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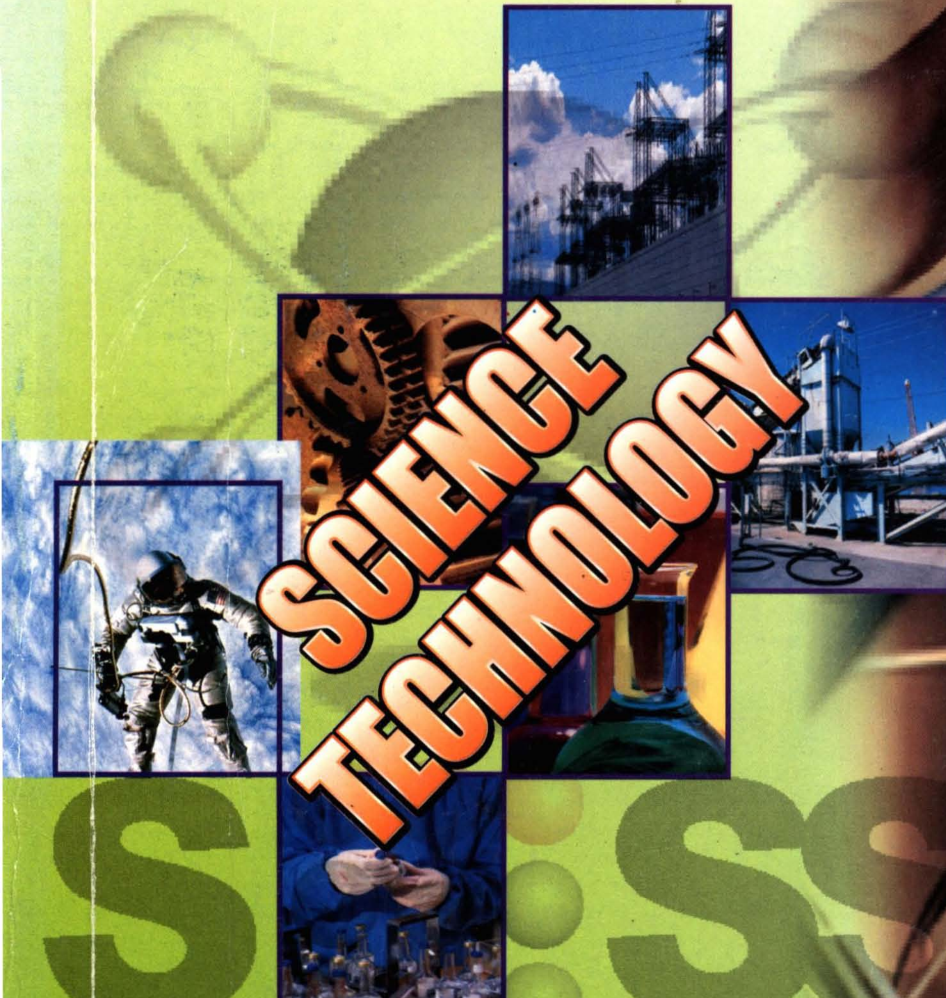

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Flow Around Cylindrical, Rectangular and Square Bluff Bodies

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ABSTRACT

The flow around a bluff body is of great interesting engineering practice. Typical example of engineering applications is the computation of wind load on building and simulations of the flow around vehicles. This work is connected to the latter and studies some aspects related to vehicle and aircraft aerodynamics, such as drag and lift. Most studies of this kind of flow are experimental.

The main objectives of conducting this research are to gain better understanding of flow through various bluff bodies. The bluff bodies that were used in this experiment are the cylindrical rods and the square rods. The dimensions are 20 mm in diameter and 100 mm long for the cylindrical rods and 20 x 20 mm wide and 100 mm long for the square rods. These cylindrical and square rods are then placed in a water stream with flat surface on its bottom of a hydraulic bench of 180 x 250 x 700 mm in dimensions. Water is pumped from one end of the stream flows out at the other end creating a flow of water along the stream. Various combinations like side by side and tandem arrangements of the bluff bodies were tried and for each arrangement the visualization studies were conducted. Then, aluminum powder sprayed on the surface of the water to visualize the flow pattern while passing over the bluff bodies. A high resolution digital camera was mounted on the top of the water stream to capture the flow pattern created by the aluminum powder at surface of the water. The results are then studied analysed. The results indicated the formation of vortices, separation lines with distinct patterns depending on the configuration under study.

Keywords : *vortices, visualization-study, tandem-arrangement, aluminum powder, interferences*

Introduction

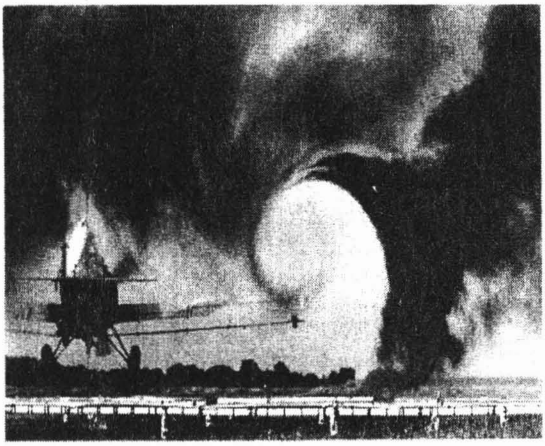
In many real life situations, flow takes place past one or more cylinders. In these such cases, interference effects occur and the forces on the cylinder are much influenced by such effects. For example, at certain position and size of the cylinders, the fluid forces may be amplified several times or in some cases attenuated. The present investigation play an important role in understanding common problems such as flow-induced vibration of chimneys, TV towers, off-shore structures, transmission lines, tube bundle vibrations in the heat exchangers of nuclear reactors and in many other situations.

It is quite common to come across flow around bodies with square and rectangular cross sections. For example, most of the buildings are either square or rectangular in section. They have finite length to width and height to width ratios. Hence, they are three dimensional. When the structures are small, then the flow in the central portion can be considered to be two dimensional. This also applies to many off-shore structures like bridge piers and decks that have square or cylindrical cross-sections. The results from the present investigations are relevant to understand flow in these situations.

A vortex can be seen in the spiraling motion of air or liquid around a center of rotation. The circular current of water of conflicting tides form vortex shapes. Turbulent flow makes many vortices. A good example of a vortex is the atmospheric phenomenon of a whirlwind or a tornado or dust devil. This whirling air mass mostly takes the form of a helix, column, or spiral. Tornadoes develop from severe thunderstorms, usually spawned from squall lines and supercell thunderstorms, though they sometimes happen as a result of a hurricane. Figures 1 (a,b) show the vortex shedding in water and air respectively.

A *mesovortex* is on the scale of a few kilometers (smaller than a hurricane but larger than a tornado). On a much smaller scale, a vortex is usually formed as water goes down a drain, as in a sink or a toilet. This occurs in water as the revolving mass forms a whirlpool. This whirlpool is caused by water flowing out of a small opening in the bottom of a basin or reservoir. This swirling flow structure within a region of fluid flow opens downward from the water surface.

(a)



(b)

Fig.1 (a) and (b): Vortex Shedding in Water and in Air

The best documented experimental work on the formation of vortices over bluff bodies is done by Laksmana Gowda (1992,) Laksmana Gowda and Mohamed Sitheeq (1998). Their work is concerned with the interference effects on the flow around prismatic bodies. Similar investigations on turbine cascade was done by Govardhan et al. (1998 and 2001). The results have shown that the flow field around prismatic bodies in tandem arrangement can be variably under interference conditions compare to that without interference. The interferences are more severe for the taller body than for the shorter one. These results enabled us to better understand and appreciate the changes in wind loads that would occur on such structures due to interference effect. Also the flow patterns indicate the changes in the wind environment that occur in practical situations, where interference effects invariably exist.

Experimental Setup and Procedure

Experimental investigations are carried out using the hydraulic bench in the lab. Water with aluminum powders on its surface is used to initiate the flow past the bluff bodies. A digital camera together with some proper lighting is mounted above the bluff bodies to capture the flow pattern of the aluminum powders. It is quite common to come across flow around bodies with square, rectangular and circular cross sections, e.g. buildings and bridge piers. Hence, the bluff bodies that are used are of the same shape. The dimensions are 20 mm in diameter and 100 mm long for the circular bodies, 20 mm x 40 mm x 100 mm for rectangular bodies and 20 mm x 20 mm x 100 mm for the square bodies. These prismatic cylindrical bodies are placed in a water tunnel of 180 mm x 250 mm x 700 mm dimensions. Typical cylindrical and square rods used for the present investigation is shown in Fig. 2(a) and 2(b). Water from the pump flows through carefully designed plenum chamber where the turbulence of the water is reduced and the uniform flow flows over the bodies, (Fig. 3). At the suitable location upstream of the bodies, aluminum powder is sprayed and the flow pattern formed around the bodies is photographed using a digital camera. Various combinations of the bodies are studied, namely: single cylinder, cylinder in tandem, cylinder in side by side. The gap between the cylinders is also varied. The following terms are used to describe the arrangement of the cylinder rods

g = gap between two cylinder rods (mm)
d = diameter of the cylinder rods (mm)
w = width of the square rods (mm)

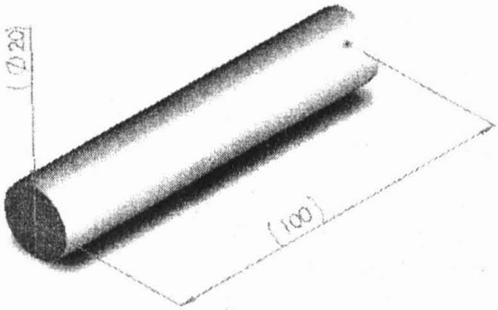


Fig. 2: (a): Details of Cylindrical Rod

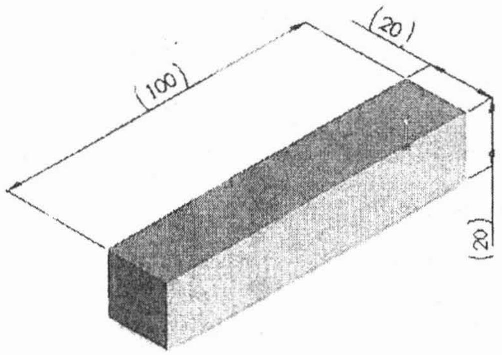


Fig. 2(b): Details of Square Rod

Results and Discussion

Figure 4(a) shows the stagnation region in front of the cylinder. As expected flow separates and creates large wake flow behind the cylinder. The vortex alternates between top and bottom sides creating oscillation of the body. This is known as flow induced vibration. When the cylinders adjoin each other (Fig. 4(b)), they act like a single body with a stagnant fluid in the junction. The flow separates from the first cylinder and does not get reattached. When the gap between the cylinders is increased (g/d = 1, Fig. 4(c)), there is a jet like flow between the cylinders which switches up and down. A strong vortex is seen behind the front cylinder at the bottom side which is replaced by another one at the top periodically. When the gap is further increased (g/d = 4, Fig. 4(d)), the strong vortex behind the front cylinder modifies the flow structure around the second cylinder with separation occurring much earlier than that of the front cylinder. Interestingly, the vortex shedding behind the front cylinder is suppressed. The lift force normal to cylinder can be expected to be nearly zero. With three cylinders in tandem (Fig. 4(e)), the vortex shedding continues for the second and third cylinders.

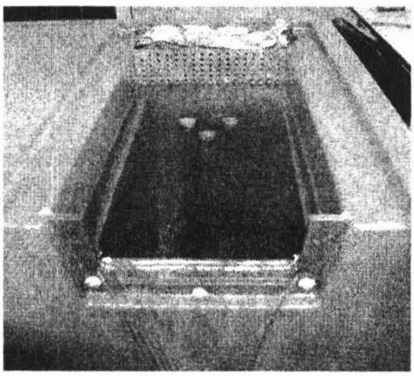
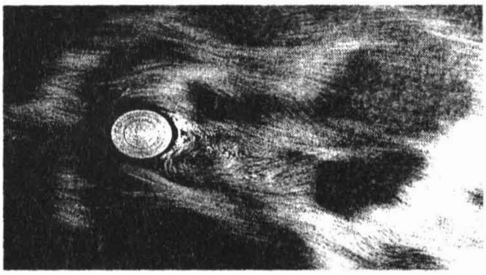
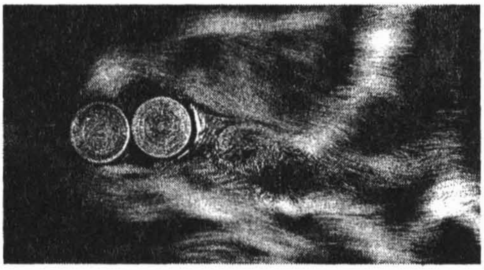


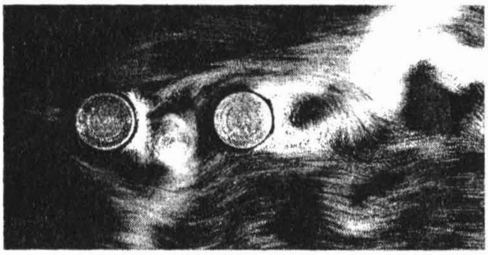
Fig. 3: Hydraulic Bench



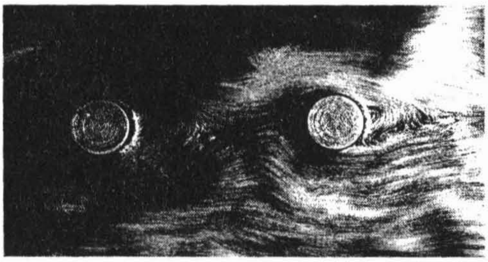
(a) Single Cylinder



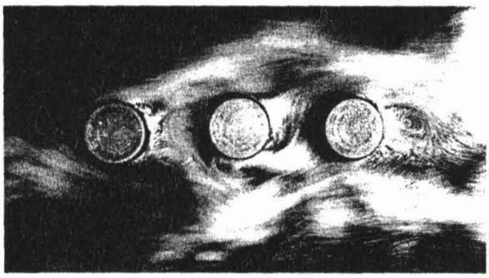
(b) Two Cylinders with g/d = 0.0



(c) Two Cylinders with g/d = 1.0



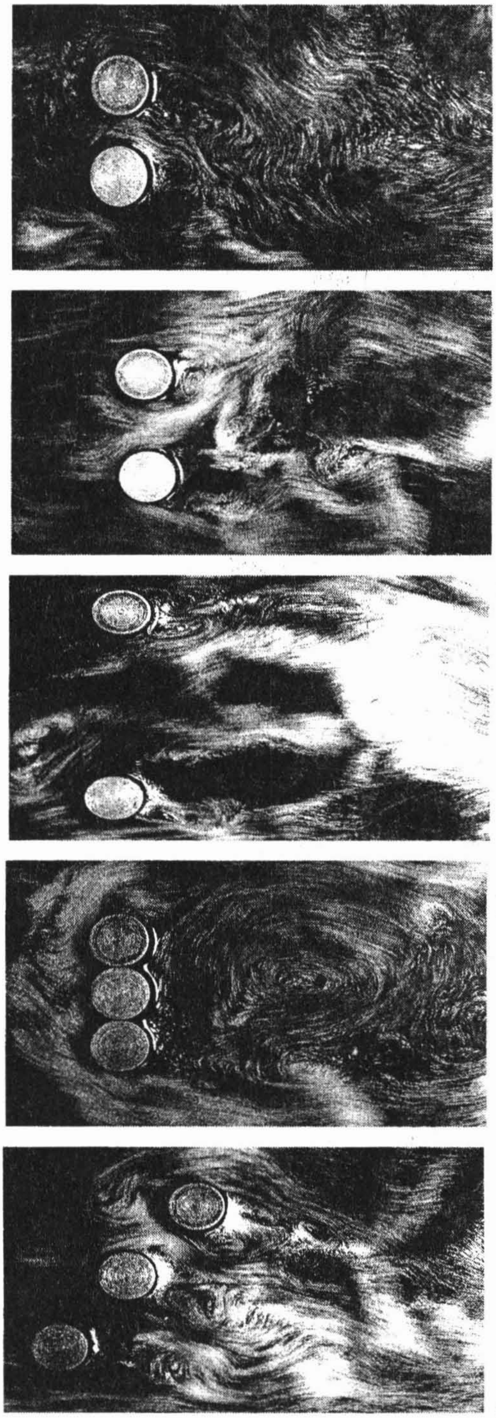
(d) Two Cylinders with g/d = 4.0



(e) Three Cylinders with g/d = 1.0

Fig. 4: Circular Cylinders in Tandem Arrangement

Figure 5 shows the flow visualization patterns obtained with circular cylinders arranged in side by side mode. Vortex shedding is seen at one of the cylinders and there is a pair of symmetrical vortices behind the other. Periodically the flow conditions behind the cylinders switch, the vortex pair occurring at the other cylinder (Fig. 5 (a)). When the gap between the cylinders is increased to g/d = 4, the effect of interference reduces and they act like individual cylinders. The vortex shedding is symmetric about the gap axis (Fig. 5(c)). When the bodies of the cylinders are arranged in slanted position (at 45^0), the bottom most cylinders receive the flow first and modify the flow around it. This seems to be affecting the top two cylinders. Due to this reason, the vortex shedding behind the top cylinder is very strong creating large wakes. Flow from top cylinder separates much earlier than the bottom cylinder.



(a) Two Cylinders with g/d = 0.5

(b) Two Cylinders with g/d = 1.0

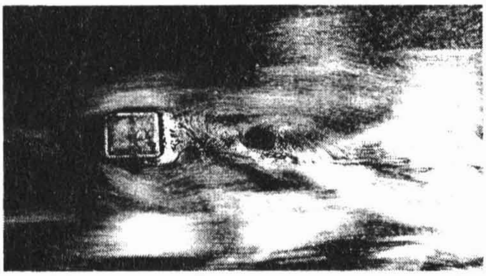
(c) Two Cylinders with g/d = 4.0

(e) Three Cylinders with g/d = 0.0

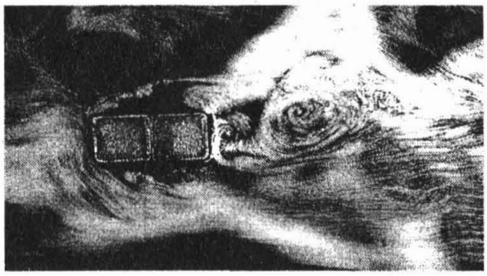
(e) Three Cylinders Slanted by 45^0 with g/d = 1.0

Fig. 5: Circular Cylinders in Side by Side Arrangement

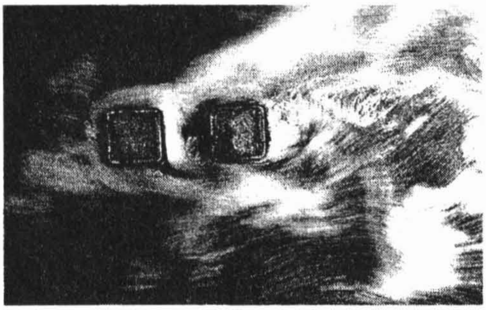
A square cylinder is a body with a sharp corner, hence separation point is fixed and the separation phenomenon is independent of the Reynolds number. Figure 6(a) shows an arrangement with square cylinder. The separations from the front corner edges are distinctly seen. The flow does not reattach as the length of the body along the streamwise direction is not enough. The wakes are stronger with the result the drag force of this body will be higher than that of cylinder of the same cross sectional area. When two square cylinders are joined lengthwise (forming a rectangular body), the separating flow seems to be reattaching at the bottom side, Fig. 6(b)). When the g/w = 1.0, Fig. 6(c), there is a weak gap flow between the bodies.



(a) Single Square Cylinder



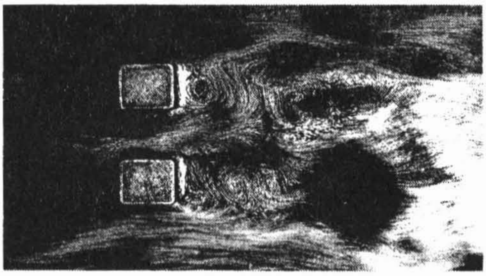
(b) Two Square Cylinders with g/w = 0.



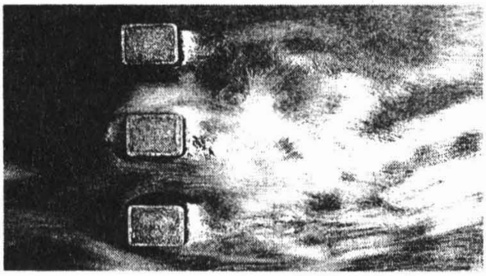
(c) Two Square Cylinders with g/w = 1.0

Fig. 6 Square Cylinders in Tandem Arrangement

When square cylinders are kept side by side, a jet like flow is issued from the gap between the cylinders. Vortices are formed behind each body and are almost symmetrical, Fig. 7(a). Similar phenomenon is observed when three square cylinders are arranged side by side as shown in Fig. 7(b).



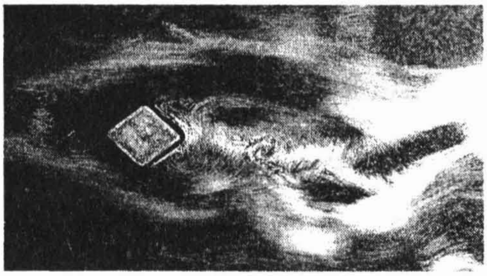
(a) Two Square Cylinders with g/w = 1.0



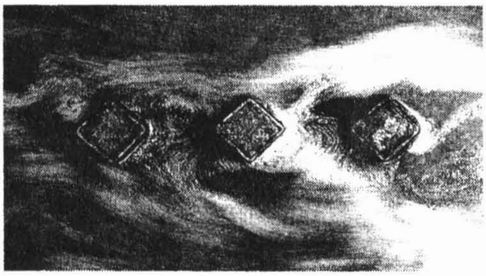
(b) Three Square Cylinders in Side by Side Arrangement with g/w = 1.0

Fig. 7: Square Cylinders in Side by Side Arrangement

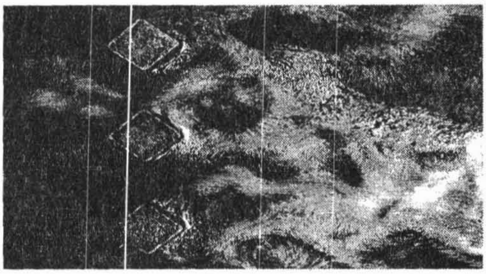
When the body is tilted by 45^0, the flow divides itself at the symmetrically situated front stagnation point (Fig. 8(a)). Figure 8(b) shows the arrangement of the square cylinders in tandem, the flow separates from each corners and when they are arranged side by side at g/l=1.0, Fig. 8(c), the separation lines from each cylinder are distinct and vortices are formed behind each square body.



(a) Single Square Cylinder at 45^0



(b) Three Square Cylinders at 45^0 with g/w =1.0



(c) Three Square Cylinders in Side by Side Arrangement, g/w = 1.0

Fig. 8: Circular Cylinders in Side by Side and Tandem Arrangement at 45^0

Conclusions

Flow around bluff bodies with cylindrical and square cross sections is visualized in a water tunnel with aluminum powder as tracing medium. The flow around the body is not only influenced by the shape of the body but also by the arrangement. Each arrangement shows distinct flow patterns with the formation of vortices, separation and reattachment lines. The vortices formed are very much influenced by the gap between the bluff bodies.

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