*11th Australasian Fluid Mechanics Conference*
*University of Tasmania, Hobart, Australia*
*14-18 December 1992*

**4E-4**

# CONTROL OF FLOW AROUND A CIRCULAR CYLINDER BY A SMALL STRIP OF THIN PLATE IN THE NEAR WAKE

**M. MIYATA[1] and T. OHSHIMA[2]**

[1]Dept of Mechanical Systems Engineering, Yamanashi University, Kofu 400, JAPAN

[2]Toyobo Company Ltd, JAPAN

## ABSTRACT

The flow around a two-dimensional circular cylinder at a Reynolds number of $10^4$ was investigated experimentally by inserting a strip of a thin plate in the near wake of the cylinder. It was found that the pressure drag of the cylinder decreases in the presence of the plate at the streamwise positions lx/d smaller than 3.8. The maximum reduction of about 30% was attained at the plate position of lx/d=3.7. At lx/d=3.8, however, the pressure drag recovers suddenly its undisturved value. The Strouhal number decreases almost linearly with increasing the streamwise distance of the plate in the same region where the drag reduction occurs. Measurements were made also by oscillating the plate with a vortex shedding frequency and its first subharmonic. Unexpectedly, no discernible effects of oscillation of the plate were observed irrespective of the streamwise position and the oscillating frequency of the thin plate investigated.

## NOTATION

| | |
|---|---|
| Cdp | Pressure drag coefficient of circular cylinder |
| d | Diameter of circular cylinder |
| f | Frequency of vortex shedding |
| F | Frequency of oscillating plate |
| L | Plate length |
| lx | Streamwise distance between cylinder axis and center line of plate |
| p | Static pressure |
| qo | Dynamic pressure in free stream |
| Uo | Free stream velocity |
| U | Mean streamwise velocity |
| u | Instantaneous streamwise velocity |
| Re | Reynolds number = Uod/ $\nu$ |
| St | Strouhal number = fd/Uo |
| x,y | Streamwise and transverse coordinates, respectively. x=0 and y=0 corresponds to center of cylinder. |
| $\nu$ | Kinematic viscosity |
| $\theta$ | Oscillating angle of plate |

## INTRODUCTION

The reduction of resistance, noise and vibration due to flow is always a matter of primary concern for engineers in various fields. Many efforts have been made to improve the flow around a circular cylinder, because it is one of the most frequently encountered structual elements exposed to the flow. Thus, the flow around a circular cylinder has been continuously providing fundamental and challenging problems for fluid dynamicists. Among others the problem concerning various aspects of vortex shedding phenomena is particularly interesting from both theoretical and practical points of view. It is well known that a so-called splitter plate affects the flow around a cylinder significantly(Apelt and West, 1973,1975).

Very impressive is the recent experimental results of Strykowski(1986), who showed that the suppression of vortex shedding occurs by inserting a small "control cylinder" near the circular cylinder at Re=90.

On the other hand, an increasing knowledge on the important role of the coherent structure in a turbulent shear flow made it possible to manipulate it to a certain extent by affecting the coherent organized motion somehow with the aids of such mechanical devices as LEBU or riblet (Bandyopadhyay, 1986).

The aim of this research is to show a possibility of affecting the process of the vortex shedding by inserting a small strip of a thin plate in the near wake of a circular cylinder and oscillating it with frequencies of vortex shedding and its subharmonic.

## EXPERIMENTAL SET-UP AND INSTRUMENTATION

A circular cylinder of 14.0 mm in diameter was placed perpendicular to the flow at the center of a blow-down wind tunnel test-section. The test-section has a constant 300 x 300 $mm^2$ area and is 1.05 m long. The center of the circular cylinder was located 300 mm downstream from the entrance of the test-section, where the flow is uniform within 1% of the mean value and the turbulence intensity u'/Uo is 1% except in the boundary layer on the side walls. The circular cylinder has a static hole of 0.3 mm in diameter in the midst of the span and rotatable about its axis. The gap between the end of the cylinder and the side wall is about 1.3 mm.

A thin plate(filler gauge) with 0.20 mm thickness and 12.8 mm width was inserted parallel to the circular cylinder in the plane of flow symmetry as shown schematically in Fig. 1. The plate, installed in a plate holder unit equipped with bearing blocks and tensioned appropriately in order to prevent flutter, is driven directly at both ends by stepping motors, which enables a torsionless rotational oscillation of the plate about a mean position up to roughly 200Hz. The holder unit can be moved as a whole in the streamwise direction to change the gap between the circular cylinder and the plate. Due to structual difficulties, the plate could not contact to the cylinder surface, hence when a plate comes nearest to the cylinder there still exists a 2 mm gap between the cylinder surface and the leading edge of the plate.

In order to clarify the difference between a "short" plate with a relatively large gap between the cylinder surface and the leading edge of the plate and a normal "long" splitter plate, measurements were also made using the cylinder with a plate of 50 mm width.

The Reynolds number based on the free stream velocity and the diameter of the cylinder was set $10^4$ as the largest Reynolds number under which a relatively distinct vortex shedding can be still observed. The free stream velocity then was in the range of $10 < Uo < 11$ m/s.

We used a constant temperature hot-wire anemometry with a probe having a 1 mm unplated, heated length of 5 μm tungsten wire. Presuure was measured by a digital manometer(0-100 mm Aq). All measurements, including a calibration of the hot-wire, were made with a computer controlled measuring and analyzing system.

## RESULTS AND DISCUSSION

Pressure distributions around the circular cylinder, measured with the different streamwise positions of the quiescent "short" plate, are shown in Fig.2, which includes also the results of a plain cylinder (no plate) and the circular cylinder with the splitter plate of 50 mm width (wide plate). As can be seen clearly, we can separate the pressure distributions roughly into two groups, depending on the plate position lx/d. For lx/d<3.7, the distribution is essentially the same as that for the wide plate, i.e., that with a normal splitter plate, although a slight variation with lx/d can be observed. Therefore, the short plate, when placed at an appropriate streamwise position, has an equivalent effect as a normal splitter plate. For lx/d>3.7, on the other hand, the distribution nearly coincides with that of a plain cylinder. The short plate, when inserted with a large gap to a cylinder, thus has a negligible effect on the pressure distribution of a circular cylinder.

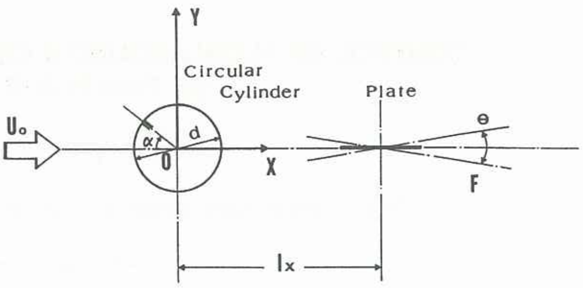

Fig. 1 Schematic of flow geometry.

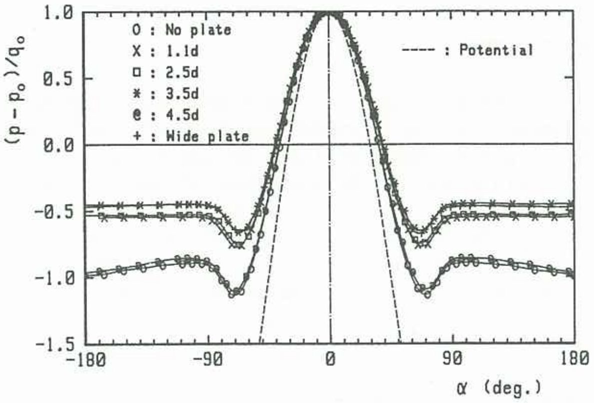

Fig. 2 Pressure distributions around circular cylinder with quiescent short plate.

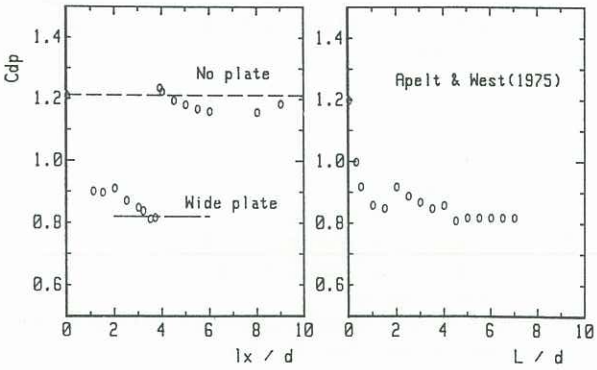

Fig. 3 Pressure drag coefficients of circular cylinder with quiescent short plate.

The pressure drag coefficients of the circular cylinder Cdp obtained by integrating the results of Fig.2 were shown plotted in Fig.3 as a function of the plate position lx/d. Also shown on the right-hand side are the results by Apelt & West (1975) obtained at $Re=10^4$ with circular cylinders having splitter plates of various lengths. It should be noted that from the definition, the trailing edge of the "short" plate used in the present study approximately coincides with that of the usual splitter plate with the same L/d as lx/d because the length of short plate nearly equals to the diameter of the circular cylinder. The effect of plates with lx/d<3.7 on Cdp is very similar to that with a splitter plate both in the magnitude of reduction and the tendency with lx/d, indicating a relative unimportance of the upstream part of a splitter plate.

The magnitude of maximum reduction in Cdp, which occurs at lx/d=3.7 is exactly the same as that by the wide plate;a splitter plate of L/d=3.6. A slight increase in lx/d over 3.7 brings about a drastic change in Cdp as can be seen in the figure. Cdp increases almost discontinuously and overshoots even its undisturbed value of 1.2 slightly but distinctly. The change is so abrupt that no intermediate value of Cdp could be observed. A further increase in lx/d results in only a gradual decrease in Cdp.

It is interesting to note that the particular position of lx/d=3.7 approximately corresponds to the streamwise location where the rolling-up of the shear layer separated from a plain circular cylinder is almost completed and the vortex first comes to cross the plane of symmetry, as shown in the visualized picture at Re=$10^4$(Van Dyke,1982).

Fig.4 shows some typical hot wire signals obtained just outside of the cylinder wake in the streamwise sections indicated on the top of the figure for each plate position, including the cases of the no plate and wide plate. A sinusoidal fluctuation of a hot wire signal does not necessarily reflect a rolling-up of a separated shear layer, it can be still considered as a good indication of the development of vortex formation. Keeping this in mind, we can see in the figure that the hot wire signals for the case of lx/d=4.5 do not differ significantly from those for the no plate and that when the plate is placed closer to the cylinder than 3.7d, the rolling-up of the vortex is delayed in proportion to lx/d. When the plate is placed further downstream than 3.7d, however, the rolling-up of vortex takes place somewhere between the trailing edge of the cylinder and the leading edge of the plate. The plate which exists downstream of the initial roll-up of the vortex does not seem to affect the flow significantly.

As noted before, the trailing edge of the plate of lx/d=3.7 is almost the same as that of the wide plate and the hot wire signals show also a similar feature for both cases. There is, however, a decisive difference between them, i.e., the vortex formation occurs further downstream of the plate in the former, but the vortex formation suppressed completely for the latter. We confirmed the suppression of vortex formation in a more detailed hot wire survey.

The fundamental frequency of the hot wire signal does not change irrespective of a hot wire position except for the region near the plane of symmetry where the frequency has twice the value in the other place. Thus the observed frequency can be correctly inferred to that of the vortex shedding. Fig.5 shows the variation of the Strouhal number of the vortex shedding with the plate position lx/d. As shown in the figure, the Strouhal number decreases from the value of 0.21 of no plate almost linearly with lx/d in the range where reduction in Cdp does occur, namely when the plate is placed at lx/d<3.7. Corresponding to a sudden increase of Cdp, there can be also observed a sudden increase of St when lx/d goes beyond 3.7.

It is very interesting to see what happens if the plate described above oscillates rotationally by a small angle at a frequency associated with vortex shedding. As stated above, the vortex shedding frequency decreases depending on the plate position. The oscillating frequency of the plate,therefore, so selected as to give the same frequency as that with a quiescent plate at each plate position and its first subharmonic. A subharmonic frequency was expected to affect the

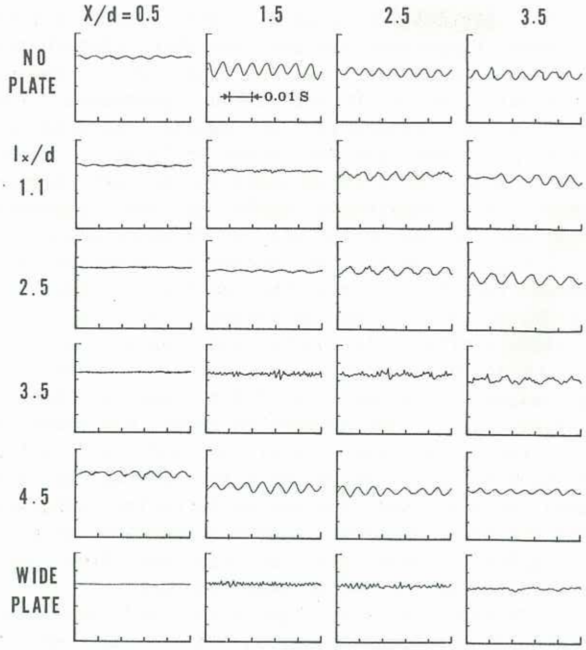

Fig. 4 Hot wire signals in the near wake of circular cylinder with quiescent short plate.

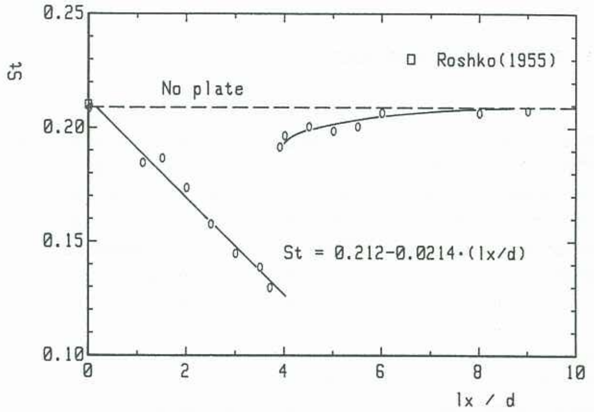

Fig. 5 Strouhal number of vortex shedding from circular cylinder with quiescent short plate.

| $l_x$/d | St | F(Hz) | θ(deg.) | |
|---|---|---|---|---|
| | | | nominal | measured |
| 1.1 | 0.185 | 68 | 7.2 | 12 |
| | | 138 | 2.9 | 2.7 |
| 2.5 | 0.158 | 59 | 7.2 | 8.5 |
| | | 118 | 2.9 | 1.8 |
| 3.5 | 0.139 | 51 | 7.2 | 8.1 |
| | | 103 | 7.2 | 6.7 |
| 4.5 | 0.201 | 75 | 7.2 | 7.8 |
| | | 149 | 2.9 | 3.4 |

Table 1 Oscillating frequency and angle of short plate.

vortex formation process at least to some extent because it provides the most unstable disturbance for the development of a free shear layer, leading eventually to a vortex-pairing phenomena. The oscillating frequencies and angles employed at each plate position were shown in Table 1, where the nominal oscillating angle in the last column shows the rotational angle in the computer programm for the driver unit of stepping motors.

Fig. 6 shows the pressure distributions around the cylinder with the oscillating plate at lx/d=3.5, where the quiescent plate has the greatest effect. As can be seen clearly, we can not find any discernible difference between the quiescent (shown by a solid line) and the oscillating plates. This unexpected result was found to be true at any plate position and oscillating frequency. Fig.7 shows the distributions of the mean velocity and fluctuation intensity obtained for the plate of lx/d=3.5 at a streamwise section of x/d=4.5. Here also we can not find any meaningful difference between the results.

Typical hot wire signals obtained near the center line, u' peak position and just outside of the cylinder wake in the same streamwise section as Fig.7 are shown compared for the quiescent and oscillating plates in Fig.8, indicating that the oscillation of the plate does not affect the flow in any discernible manner.

## CONCLUDING REMARKS

A small strip of a thin plate inserted in the near wake of a circular cylinder works substantially as an usual splitter plate and causes the same maximum reduction in the pressure drag of the circular cylinder when placed at an appropriate position. With a large gap, however, the plate has almost no effect. Unexpectedly the oscillation of the plate does not affect the flow in any discernible manner. Effects of the oscillation may appear if the plate oscillates at an interval synchronous with the vortex shedding. Such experiments are now in preparation in our laboratory.

## REFERENCES

APELT, CJ, WEST, GS and SZEWCZYK, AC(1973) The effects of wake splitter plates on the flow past a circular cylinder in the range $10^4 < Re < 5 \times 10^4$. J Fluid Mech, 61, 187-198.

APELT, CJ AND WEST, GS(1975) The effects of wake splitter plates on blunt body flow in the range $10^4 < Re < 5 \times 10^4$ Part 2. J Fluid Mech, 71, 145-160.

BANDYOPADHYAY, PR(1986) Review-mean flow in turbulent boundary layer disturbrd to alter skin friction. J Fluids Engineering, 108. 127-140.

STRYKOWSKI, PJ(1986) The control of absolutely and conventively unstable shear flows. PhD thesis. Yale Univ., New Haven, Conn.

ROSHKO, A(1954) On the development of turbulent wakes from vortex street. NACA Rep. 1191

VAN DYKE, M(1982) An Album of Fluid Motion. The Paraboric Press, Stanford, CA.

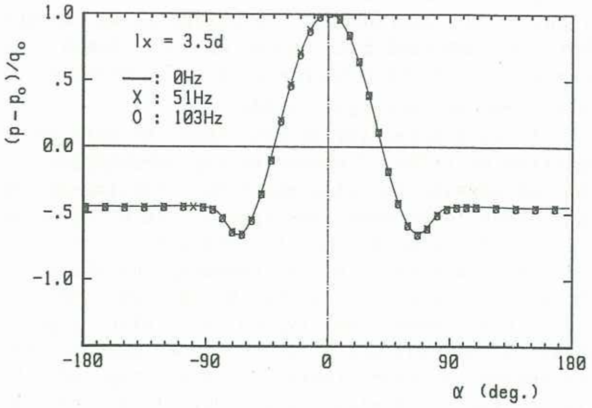

Fig. 6 Pressure distributions around circular cylinder with oscillating short plate.

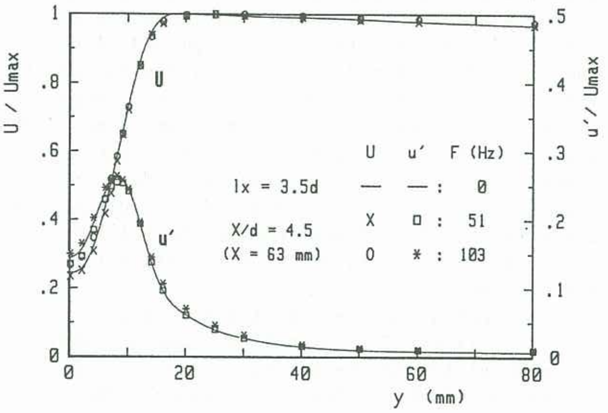

Fig. 7 Mean velocity and fluctuation intensity distributions in the near wake of circular cylinder with oscillating short plate.

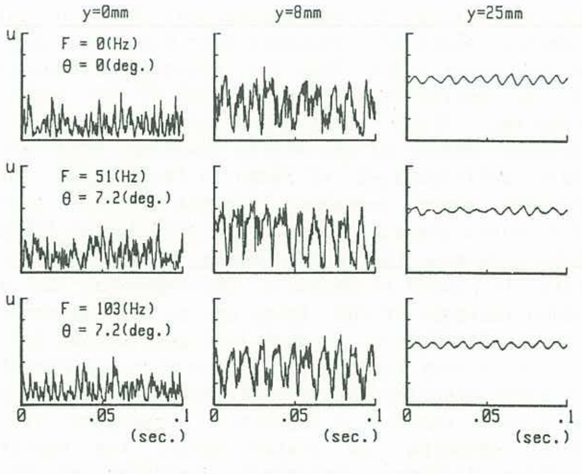

Fig. 8 Hot wire signals obtained at typical positions of u' distrubution in Fig. 7. F=0 and θ =0 means quiescent short plate.