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EFFECTS OF END CONDITIONS ON VORTEX SHEDDING FROM THICK FLAT PLATES

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ABSTRACT

A hydrogen bubble flow visualisation study has been made of vortex shedding from a thick flat plate with an elliptical leading edge, at flow Reynolds numbers up to 350.

Various procedures were used to modify the end conditions in an attempt to produce two-dimensional wake flow with parallel vortex shedding over the greater part of the plate span. Greatest success was obtained by using a pair of circular cylinders mounted a short distance downstream of the plate and perpendicular to it.

INTRODUCTION

The present investigation forms part of a study of the mechanisms of noise generation by bluff bodies immersed in a vortex wake. In this particular study the vortex wake is generated by a thick flat plate with an elliptical leading edge. The vortices formed at the plate trailing edge are convected downstream and interact with a rectangular-section plate placed in tandem with, and spaced from, the vortex generator plate, the chords of the two plates being aligned with the flow. Bull et al. (1992) showed that as the vortices are displaced by, and flow over, the leading edge of the downstream plate large fluctuating pressures are induced near the leading edge which give rise to the significant acoustic radiation observed by Bull and Pickles (1991). More detailed study of the relationship between the fluctuating force on the plate and the resulting acoustic radiation requires knowledge of the spanwise correlation of the vortex/body interaction process.

Many experimenters have observed that the vortex shedding from a finite-span circular cylinder in a laminar flow is two-dimensional (with vortex axes parallel to the cylinder axis) only at low Reynolds numbers. At a certain value of Reynolds number, which varies with the test facility and experimental configuration, transition to oblique shedding occurs, where the vortex axes are parallel to each other but inclined to the axis of the cylinder. This behaviour has been shown by Hammache and Gharib (1991) to result from an asymmetric spanwise base-pressure distribution, which in turn is probably a consequence of small asymmetries in the interactions of each cylinder end with the flow facility wall boundary-layer. The flow visualisation study reported here was undertaken to determine the spanwise vortex shedding pattern of a thick flat plate of finite span, and to investigate possible methods for ensuring that two-dimensional parallel vortex shedding was obtained.

EXPERIMENTAL APPARATUS

Water Channel

Flow visualisation was conducted in a small water channel constructed entirely of clear perspex with an open-topped working section 100 mm wide by 200 mm deep and 540 mm long.

Test Model

The flat plate used in these experiments had an elliptical leading edge with a major-to-minor semi-axis ratio of 5:1. Its thickness (t) was 2 mm, its chord length (c) 25 mm, and its span between the channel walls was 100 mm. Chord-to-thickness ratio was 12.5, and aspect ratio based on thickness was 50. The rear face of the plate was square, with sharp trailing edge corners. The plate was made marginally larger than the width of the working section and was wedged in place between the side walls.

Test Flow Conditions

The maximum flow velocity in the working section was 175 mm/s, corresponding to a Reynolds number Re_t (based on plate thickness) of 350. Calibration was effected by a small vortex-meter probe that had been previously calibrated in a wind tunnel. Previous experiments (Bull et al. 1989) have shown that the boundary layer on an elliptic leading edge profile thick flat plate remains laminar at these Reynolds numbers.

Hydrogen Bubble Generation

A sheet of hydrogen bubbles was generated from a 0.125 mm diameter platinum wire spanning the working section parallel to the plate leading edge. To minimise flow interference the wire passed through small sealed holes in the channel wall. The wire was anchored at one end and spring loaded at the other to maintain wire tension. The plate was positioned relative to the wire so that bubbles were entrained only into one side of the vortex street.

The bubble sheet was illuminated by an incandescent light source with an adjustable horizontal slit. A video camera was mounted vertically above the model to record the flow patterns.

Flow Control Methods

Control of the vortex shedding process was attempted using three methods that have been proposed in the literature. Eisenlohr and Eckelmann (1989) induced parallel vortex shedding from a circular cylinder by using enlarged end-cylinders, coaxial with the main cylinder. A similar geometry was obtained on the flat plates used here by building up the end thickness with layers of thin perspex. These were wrapped around the elliptical leading edge, stuck in position and trimmed flush with the plate trailing edge. By this means the thickness of the plate was increased to 4.1 mm (2.05t) for a distance of 20 mm (10t) from each end.

Hammache & Gharib (1991) proposed a method of control that uses a pair of cylindrical rods mounted upstream of, and perpendicular to, the vortex shedding cylinder. Provided the rods were of sufficient diameter, and placed at an optimum distance upstream of the main cylinder, parallel shedding could be obtained. In our experiments rods of diameter 1t, 1.5t, 2t, 2.5t and 3t were used.

End-plates have been widely used to isolate the central part of the span of a body from the worst effects of wall interference, with the principal aim of producing a more uniform base pressure. Williamson (1989) has made an extensive study of oblique and parallel vortex shedding behind a circular cylinder with and without endplates. We have used 0.25 mm thick rectangular end plates located sufficiently far (10 mm (5t)) from each end of the vortex shedding plate to be outside the channel wall boundary layer. The plates were set up parallel to each other. They extended 10 mm (5t) upstream and downstream of the leading and trailing edges respectively of the vortex shedding plate, and 15 mm (7.5t) above and below the plate upper and lower surfaces. The corners of the end plate were rounded.

RESULTS AND DISCUSSION

No Control

At the lowest Reynolds number for which uniform stable flow could be obtained ($Re_t \approx 95$) the shed vortex axis is slightly curved (figure 1) indicating a difference between shedding frequencies at centre-span and the walls. At higher Reynolds numbers the vortex shedding became more markedly oblique (figure 2). Shedding commenced near centre span and spread outwards towards the ends of the plate.

König et al. (1990), in experiments on a circular cylinder, showed that parallel shedding over the whole span occurred only for $Re_t < 55$. As the Reynolds number increased the region of parallel shedding contracted towards mid-span, finally disappearing at $Re_t \approx 65$.

End Plates

For $Re_t < 96$ the vortex shedding was parallel to the plate trailing edge. For $Re_t > 100$ there was little difference from the oblique shedding pattern observed with no end plates.

The comments of Hammache & Gharib (1991) on the difficulty of setting up end plates to give the desired parallel shedding from circular cylinders, and the strong dependence of the optimum configuration on Reynolds number and cylinder aspect ratio, should be noted. It may be that with greater persistence on our part more satisfactory results could have been obtained.

Thickened Ends

Parallel shedding was observed up to $Re_t = 192$ (figure 3). Above this Reynolds number periods of apparently parallel shedding were interspersed with periods of vortex splitting (figure 4), similar to that observed by Eisenlohr and Eckelmann (1989).

Control Rods

Hammache and Gharib (1991) were able to control the vortex shedding from a circular cylinder by placing control rods upstream of the cylinder; positioning the rods downstream did not have the desired effect. We have confirmed their results in our facility using a 1.08 mm diameter circular cylinder and 5 mm diameter control rods. Optimum upstream centreline spacing between rod and cylinder was 4.5 mm, a gap between the cylinder and rod surfaces of 1.5 mm. Spacings of less, or more, than this value gave vortex axes curved concave, or convex, downstream respectively.

We have found the converse to be true for the flat plate used in our investigation. Parallel shedding was never observed when the rods were placed upstream of the plate, for any size of rod or any spacing between rod and plate. With the rods positioned downstream of the plate, on the other hand, parallel shedding was obtained from the mid-span region. It was found that the 1t diameter rod was too small to affect the oblique shedding process, while the 3t diameter rod produced such a wide wake that the spanwise extent of the parallel shedding region was greatly restricted. A rod diameter of 4mm (2t) appeared to give best results in our test facility.

The position of the rods relative to the plate trailing edge was found to be very important. If the rods were touching the plate parallel shedding could be obtained up to $Re_t \approx 160$. Above this Reynolds number the shed vortex was curved concave downstream. When the gap between the rod and the plate was 10 mm control over the shedding process was lost, and the pattern was similar to that obtained with no rods present. With the rod centreline spaced 5 mm (2.5t) from the plate trailing edge (a gap of 3mm or 1.5t) parallel shedding was obtained from the plate mid-span over the whole Reynolds number range (figure 5).

Hammache and Gharib (1991) believed that their control rods controlled the vortex shedding process by providing symmetric pressure boundary conditions at the main cylinder. They suggested that the reason why the rods had to be located at a specific distance from the main cylinder, was so that the pressure defect in the wake of the control rod at the main cylinder position was equal to the main cylinder base-pressure corresponding to two-dimensional vortex shedding. It is not easy to see how this explanation can be applied to the control effected by downstream control rods, although the upstream influence of the rods may still be responsible for producing a symmetrical base-pressure distribution. Further investigation of the effect is clearly required.

CONCLUSIONS

A modification of Hammache and Gharib's (1991) control rod method proved to be the most reliable way of producing two-dimensional parallel vortex shedding over the mid-span region of a thick flat plate, for the experimental conditions reported here.

ACKNOWLEDGMENTS

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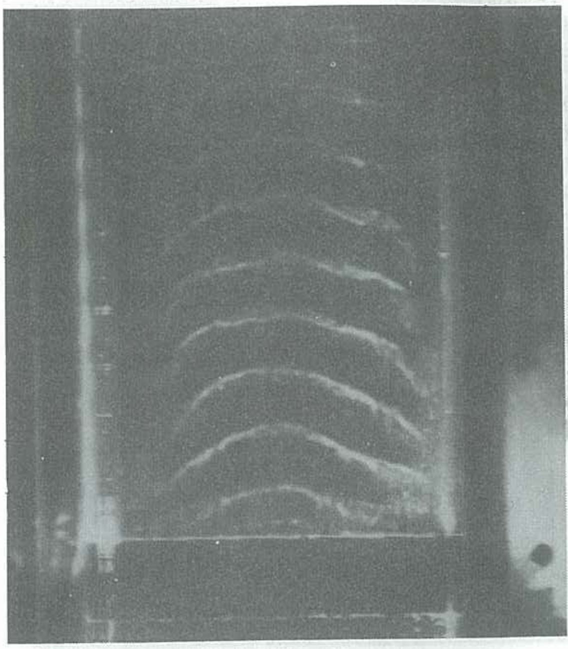

Figure 2. Vortex shedding from flat plate: $Re_t = 224$.

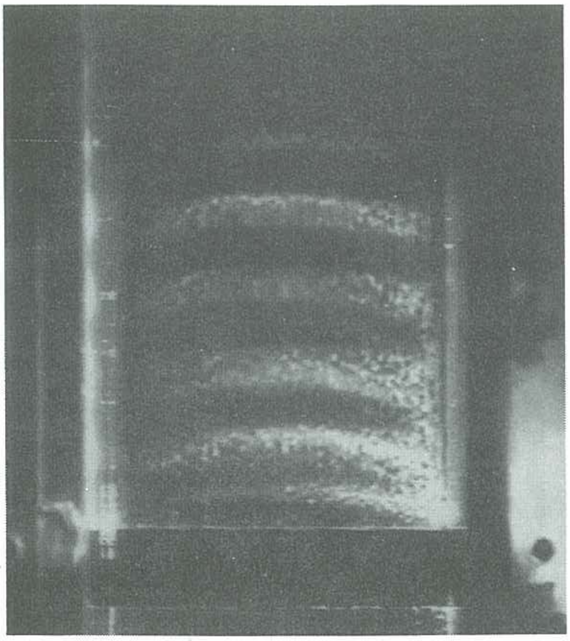

Figure 1. Vortex shedding from flat plate: $Re_t = 96$ (flow from bottom to top).

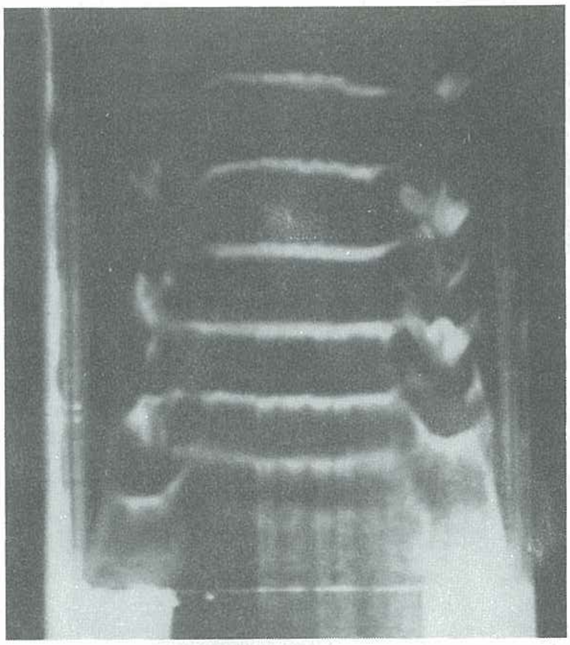

Figure 3. Vortex shedding from flat plate with thickened ends: $Re_t = 156$.

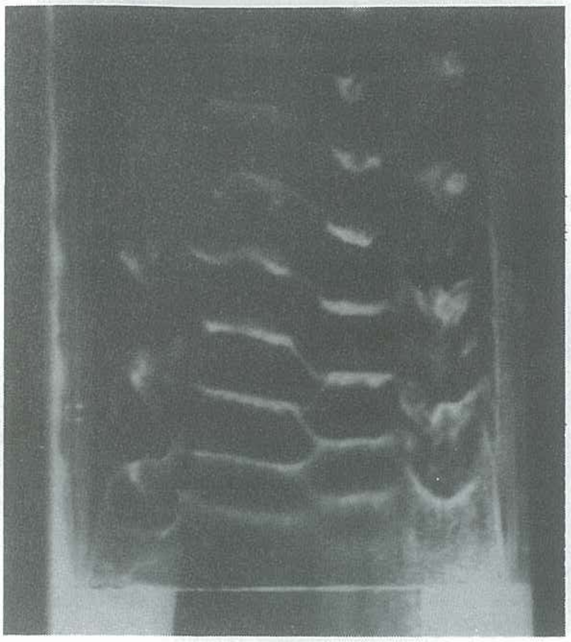

Figure 4. Vortex shedding from flat plate with thickened ends: Re_t = 192.

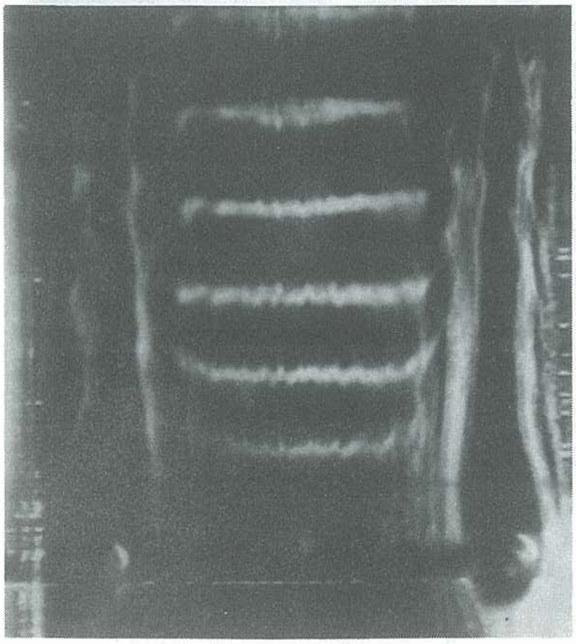

Figure 5. Vortex shedding from flat plate with downstream control rods: Re_t = 206.