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FLOW VISUALISATION OF VORTEX SHEDDING FROM SLENDER CYLINDERS IN NEAR-AXIAL FLOW

W.A. DEKKERS and M.K. BULL

Department of Mechanical Engineering
University of Adelaide
GPO Box 498, Adelaide, SA 5001, AUSTRALIA

ABSTRACT

The vortex wake of a long slender cylinder in near-axial flow has been visualised using hydrogen bubbles in a water flow. Experiments were conducted at Reynolds numbers Re_d of 300 and 600 based on the cylinder diameter. The cylinder used was a 3mm diameter nylon line. For small yaw angles β the cylinder length to diameter ratio was 1000. Shorter cylinders were used at larger yaw angles for accommodation within the water tunnel test section. The formation of a regular vortex wake has been observed for yaw angles as small as 2°. The effect of varying the yaw angle was observed for angles up to 30° to allow comparison with previous work. The formation of the vortex street is shown to be three dimensionaly complex, however once formed, the vortices roll up into an almost planar array similar to that formed by cylinders perpendicular to the flow. The inclination of the vortex axes within these arrays are described as a function of the cylinder yaw angle.

INTRODUCTION

The 'hydrogen bubble' technique of flow visualisation has been used to examine vortex shedding from slender cylinders in near-axial flow as part of a study of the thick axisymetric turbulent boundary layer generated on a long cylinder in axial flow, and the transition to a wake like flow at small angles of yaw. This visual study follows a quantative examination of these processes (Bull and Dekkers, 1989) using hot-wire anemometry to detect velocity variations in the cylinder wake associated with the convection of shed vortices, which determined that regular vortex shedding occurs over a limited Reynolds number range for yaw angles as small as 2 degrees.

For cylinders with their axes normal to the flow it is expected that, in the absence of end effects, the vortex axes will be parallel to the cylinder axis. Previous stuc yawed cylinders by Ramberg (1983) found that s parallel shedding will only occur from a yawed cylinder when the vortex shedding frequency 'locks in' to a natural vibratory mode of the cylinder, and that in the absence of vibration, that the vortex axes will be inclined to the cylinder axis.

Flow visualisation has been used to measure the vortex axis inclination and to examine the effects of cylinder yaw angle and Reynolds number in the near-axial flow regime. Measurements were also made at larger angles for comparison to Rambergs (1983) results for yaw angles greater than 30 degrees.

EXPERIMENTAL ARRANGEMENT

Experiments were conducted in the 175 by 350 mm by 3.6 m long rectangular test section of a return circuit water tunnel. The flow velocity in the test section can be varied from 0 to 0.26 m/s by throttling the flow through a gate valve. A uniform flow is achieved by a series of screens and a honeycomb section followed by a 4:1 contraction upstream of the test section.

The test cylinder used was a 3 mm diameter nylon line held in tension between two stainless steel rods (figure 1.). The cylinder is yawed in the vertical plane, with the upstream support approximately 1 mm above the water surface, and the down stream support submerged to give the desired yaw angle. The cylinder length was determined by the yaw angle and the depth of the test section. For yaw angles less than 5° a 3 m long cylinder was used, then a 1.8 m cylinder up to 10°, and a 0.6 metre cylinder for 20 and 30 degrees yaw.

The hydrogen bubbles were produced on a fine steel wire held vertically in the cylinders plane of yaw by an insulated stainless steel support. A stainless steel rod downstream of the experiment served as the anode, with the bubbles generated by a 100 volt DC power supply.

A vertical sheet of light was produced to illuminate the bubbles, and the flow patterns recorded on video.

RESULTS

The cylinder yaw angle β and vortex shedding angles α_i and α_f are defined in figure 2, where α_i is the angle between the cylinder axis and the initial vortex formation axis, and α_f is the angle from the cylinder axis to the axis of the rolled up vortex downstream. Flow patterns were recorded for a range of yaw angles between 1 and 30 degrees at Re_d = 300 and 600, and for a range of Reynolds numbers (200 - 600) at 5° yaw.

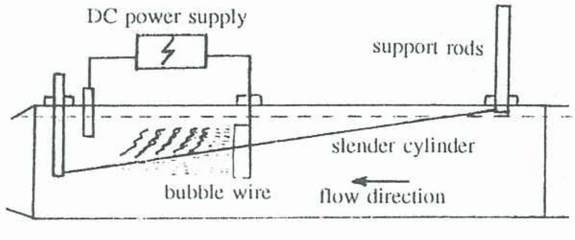


Figure 1. Experimental Arrangement.

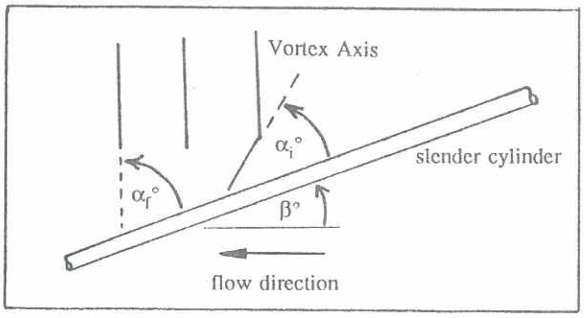
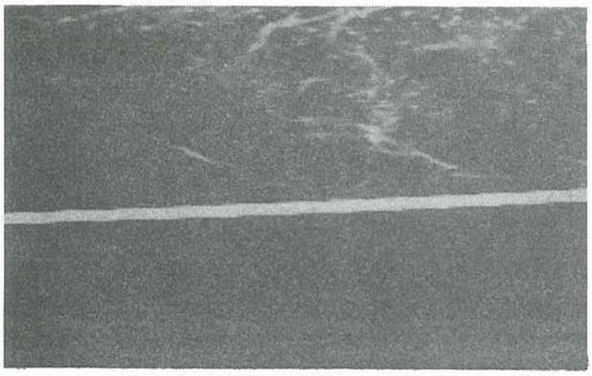


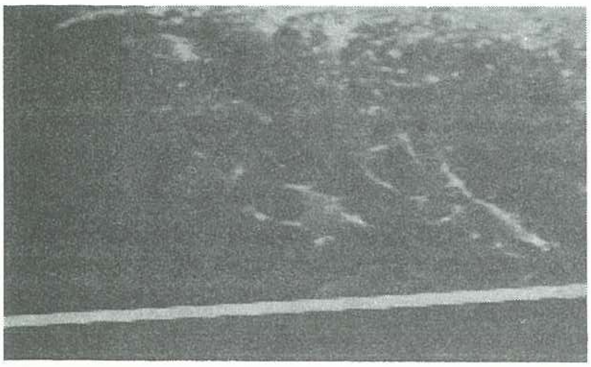
Figure 2. Cylinder Yaw Angle and Vortex Axis Angle.

The effect of increasing yaw angle at constant Reynolds number is shown in figure 3. for $Re_d = 300$. At large yaw angles the vortex forms and rolls up inclined to the cylinder axis without any apparent change in inclination during formation. At small yaw angles the inclination of the final rolled up vortex becomes larger than the initial inclination, this apparent change may be due to the three dimensional nature of the flow where the visible initial vortex is only part of a larger vortical structure.

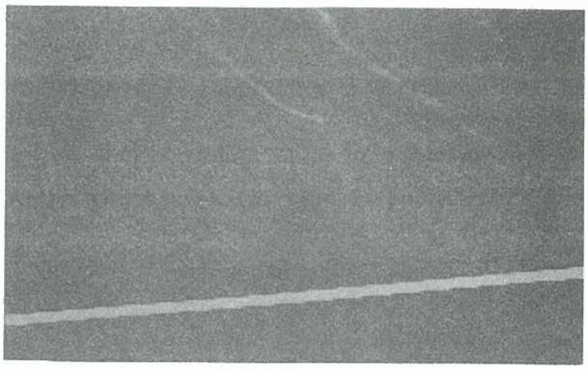
The effect of increasing Reynolds number is shown in figure 4. as a decrease in the vortex spacing resulting from the increased vortex shedding frequency. The trend lines drawn through the vortex inclination data of figure 5 show that the final vortex angle is consistently higher at larger Reynolds number. Figure 5 also shows that the difference between the apparent initial vortex shedding angle and the final rolled up vortex inclination decreases to zero as the cylinder yaw angle is increased.



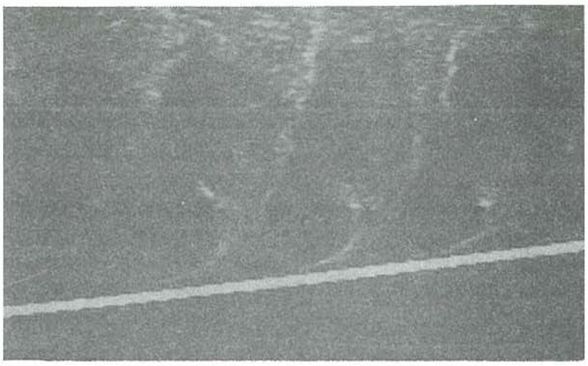
3a. $\beta = 2°$



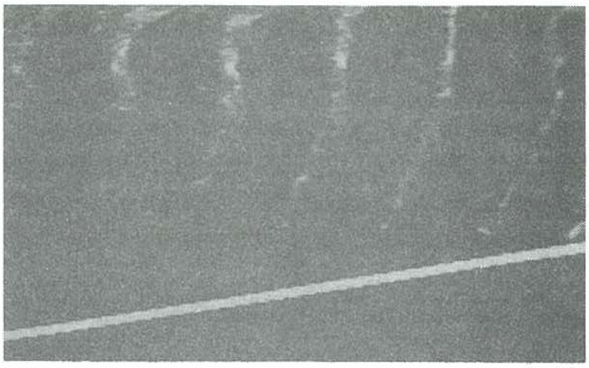
3b. $\beta = 3°$



3c. $\beta = 4°$



3d. $\beta = 6°$

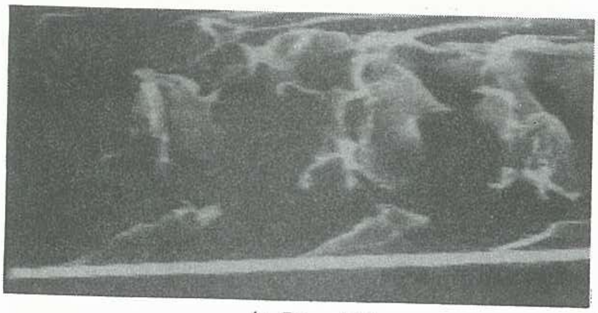


3e. $\beta = 8°$

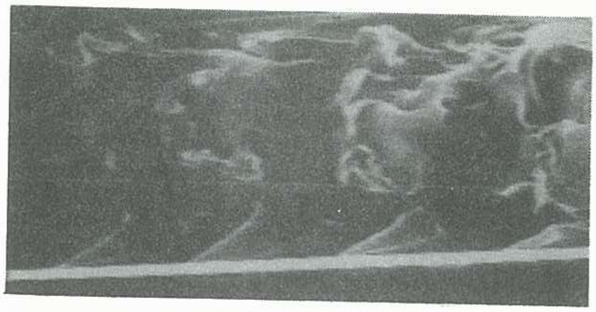
Figure 3. Vortex Formation at Constant Reynolds Number $Re_d = 300$ and Yaw Angles in the range 2° - 8°.

CONCLUSIONS AND DISCUSSION

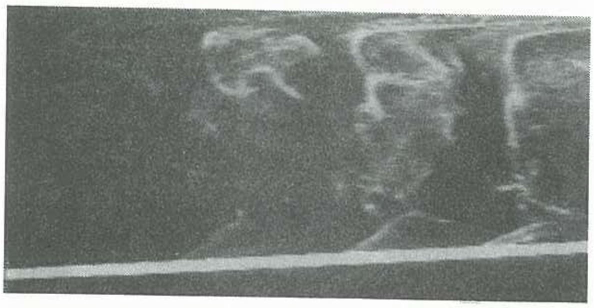
The trend lines shown in figure 5 show that the inclination of the vortex axes to the cylinder axis decreases rapidly as the cylinder yaw angle is increased up to 30°. The results of Ramberg (1983) for yaw angles of 30° and greater show the vortex axis inclined in the opposite direction to that shown in figure 6, however Rambergs analysis of the expected vortex inclination based on the vorticity components resulting from the cross and axial flow velocity components is in agreement with the visualisation results produced here.



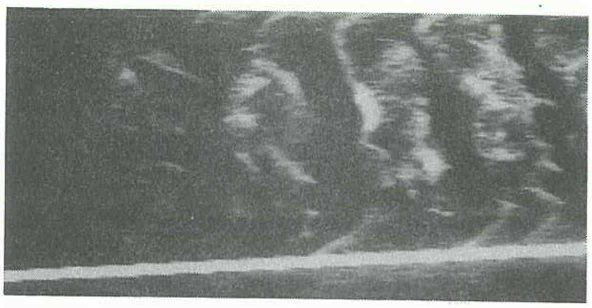
4a. $Re_d = 200$



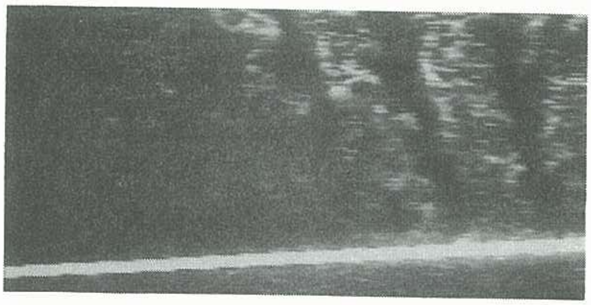
4b. $Re_d = 300$



4c. $Re_d = 400$



4d. $Re_d = 500$



4e. $Re_d = 600$

Figure 4. Vortex Formation at Constant [illegible] Reynolds Number $Re_d = 200 - 600$.

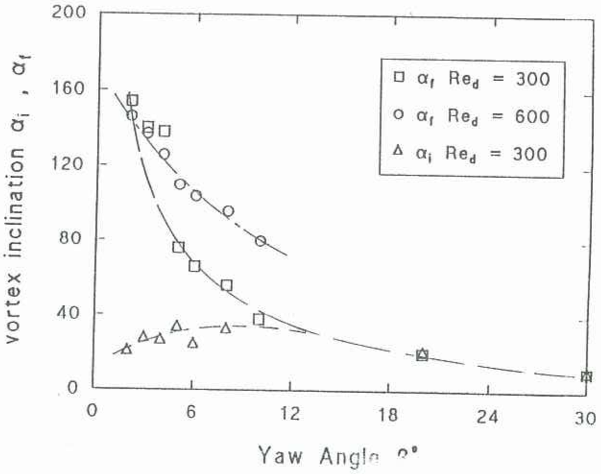
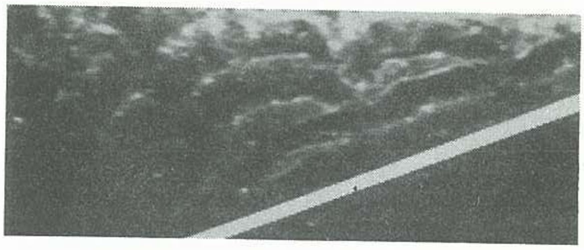
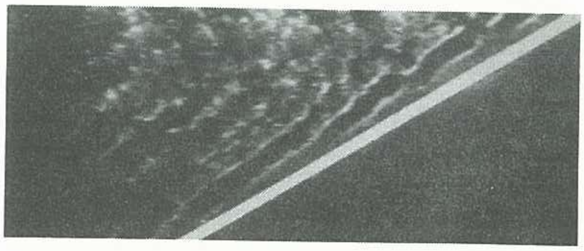


Figure 5. Variation of Vortex Axis Inclination with Cylinder Yaw Angle.

6a. $\beta = 10°$



6b. $\beta = 20°$



6c. $\beta = 30°$

Figure 6. Vortex Axes at Large Yaw Angles, $Re_d = 300$.

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RAMBERG,S.E (1983) The effect of yaw and finite length upon the vortex wakes of stationary and vibrating cylinders.Journal of Fluid Mechanics,128,81-107.