Feedback control of vortex shedding from a circular cylinder by cross-flow cylinder oscillations", *Experiments in Fluids*, vol 21, pp49-56.

WILLIAMSON, C. H. K., 1989, “Oblique and parallel modes of vortex shedding in the wake of a circular cylinder at low Reynolds numbers”, *J. Fluid Mech*, vol 206, pp579-627.