INVESTIGATION INTO THE BEHAVIOUR OF LONG THIN CYLINDERS IN AXIAL FLOW WITH A FORCED OSCILLATION

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ABSTRACT

The motion of a very long flexible cylinder immersed in an axial viscous flow is at the centre of the present investigation. The effect of forced vibration on the boundary layer development of a long thin cylinder is studied by means of an experimental flow visualisation technique. Attention is focused on the observation of flow patterns developing around very long cylinders of various static shapes, which may be seen as simplified instantaneous shapes likely to be taken by a cable vibrating as a result of flow excitation. To simulate vibration, a rigid cylinder is immersed in an open water channel and oscillated about its mean axial position at different frequencies and amplitudes.

KEYWORDS: Sonar arrays, Flow visualisation, Long thin cylinder, Thick axisymmetric boundary layer.

1. INTRODUCTION

The use of sound navigation and ranging systems, known as sonars, is extensive. The applications range from detecting other vessels or objects in the ocean to mapping the ocean floor. A towed sonar array is composed of a linear arrangement of hydrophones placed at equal intervals inside a hollow cylinder filled with a fluid of similar density as the surrounding fluid to produce neutral buoyancy. The hollow cylinder is strengthened axially, is flexible and can be up to several kilometers long. The sonar array is towed underwater behind a ship or a submarine and more than one array can be towed at one time. The hydrophones that make up the sonar array are capable of detecting acoustic waves that are propagating underwater. When the hydrophone is exposed to an acoustic wave, the pressure variations are detected by the sensors and fed into a processing unit for an estimation of direction and distance.

The turbulent boundary layer that develops on the array generates wall pressure fluctuations that can be similar of magnitude as the far field sound. This results in a noise problem as the performance of the sonar array is directly related to the level of noise it generates as it travels through the ocean. The ability to detect sound waves and to determine their strength and origin with accuracy is therefore reduced. It is crucial to gain a better understanding of the noise creation mechanism for the towed sonar array in order to minimise the problems encountered.

The present investigation is concerned with the effect of vibration on the boundary layer development of a long cylinder in axial or near axial flow. A scaled model of a towed submerged cable is used to identify the flow behaviour of the cylinder using the hydrogen bubble technique. To simulate vibration a rigid cylinder is immersed in an open water channel and oscillated about its mean axial position. The upstream end of the cylinder is fixed but is allowed to pivot, the downstream end of the cylinder is attached to a device capable of oscillating the cylinder normal to the flow with known frequency and amplitude.

1.1 AIMS OF THE PROJECT INVESTIGATION

The aim of the research project is to determine the effect of cylinder vibration on the boundary layer development. In particular does large amplitude of vibration cause shedding of the boundary layer and the start of a new thin boundary layer on the cylinder.

1.1.1 Specific Aims

- The effect of vibration on the flow pattern at various streamwise positions and at various amplitudes and frequencies.
- The occurrence of vortex shedding from the cylinder.
- The effect of vibration on vortex shedding, in particular the relationship between the shedding frequency of vibrating cylinder to that of the shedding frequency of a yawed cylinder.

1.2 LITERATURE REVIEW

Research into the turbulent and laminar boundary layers that develop on a cylinder in axial flow has been documented over the last fifty years. Paidoussis [1] a pioneer in this field of study derived a differential equation, which governs the motion of a cylinder subjected to fluid flow. This equation however is only valid for cylinders with vibrations of small amplitude. His differential equation established the basis for future work.

Lueptow [2] reviewed the research on cylindrical boundary layers from the 1950's. The cylindrical boundary layer is axisymmetric and shows some similarities to the planar boundary layer. The cylindrical boundary layer however, is not as simple as its axisymmetric character implies. This is due to the additional length scale and its radius of transverse curvature. Integration of this additional length scale into a nondimensional parameter leads to several possibilities: a_+, δ / a, R_a, and ξ. The variation in the parameters is primarily a result of changing the radius of curvature or the freestream velocity. Lueptow faced some difficulties in the lack of experimental data for a non-dimensional parameter variation. This is accomplished by measuring the boundary layer characteristics at different axial locations given the same transverse curvature in order to vary a_+, δ / a or ξ independently from R_a. This has made the selection of an appropriate nondimensional parameter difficult. The transverse curvature ratio δ / a was chosen due to its clear geometric interpretation; however, detailed measurements of the boundary must be made.

Given a transverse curvature $\delta / a < O(1)$ the Reynolds stress, turbulence intensity and wall pressure are similar to planar wall-bounded flows. For a transverse curvature $\delta / a > O(1)$ experimental results are limited, however the available results provide some insight into the effect of transverse curvature on the turbulence field. Despite the similarities in turbulence measurements near the wall between a cylindrical boundary layer with other well-bounded flows, some differences have been identified.
In the case where the transverse curvature $\delta / a = O(4)$ the Reynolds stress decreases quickly away from the wall unlike the planar case. This is most likely the result of increased spreading of the flow field to larger and larger circumferences moving away from the cylinder, compared to a flat plate where there can be no spreading.

At moderate transverse curvature $\delta / a = O(8)$ the turbulence intensity near the wall has nearly the same maximum value and occurs at the same distance from the wall in both the streamwise and wall normal directions as in other wall bounded flows. These results suggest that the turbulence generation mechanism in a cylindrical boundary layer is related to the burst-sweep cycle. When the boundary layer is large compared with the cylinder radius $\delta / a = O(20)$, the cylindrical boundary layer is more like an axisymmetric wake than a boundary layer.

Luxton et al [3] investigated the transverse curvature effects in the thick turbulent boundary layer on a long thin cylinder in axisymmetric flow. A physical test flow model was implemented to gather experimental data for further analysis. The model consisted of a wind tunnel, 0.9 mm diameter cylindrical wire in tension aligned axially to the flow. The model was used to investigate the mean flow and turbulence parameters in axisymmetric turbulent boundary layer.

The experimental data presented sought to explain the very high turbulence levels found close to the cylinder wall at values of $140 \le R_a \le 785$ which should, according to stability theory, be bordering on laminar flow. The measurements were taken with a hot wire probe at locations in which δ / a is large ($26 \le \delta / a \le 42$), and $x/a = 5640$, this ensured a thick boundary layer that is unaffected by the test nose section (initial condition). It was found that for values of $x/a > 5000$ the boundary layer on the test cylinder is independed of the initial conditions. Using two different nose sections and comparing the velocity profiles at different values of x/a verified that the boundary layer was unaffected by the slender nose piece.

The measurements of longitudinal velocity fluctuation within the boundary layer produced traces that identified the presence of many strong negative-going spikes. From the results obtained they concluded, (without quantitative support), that in a boundary layer on a plane surface the presence of the surface inhibits the approach of large scale motions from the outer region into the wall region. It is unlikely that the cylinder can present any significant inhibition to the passage of a large structure. They postulated that the large structures sweeping past the cylinder remove the inner layer at frequent intervals and convect low speed fluid away from the wall. Each time the inner layer is swept away from the cylinder a new inner layer must be established. This is an extremely efficient means of maintaining the vorticity in the layer and is consistent with the observed very high turbulence intensities in the inner region of the boundary layer.

For cylinders slightly yawed to the main flow, the amount of literature discussing the effect of the angle of yaw is limited. When the cylinder is inclined to the flow a vortex wake forms for angles of yaw as little as few degrees [4], yet the Strouhal-Reynolds number relationship for yawed cylinders, which relates the shedding frequency to the flow velocity is still subject to discussion among researches. In his experiments ,Hanson [5] found that the angle of yaw had significant effects on the shedding frequency. It appears that the flow over cylinders with small angles of yaw is highly three-dimensional and is not well understood.

1.3 EXPERIMENTAL INVESTIGATION

Flow visualisation has contributed greatly to the development of modern fluid dynamics and has been utilised by pioneers such as Reynolds (1842-1912) and Prandtl (1857-1953). The work presented investigates flow patterns developing around a long thin cylinder in axial flow or near axial flow. In the experiments undertaken as part of this study, the hydrogen bubble technique was selected to visualise the flow. It is a simple, versatile and suitable technique for the study of boundary layers and wake flows.

1.3.1 Test Facility

The study of flow over cables is being carried out in a long water channel. A volumetric pump delivers fluid to a settling chamber where a pair of fine screens and a honeycomb smooth out the flow. The fluid is than driven through a contraction leading to the open working section of the channel 0.2m wide, 0.4m deep and 3m long. The channel walls and floor are made of Perspex allowing visualisation of the flow from almost any angle. The pump is capable of generating flows up to 0.3 m/s. The flow speed can be controlled manually by means of a ball valve. The images produced with the visualisation technique are recorded on a standard VHS tape for further detailed analysis.

1.3.2 The Hydrogen Bubble Technique

The hydrogen bubble technique is popular, simple and cost effective (no contamination from markers) method for flow visualisation. It is an ideal method for a closed circuit water tunnel experimental setup. The hydrogen bubbles generated do not contaminate the working fluid and hence there is no need to change it after each experiment. This method employs electrolysis to generate hydrogen bubbles in the water flow (i.e. hydrogen and oxygen bubbles by means of the electrolysis of an electrolytic solution). It is fortunate that normal tap water is a suitable electrolyte and good visual perceptions are possible.

Two electrodes are introduced into the working fluid and a DC voltage is applied between them. The cathode will produce hydrogen bubbles and the anode will produce oxygen bubbles. Due to the fact that there is more hydrogen bubbles produced than oxygen bubbles (oxygen gives half the output and bigger bubbles), hydrogen bubbles are the preferred marking method.

The generation of small hydrogen bubbles is achieved by the use of a thin wire used as a cathode. The wire is typically 25 to 50 microns in diameter, as it needs to be as small as possible to minimise the amount of disturbance in the flow caused by the electrode. The hydrogen bubble wire is generally made from platinum (Smits & Lim, 2000). Various other wire materials such as steel, stainless steel, aluminum and tungsten have all been used with varying degrees of effectiveness.

There are two different shapes of hydrogen bubble wire that generate the marking pattern; standard wire that produces material sheets and time lines, crinkled wire that produces streak lines. The hydrogen bubble wire is held between two insulated support prongs as illustrated in Figure 1. In this configuration, it can be easily positioned at the point of interest in the working fluid. As the fluid flows past the bubble wire the hydrogen bubbles are swept away by the hydrodynamic forces induced by the flow and a visible flow field is produced.

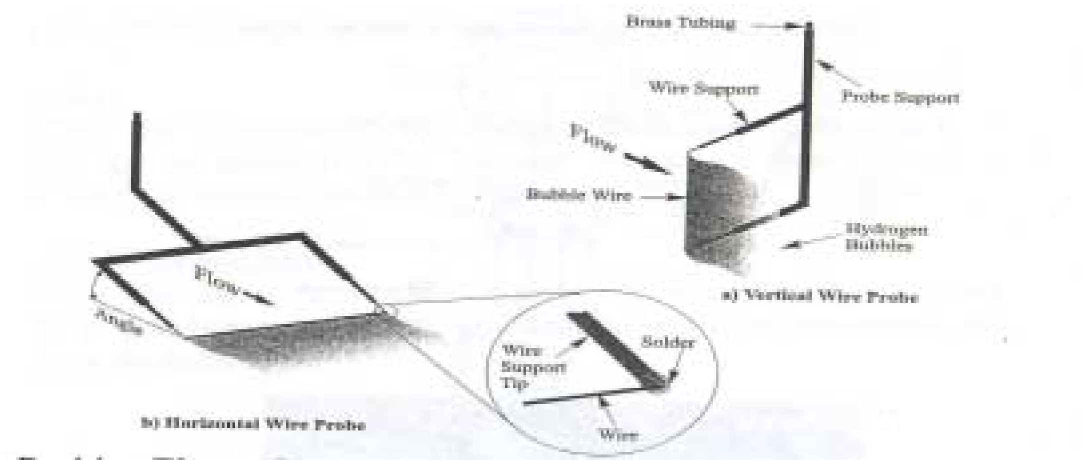

Figure 1. Hydrogen bubble wire probes.

1.4 CONCLUSION

The flow over a long cylinder with its axis parallel to the main stream results in the development of a very thick boundary layer compared to cylinder diameter. This result has been documented in several journals over the last fifty years. At this stage of the project the experimental data is recorded on a standard VHS tape and detailed analysis is required to give some insight into the flow behavior. The problem at this stage is the failure of the frame grabber, which is a tool for detailed analysis of this type of flow. Unfortunately the frame grabber only just been returned from being repaired and thus has not been available for use. A significant amount of recorded data is ready for detailed analysis and will be addressed in the final report.

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