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VIV SUPPRESSION AND DRAG REDUCTION WITH PIVOTED CONTROL PLATES ON A CIRCULAR CYLINDER

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ABSTRACT

Experiments have been carried out on two-dimensional devices fitted to a rigid length of circular cylinder to investigate the efficiency of pivoting control plates as VIV suppressors. Measurements are presented for a circular cylinder with low mass and damping which is free to respond in the cross-flow direction. It is shown how vortex-induced vibration can be practically eliminated by using free to rotate, two-dimensional control plates. Unlike helical strakes, the devices achieve VIV suppression with drag reduction. The device producing the largest drag reduction was found to have a drag coefficient equal to about 70% of that for a plain cylinder at the same Reynolds number.

Keywords: *VIV Suppression, Drag reduction, Control Plates, Circular Cylinder.*

INTRODUCTION

Vortex-induced vibrations are a continuing problem in offshore operations. A widely used method for suppressing VIV, developed originally in the wind engineering field, is the attachment of helical strakes. However, strakes suffer from two major problems: the first being that they increase drag and the second that their effectiveness reduces with decreases in the response parameter $m^*\zeta$, where m^* is the ratio of structural mass to the mass of displaced fluid and ζ is the fraction of critical damping. Whereas a strake height of 10% of cylinder diameter is sufficient to suppress VIV in air at least double this amount is required in water, and this increase in height is accompanied by a corresponding further increase in drag. It is known that if vortex shedding from a fixed cylinder is eliminated, say by the use of a long splitter plate, then drag is reduced hence conceptually an effective VIV suppression device should be able to reduce drag rather than increase it. This simple idea was the motivation for the work described here.

A simple analysis for a linear oscillator-based model of flow-induced vibration, assuming harmonic forcing and harmonic response, shows that response is inversely proportional to the product of m^* and ζ. Hence the most rigorous way to test the effectiveness of a VIV suppression device is to work at low mass and damping. In the experiments to be described in this paper the parameter $m^*\zeta$ was equal to 0.014. Owen et al. [1] describe a method for low drag VIV suppression that had shown itself to be effective down to values of $m^*\zeta$ of about 0.5. This was the attachment of large scale bumps to induce three-dimensional separation and eliminate vortex shedding. However, later experiments at lower values of $m^*\zeta$ have shown a return of VIV with amplitudes similar to those of a plain cylinder. This behaviour has been repeated with even grosser forms of continuous surface, three dimensionality where regular vortex shedding has been eliminated from the body when it is fixed but it returns under conditions of low mass and damping. From this experience it is concluded that sharp-edged separation from strakes, with its accompanying high drag, is required to maintain three-dimensional separation and that three-dimensional solutions will not provide the required combination of VIV suppression and low drag. There are

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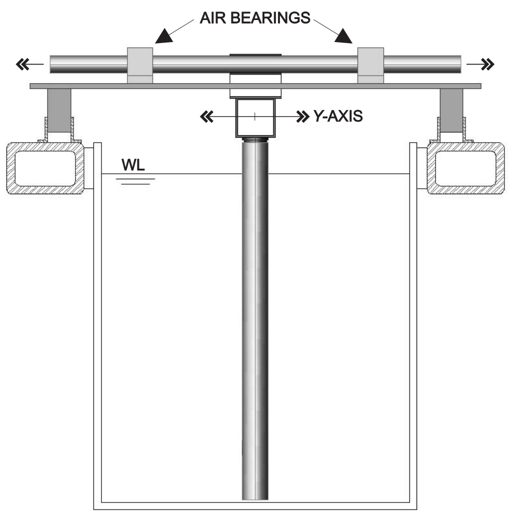

Figure 1. Illustration of the test section. The flow is moving perpendicular to the page plane and the cylinder is allowed to oscillate in the transverse direction (y-$axis$).

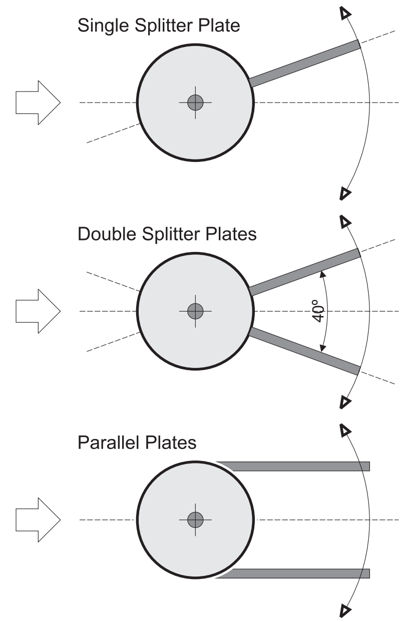

Figure 2. Sketch of proposed control plates pivoting about the centre of a circular cylinder.

a number of two-dimensional control devices that have been used to weaken vortex shedding and reduce the drag of fixed circular cylinders, with the most well known being the splitter plate. In this paper we describe the results of experiments to suppress VIV and reduce drag using various configurations of two-dimensional, control plates.

EXPERIMENTAL ARRANGEMENT

Experiments have been carried out on devices fitted to a rigid length of cylinder free to respond in only the transverse direction. A recirculating water channel with a test section $0.6m$ wide, $0.7m$ deep and $8.4m$ long is used (Figure 1). The flow speed is continuously variable and good quality flow can be obtained up to at least $0.6m/s$. The cylinder model is constructed from $50mm$ diameter Perspex tube, giving a maximum Reynolds number of approximately $30,000$. Models are mounted on a very low damping, air bearing support system allowing vibration in one direction. The cylinder spans the depth of the test section from the free surface, leaving a 2mm gap before the glass floor. A load cell is mounted between the cylinder and the support system in order to deduce the instantaneous and time-averaged hydrodynamic forces on a responding cylinder. In order to obtain the hydrodynamic transverse force acting, the inertia force (cylinder structural mass $\times$ acceleration) is subtracted from the force recorded by the load cell. Drag is measured by repeating experiments with the load cell orientated in the flow direction. With the load cell in place, the mass ratio, where mass ratio is defined as vibrating mass divided by the displaced mass of water, was 2. The structural damping is around 0.007, as a fraction of critical damping, giving a value of the product of mass ratio and damping of only 0.014. Measurements were made using one set of springs and the reduced velocity range covered was from 1.5 to 23, where reduced velocity (U/f_0D) is defined using the cylinder natural frequency measured in air.

In addition to response and force measurements, flow visualisation has been carried out using laser-illuminated fluorescent dye. Flow field measurements to obtain instantaneous spatial distributions of velocity and vorticity were obtained using a Dantec PIV system.

EXPERIMENTAL RESULTS AND DISCUSSION

Initially experiments were conducted on a circular cylinder with a fixed splitter plate equal in length to one cylinder diameter. The result was a very vigorous transverse galloping oscillation that, with increasing reduced velocity, would apparently increase without limit. Since a device to be used in the ocean must have omni-directional effectiveness the next stage was to pivot the splitter plate about the centre of the cylinder. Following the disappointing experience with a fixed plate, it was thought that a plate free to rotate might provide damping to help suppress the galloping; but when the experiment was resumed a totally unexpected result was obtained. There were found to be two stable positions for the splitter plate at roughly $\pm 20^\circ$ to the free stream direction and the plate rapidly adopted one or other of these positions when it was released. VIV was suppressed,

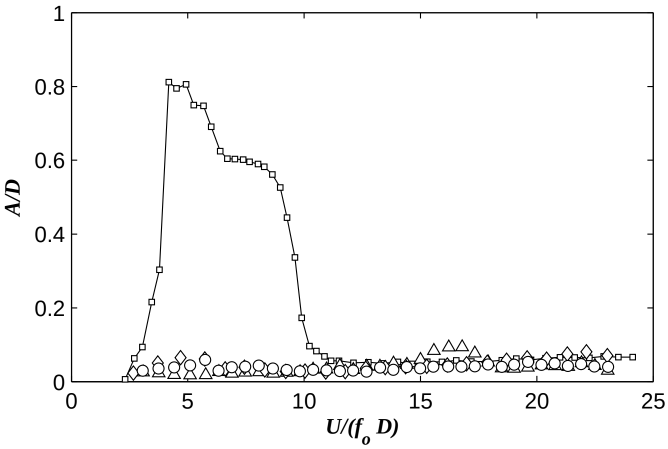

Figure 3. Amplitude of vibration versus reduced velocity. (For legend please refer to Figure 4.)

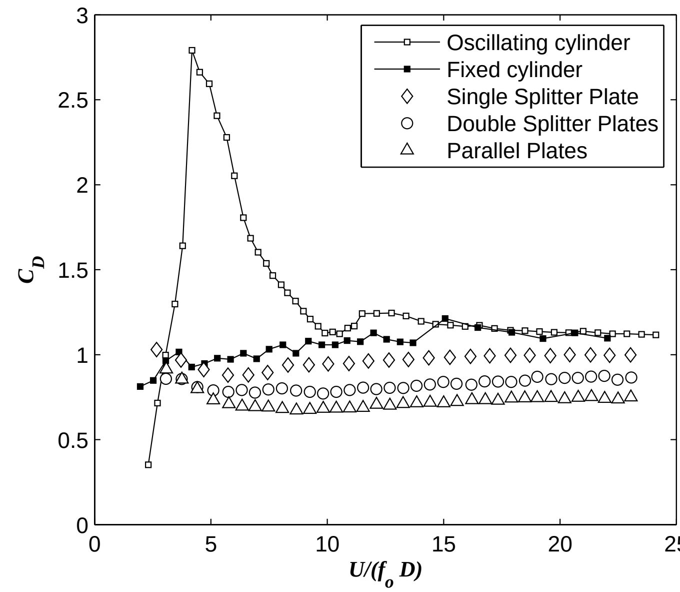

Figure 4. Drag coefficient versus reduced velocity.

throughout the range of reduced velocity investigated, and drag reduced below that of a plain cylinder.

Visualisation showed that on the side to which the plate deflected the separating shear layer from the cylinder appeared to attach to the tip of the plate and this had the effect of stabilising the near wake flow. Vortex shedding was visible downstream but this did not feed back to cause vibrations. An unwanted effect was that a steady transverse lift force developed on the cylinder. The splitter plate was free to rotate so the force, caused by differing flow on the two sides of the cylinder, must be acting primarily on the cylinder rather than the plate. The direction of the force was opposite to that which occurs on an aerofoil with a deflected flap, and caused the cylinder to adopt a steady offset position to the side to which the splitter plate deflected. It was this force which was responsible for the strong galloping response with the fixed splitter plate.

In order to try to eliminate the steady transverse force a pair of plates, one cylinder diameter long, were set at $\pm 20^\circ$ to the free stream direction (40° between each other as seen in Figure 2). The angle between the plates was fixed but the pair of plates was free to pivot about the centre of the cylinder. This configuration suppressed VIV, reduced drag below that of a plain cylinder and removed the steady side force. In this arrangement the shear layers from the cylinder stabilised and reattached to the tips of the plates. Downstream of the plates vortex shedding was observed but this did not generate an excitation sufficient to cause any serious VIV. Maximum amplitudes recorded were around 5% of the cylinder diameter.

Plates between 0.5 and 1.5 cylinder diameters long were all effective in suppressing VIV and reducing drag but, perhaps as might be expected, the shorter the plate the larger the angle required to stabilise the shear layers. When longer, free to rotate plates were attached to the cylinder a transverse flow-induced vibration returned.

Table 1. Mean drag coefficients and relative drag reduction.

Model	Mean drag	Drag reduction
Fixed cylinder	1.03	Ref. value
Single Splitter Plate	0.97	5.8%
Double Splitter Plates	0.82	21%
Parallel Plates	0.73	29%

Variations on the concept of double plates, some inspired by the early work of Grimminger [2] related to suppressing VIV of submarine periscopes, were also studied. These included plates parallel to the flow and trailing back from the $\pm 90^\circ$ points on the cylinder (Figure 2). In Grimminger's experiments the plates were fixed since the flow direction was known but in our work the plates were free to rotate. As shown in the plots in Figures 3 and 4 of amplitude and drag coefficient against reduced velocity, every configuration with plates provided excellent VIV suppression and a reduction in drag below the plain cylinder value. The maximum drag reduction achieved was almost 30% and this was for the parallel plates. In Figures 3 and 4 results for a fixed and a freely responding cylinder are also presented to provide reference data. It should be noted that amplitude levels in Figure 3 are measured root mean square values multiplied by $\sqrt{2}$.

Table 1 compares the drag reduction of each configuration taking the fixed cylinder as a reference. The mean drag represents the average behaviour of the drag coefficient through the whole range of reduced velocity.

CONCLUSIONS

Suppression of cross-flow, vortex-induced vibration of a circular cylinder, with resulting drag coefficients less than that for a fixed plain cylinder, has been achieved with the use of two-dimensional control plates. Suppression has been accomplished at a value of the combined mass and damping parameter of 0.014. The maximum drag reduction was about 30% for the parallel plates, which appear to be the most effective VIV suppressor of the devices investigated.

AKNOWLEDGEMENTS

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