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Visualization Study on Suppression of Vortex Shedding from a Cylinder

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Abstract : A narrow strip has been introduced as a control element to suppress vortex shedding from a cylinder. The strip is set parallel to the cylinder axis, and the key parameter of control in this study is the strip position, which is determined by the angle of attack of the strip and the distance between the strip and the cylinder axis. A circular cylinder and a square cylinder were tested respectively. Flow visualization and hot-wire measurement were performed in a low turbulence wind tunnel in the range of Reynolds number **Re** = $4.0 \times 10^3 \sim 2.0 \times 10^4$. Test results show that, vortex shedding from both sides of the cylinder can be effectively suppressed if the strip is located in a certain zone in the wake. The effective zones in circular cylinder wakes at different Reynolds numbers have been found out, and the mechanism of the suppression has been discussed.

Keywords : Visualization, Flow control, Bluff-body, Vortex shedding, High Reynolds number.

1. Introduction

In the past decades, great efforts have been devoted to suppression of vortex shedding from bluff bodies and a number of techniques for special engineering purposes have been developed (Zdravkovich, 1981; Mohamed, 2000; Modi and Yokomizo, 1999; Boak and Lemay, 2000; Tensi et al., 2002; Fujisawa et al., 2005; Wang et al., 2005; Yamagishi and Oki, 2005). Some suppression methods of theoretical importance have also been studied (Roussopoulos, 1993; Schumm et al., 1994; Ozono, 1999) and a good example has been given in Strykowsky and Sreenivasan (1990). In their experiment, a much smaller circular cylinder is inserted into the wake of main circular cylinder. Vortex shedding from the main cylinder can be suppressed if the position of the small cylinder is located in a certain region called effective zone. Unfortunately, their results show that the effective zone shrinks as the Reynolds number **Re** (based on the main cylinder diameter) increases. Vortex shedding cannot be suppressed if **Re** surpasses a critical value. The critical value various within the range of order 10^2 as the relative size of additive circular cylinder changes from 0.05 to 0.33. Sakamoto and Haniu (1994), Bouak and Lemay (1998), Alam et al. (2003) also applied a small circular cylinder in the vicinity of main circular cylinder, tried to extend Strykowsky and Sreenivansan 1990's work to higher **Re**. By choosing special positions of the small cylinder, they could reduce more or less the mean or fluctuating force acting on the main one. However, none of them declared to suppress vortex shedding.

In this study, a narrow strip, rather than a small circular cylinder, is introduced and set behind the main body to improve the suppression at much higher Reynolds numbers.

2. Experimental Arrangement

Fig. 1. Picture of the Wind Tunnel.

The experiment was carried out in a wind tunnel in Peking University (shown in Fig. 1). The test section of the tunnel was 4 m long, 0.6 m wide and 0.6 m high. The turbulence intensity of free stream was not higher than 0.2 % in the range of mean speed 1.0~20 m/s.

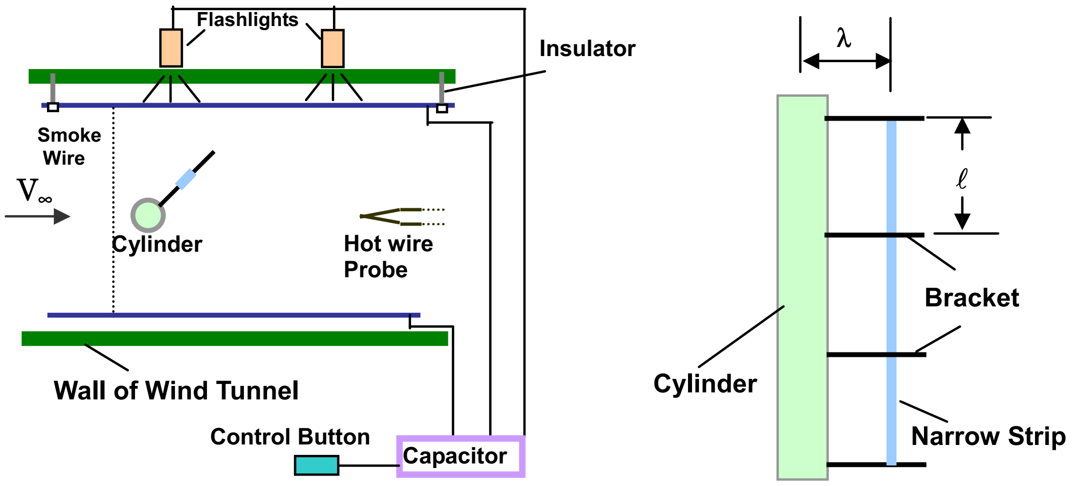
As shown in Fig. 2(a), the cylinder model was installed at the center of the test section. Two circular cylinders of diameter **D** = 3 cm and 5 cm and a square cylinder of width **D** = 6 cm were tested respectively.

A strip of thickness 0.04 ~ 0.06 cm, length 56 cm and variable width **b** was introduced as a control element and set parallel to the cylinder. A bracket, consisting of a row of parallel steel rods was used to fix the strip (Fig. 2).

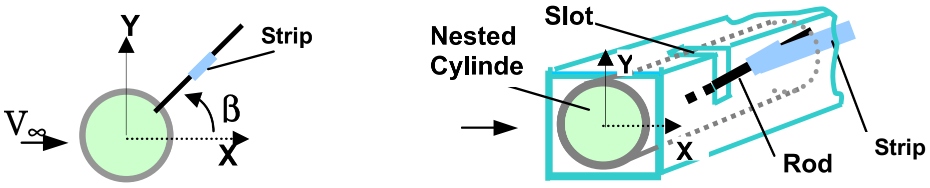
In installing the bracket on the circular cylinder model, the rods were perpendicularly and tightly connected to the surface of the cylinder and distributed along a meridian. The size of each rod was 0.045 ~ 0.067 **D** in diameter and 1.5 ~ 2.0 **D** in length. The cylinder could turn around a short shaft fixed at the wall to adjust the angle of attack, β.

In installing the bracket on the square cylinder model, a circular cylinder of diameter 5 cm was nested symmetrically inside the model, and the rods were connected to the nested circular cylinder in the same way as that described above. Slots of width 0.07 **D** were made on the upper-right part of the model (from $\beta = 0^0$ to 90^0) to let the rods move freely when turning the nested circular cylinder to adjust the angle of attack. The slots were sealed before each test.

As shown in Fig. 2(b), the distance between the cylinder axis and the length-wise centerline of the strip is denoted by λ, and the distance between neighboring rods is denoted by ℓ.



(a) Experimental Apparatus (b) Cylinder & Strip



(c) Circular Cylinder Model (d) Square Cylinder Model

Fig. 2. Sketch of Experimental Apparatus and Arrangement of Control Element.

A Ni-chrome wire (50-µm in diameter) was set perpendicularly in front of the cylinder at the mid-span and connected to an automatically recharging capacitor. Glycerin mucilage was daubed onto the wire before each test. A smoke sheet would be made in the wind when the wire was heated by an impulse of electric current. Flashlights were used to make a sheet of impulsive light to illuminate the smoke. In the test the shutter of the camera was opened in darkness waiting for the lighting flash. A time delay was set between the emanations of smoke and light. The delay time varied from 135 ms to 800 ms according to the change of wind speed from 6.0 m/s to 1.0 m/s.

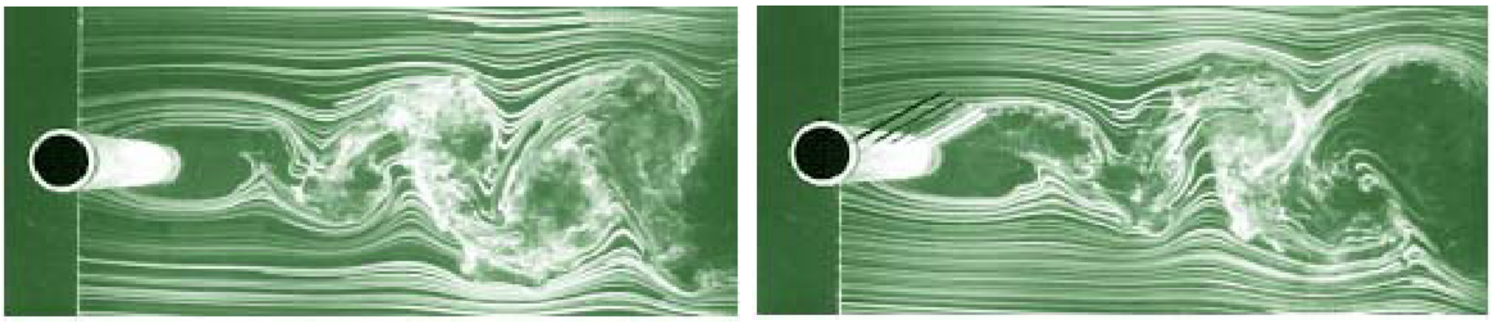
The detailed local information of the wake was measured by a DANTEC hot wire anemometer at many points on the intersection line of the plane $X/D = 12.5$ and the plane of mid-span. A single wire probe was used and the probe wire was set parallel to the Y-axis. The sampling frequency was 1024 Hz, and the sampling time was 40 ~ 60 seconds.

3. Results

The variable parameters are β = angle of attack of the strip, λ/D = distance between the cylinder axis and the length-wise centerline of the strip, ℓ/D = distance between neighboring rods of supporting bracket, and $Re = V_\infty D/\nu$ = Reynolds number, where D is the diameter of the circular cylinder or the side width of the square cylinder, V_∞ is the speed of oncoming flow, ν is the kinematical viscosity. Strip width b/D is fixed at 0.18 in this study.

3.1 Influence of Bracket

The influence of bracket has been investigated for different sizes of rods in the ranges of $Re = 4.0 \times 10^3 \sim 2.0 \times 10^4$, $\beta = 0^0 \sim 90^0$, $\ell/D = 1.0 \sim 4.0$ for circular cylinder and $\ell/D = 1.0 \sim 2.0$ for square cylinder. Hot-wire measurement and visualization results show that, the differences in flow field, velocity profile, turbulence intensity distribution, probability density of magnitude of fluctuating velocity and power spectrum of fluctuating velocity between the cylinder wake with and without bracket are very small. The influence of the bracket in the range tested is negligible, which is different from the influence of a bracket of larger rod diameter at lower Re (Shao et al., 2002). Limited by the extent of the paper, here only a typical circular cylinder case of visualization is shown in Fig. 3.



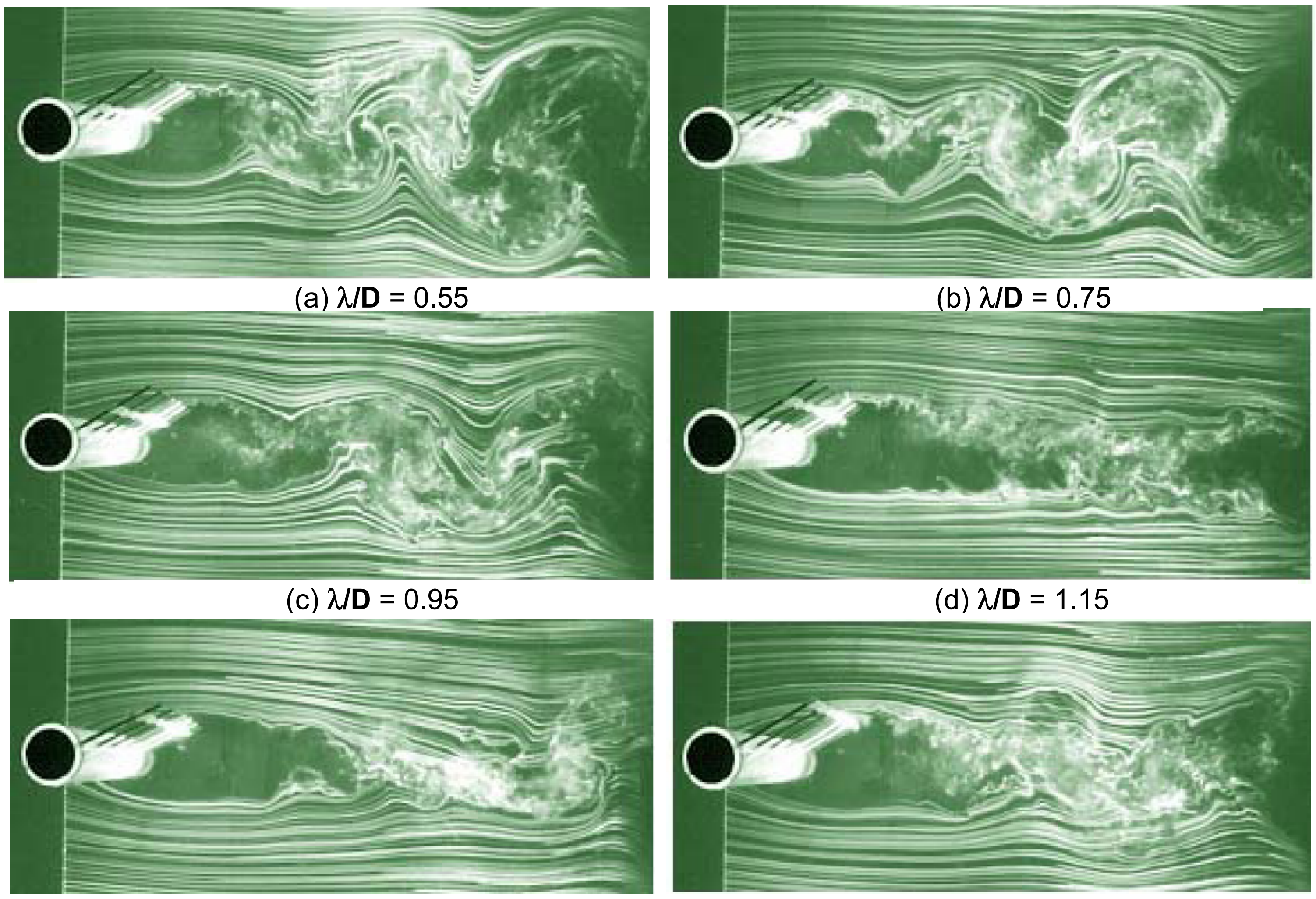
(a) Bare cylinder

(b) Cylinder with a bracket, $\beta = 30^0$, $\ell/D = 2.0$

Fig. 3. Comparison between circular cylinder wakes with and without a bracket, $Re = 5.25 \times 10^3$.

3.2 Suppression Effect on Circular Cylinder Wake

A broad wake appears and vortex shedding naturally occurs if no strip is applied (Fig. 3). The situation is changed when a strip is present. Figure 4 shows the influence of strip distance λ/D on the wake at a fixed angle of attack $\beta = 30^0$. Vortex shedding on both sides of the cylinder can be well suppressed and a much narrower wake appears if λ/D is set in the range 1.05 ~ 1.8. However, vortex shedding and broad wake recover when $\lambda/\mathbf{D}$ is outside this range.



(a) $\lambda/\mathbf{D} = 0.55$ (b) $\lambda/\mathbf{D} = 0.75$

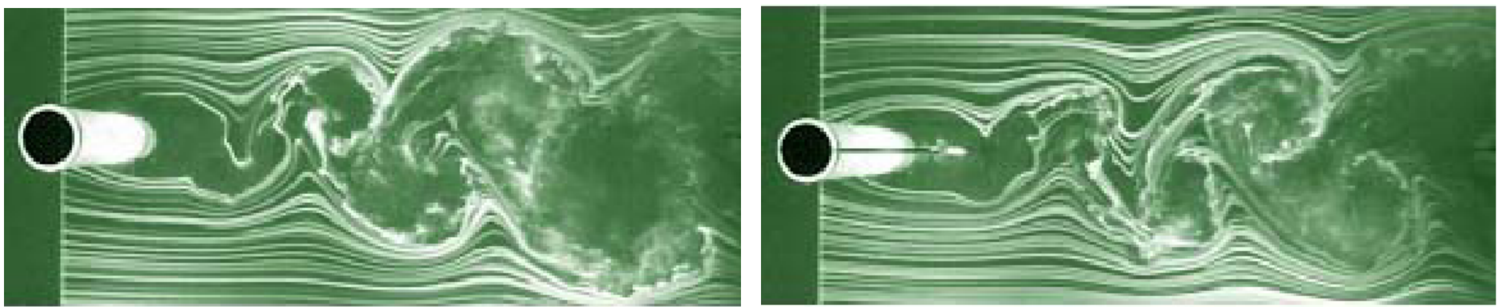
(c) $\lambda/\mathbf{D} = 0.95$ (d) $\lambda/\mathbf{D} = 1.15$

(e) $\lambda/\mathbf{D} = 1.35$ (f) $\lambda/\mathbf{D} = 1.85$

Fig. 4. Suppression effect of $\lambda/\mathbf{D}$ on circular cylinder wakes, $\mathbf{Re} = 5.25 \times 10^3$, $\beta = 30^0$, $\ell/\mathbf{D} = 2.0$, $\mathbf{b/D} = 0.18$.

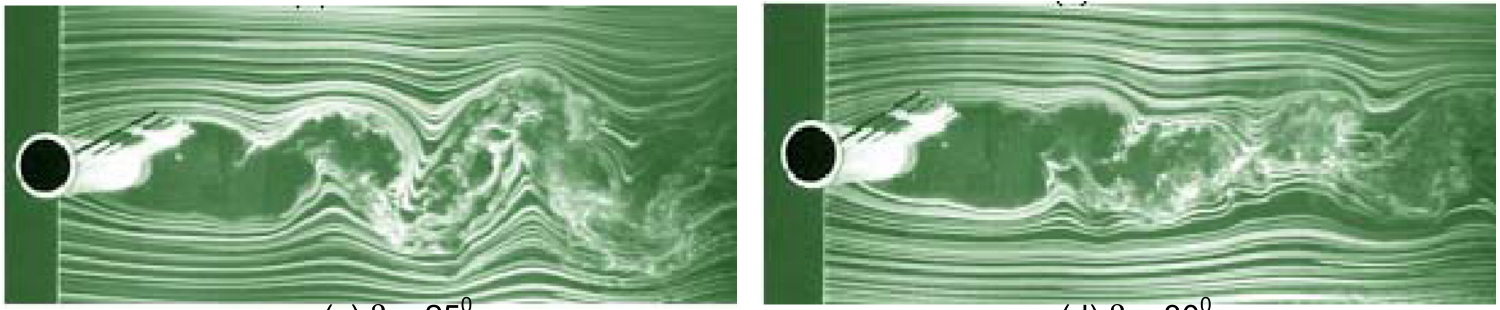
Figure 5 shows the influence of angle of attack β at a fixed distance $\lambda/D = 1.45$, $Re = 9.1 \times 10^3$. The wake is changed little if β is small. With the increase of β, the effect of strip appears. Vortex shedding on both sides of the cylinder is suppressed and the wake is narrowed when the angle is set in the range $30^0 \leq \beta \leq 55^0$. However, slight and irregular waves still appear in the shear layers due to their instability nature (Unal and Rockwell, 1988). Vortex shedding recovers gradually when the angle is further increased from $\beta = 55^0$ to 65^0 or even larger.

From Fig. 4 and Fig. 5 we may deduce that, there exists an effective zone of strip position behind the cylinder, in which vortex shedding can be suppressed. Hot wire measurements at every strip position have been performed at points of Y/D varying from -3.0 to 3.0 on the intersection line of plane $X/D = 12.5$ and the plane of mid-span. The tested strip positions form a net of intervals $\Delta\beta = 2.5^0$ and $\Delta(\lambda/D) = 0.1$ that covers the area of $0^0 \leq \beta \leq 90^0$ and $0.55 \leq \lambda/D \leq 1.75$. A sharp peak appears in the power spectrum of fluctuating velocity when vortex shedding is not suppressed. On the contrary, the velocity fluctuation at any point is weakened and there appears no obvious peak in the spectrum when vortex shedding is suppressed. Combining this criterion with the results of visualization we can determine the effective zone. Effective zones of strip (width $b/D = 0.18$) position in the wakes of circular cylinder at different Re numbers have been found out and shown in Fig. 6.



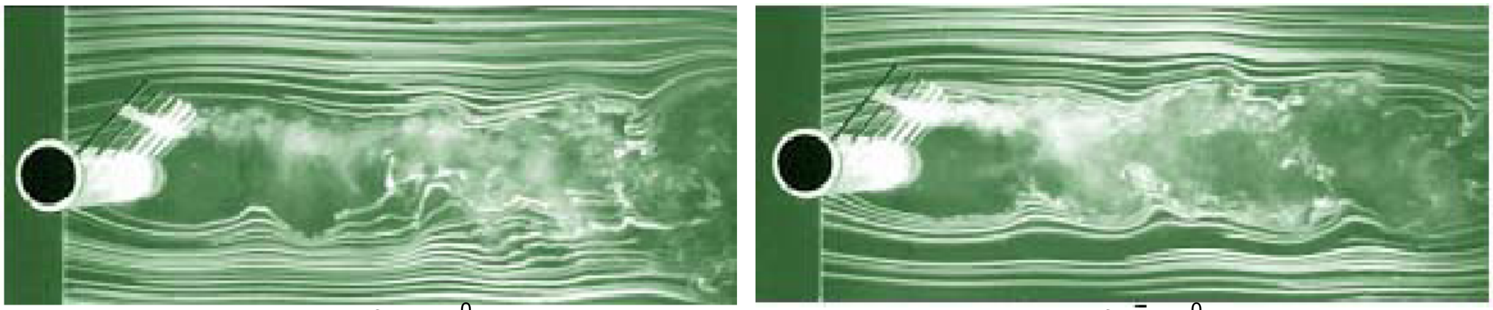
(a) Bare Cylinder

(b) $\beta = 0^0$



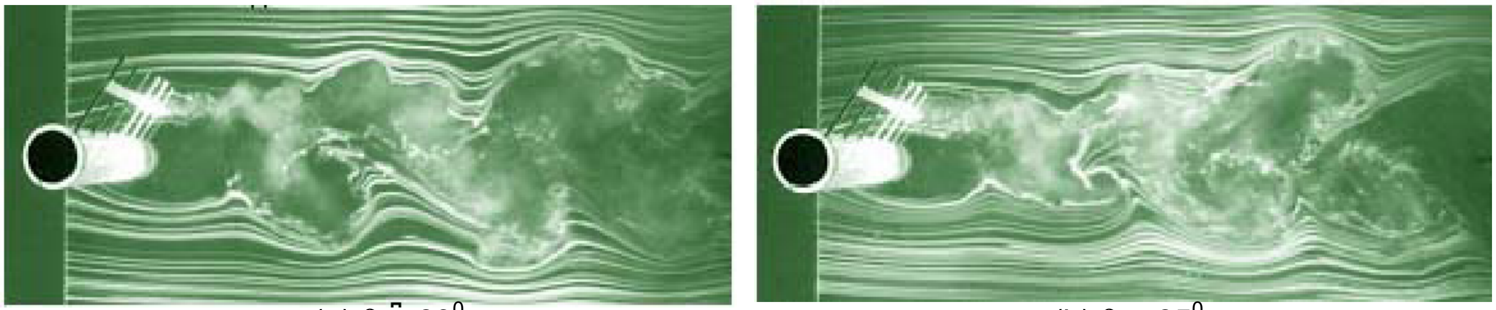
(c) $\beta = 25^0$

(d) $\beta = 30^0$



(e) $\beta = 45^0$

(f) $\beta = 55^0$



(g) $\beta = 60^0$

(h) $\beta = 65^0$

Fig. 5. Influence of β on the wake control, **Re** = 9.1×10^3, λ**/D** = 1.45, strip width **b/D** = 0.18.

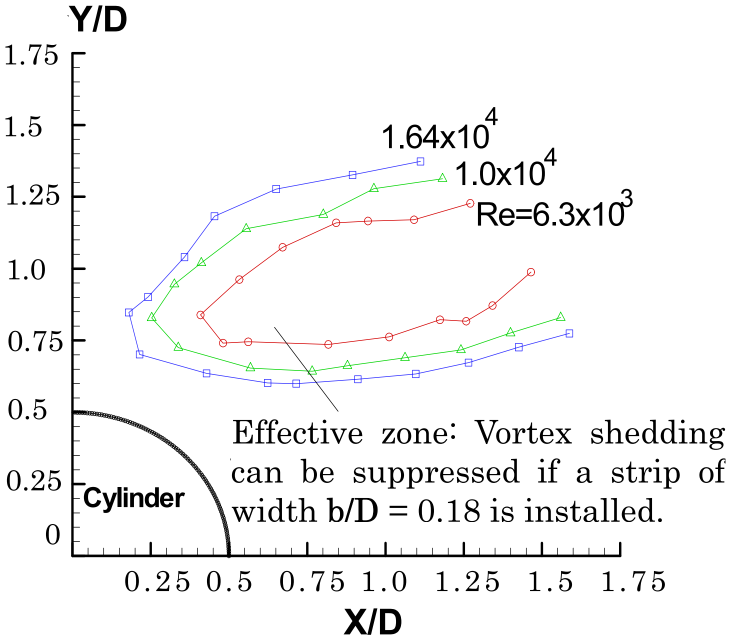
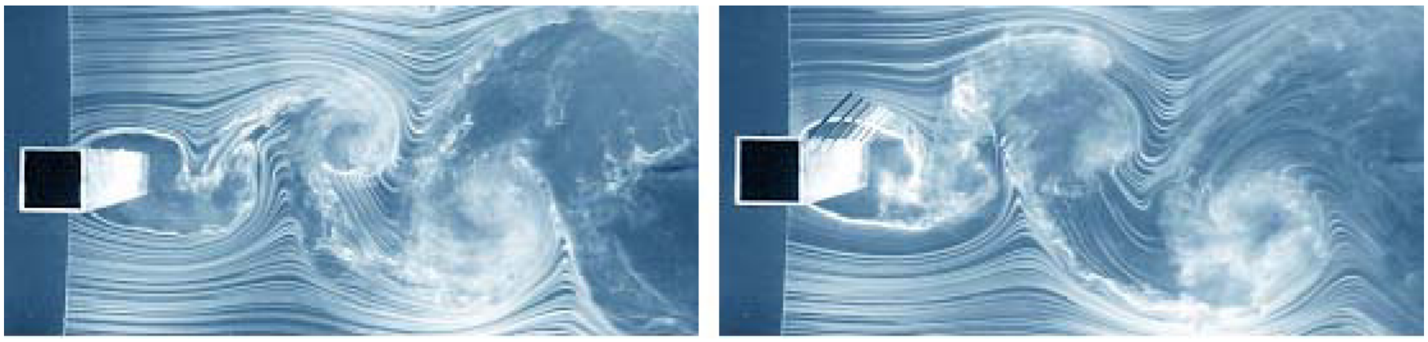


Fig. 6. Effective zones of strip position at different Reynolds numbers, **b/D** = 0.18.

3.3 Suppression Effect on Square Cylinder Wake

Strong vortex shedding occurs and a broad wake appears behind a bare square cylinder (Fig. 7(a)). Vortex shedding can hardly be influenced by merely a bracket (Fig. 7(b)). It is well suppressed and the wake is narrowed when a strip is applied and set in a certain zone behind the cylinder. Fig. 7(c) is a typical case to show the suppression effect at **Re** = 1.25×10^4.



(a) Bare square cylinder wake

(b) The wake of square cylinder with a bracket, $\beta = 45^0$, ℓ/**D** = 1.55

(c) The wake of square cylinder with a strip, λ/**D** = 1.5, $\beta = 45^0$, ℓ/**D** = 1.55, strip width **b/D** = 0.18

Fig. 7. Suppression effect of a strip on the wake of square cylinder, **Re** = 1.25×10^4.

4. Discussions

The mechanism of vortex shedding suppression by a small circular cylinder has been discussed in Strykowsky & Sreenivasan 1990 from physical as well as stability point of view. The physical viewpoint originally comes from Gerrard 1966's model of vortex generation, which describes the role of interaction between the separated shear layers. The model predicts that the circulation in the shear layer must be of a sufficient magnitude before one shear layer draws the other across the wake centerline, and this interaction must take place before a critical distance (formation length) is reached. In the model, the frequency of vortex shedding is also determined by the interactions. It is deduced in Strykowsky & Sreenivasan 1990 that vortex shedding can be inhibited if either the two shear layers are prevented from interactions over a critical formation length, or one shear is diffused over a critical thickness (diffusion length). The effect of a long splitter plate is said to prevent from the interactions. The function of a small circular cylinder is said to diffuse the vorticity in the shear layer. The circulation in the diffused shear layer is then reduced below a threshold, so that the mutual attraction between the opposing shear layers is too weak to form the vortex roll up on both sides. However, a phenomenon of mono-side vortex shedding has been found in this study. It happens when the strip is installed at certain places close to the outer border of the effective zone, where the shear layer is diffused and vortex shedding on that side is suppressed, but vortex shedding as well as its shedding frequency on the opposite side is not notably influenced. This phenomenon is a negative example to Strykowsky and Sreenivasan 1990's physical explanation and Gerrard 1966's model of vortex generation.

The properties of the wake have been investigated by introducing the concepts of global instability and local absolute & convective instability. Stability analyses (Koch, 1985; Triantafyllou, 1986; Monkewitz, 1988) show that, there is a region in the near wake of bluff body, where the velocity profiles are absolutely unstable. Relations among local absolute instability, temporally growing global modes and vortex shedding have been explored in Strykowsky and Sreenivasan 1990, but have not yet been established. Latter advances in stability theory of weakly non-parallel flow (Monkewitz et al., 1993; Chomaz, 2005) indicate that, a sufficiently large region of absolute instability is responsible for global instability and vortex generation. Test results show that, the velocity profiles in the near wake are altered locally by the presence of the strip. The local modifications of the profiles may induce changes in their stability nature. We may deduce that, when the strip is installed in the effective zone, the absolute instability region in the wake is eliminated or reduced to sufficiently small, so that large-scale vortex shedding cannot generate, but it has to be proved by further study.

5. Conclusions

A narrow strip is introduced as a control element to suppress vortex shedding behind a cylinder. A circular cylinder and a square cylinder have been tested respectively in a low turbulence wind tunnel in the range of Reynolds number from 4.0×10^3 to 2.0×10^4. The strip is set parallel to the cylinder axis and the key factor of control in this study is the strip position, which is determined by the angle of attack of the strip and the distance between the strip and the cylinder axis. Vortex shedding on both sides of the cylinder can be effectively suppressed and the wake narrowed if the strip is located in an effective zone in the wake. Effective zones in circular cylinder wakes at different Reynolds numbers have been found out by visualization and hot-wire measurement. The results mean that, local passive interference of the narrow strip can induce global changes of the cylinder wakes at high Reynolds numbers.

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References

Alam, M. M., Sakamoto, H. and Moriya, M., Reduction of fluid forces acting on a single circular cylinder and two circular cylinders, J. Fluids and Structures, 18 (2003), 347-366.

Bouak, F. and Lemay, J., Passive control of the aerodynamic forces acting on a circular cylinder, J. Experimental Thermal and Fluid Science, 16 (1998), 112 -121.

Bouak, F. and Lemay, J., Use of the wake of a small cylinder to control unsteady loads on a circular cylinder, J. Visualization, 4-1 (2001), 61-72.

Chomaz JM, Global instabilities in spatially developing flows: non-normality and non-linearity, Ann. Rev. Fluid Mech., 37 (2005), 357-392.

Fujisawa, N., Ugata, M. and Suzuki, T., A study on drag reduction of a rotationally oscillating circular cylinder at low Reynolds numbers, J. Visualization, 8-1 (2005), 41-48.

Gerrard, J. H., The mechanics of the formation region of vortices behind bluff bodies, J. Fluid Mech., 25 (1966), 401-413.

Koch, W., Local instability characteristics and frequency determination of self-excited wake flows, J. Sound and Vibration, 99 (1985),53-83.

Modi, V. J. and Yokomizo, T., Pressure distribution on a roof in presence of the moving surface boundary-layer control, J. Visualization, 1-3 (1999), 255-260.

Mohamed, G.-E.-H., Flow control – passive, active and reactive flow management, (2000), Cambridge University Press.

Monkewitz, P. A., Huerre,P. and Chomaz, J.M., Global linear stability analysis of weakly non-parallel shear flows, J. Fluid Mech., 251 (1993), 1-20.

Monkewitz, P. A. and Nuygen, L. N., Absolute instability in the near-wake of two-dimensional bluff bodies, J. Fluids and Structures, 1, 165-184

Ozono, S., Flow control of vortex shedding by a short splitter plate asymmetrically arranged downstream of a cylinder, Phys. Fluids, 11 (1999), 2989-2998.

Roussopoulos, K., Feedback control of vortex shedding at low Reynolds numbers, J. Fluid Mech., 248 (1993), 267-296.

Sakamoto, H. and Haniu, H., Optimum suppression of fluid forces acting on a circular cylinder, J. Fluids Engineering, 116 (1994), 221-227.

Schumm, et al., Self-excited oscillations in the wake of two-dimensional bluff bodies and their control, J. Fluid Mech., 271 (1994), 17-53.

Shao, C.P., E, X. Q., Wei, Q. D. and Zhu FR, Control of vortex shedding at moderate Reynolds numbers, China Ocean Engineering, 16 (2002), 61-68.

Strykowsky, P. J. and Sreenivansan, K. R., On the formation and suppression of vortex shedding at low Reynolds numbers, J.

Fluid Mech., 218 (1990), 71-83.

Tensi, J., Boue, I., Paille, F. and Dury, G., Modification of the wake behind a circular cylinder by using synthetic jets, J. Visualization, 5-1 (2002), 37-44.

Triantafyllou , G. S., Triantafyllou, M. S. and Chrissostomidis, C., On the formation of vortex streets behind stationary cylinders, J. Fluid Mech., 170 (1986),461-477.

Unal, M. F. and Rockwell, D., On vortex formation from a cylinder, part 2: Control by splitter-plate interference, J. Fluid Mech., 190 (1988), 491-512.

Wang, F. H., Jiang, G. D. and Lam, K., Flow patterns of cross –flow around a varicose cylinder, J. Visualization, 8-1 (2005), 49-56.

Yamagishi, Y. and Oki, M., Effects of the number of grooves on flow characteristics round a circular cylinder with triangular grooves, J. Visualization, 8-1 (2005), 57-64.

Zdravkovich, M. M., Review and classification of various aerodynamic and hydrodynamic means for suppressing vortex shedding, J. Wind Engineering and Industrial Aerodynamics, 7 (1981), 145-189.

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