Flow around Circular Cylinder in a Pipe

A. Venugopal, Amit Agrawal and S.V. Prabhu
Department of Mechanical Engineering, Indian Institute of Technology Bombay, Powai, Mumbai 400076, India

Abstract Flow over a circular cylinder placed inside a circular pipe is studied experimentally to understand the influence of Reynolds number and blockage effects. In the present configuration the influence of confinement, aspect ratio, upstream turbulence, shear and end conditions all coexists together. The wake dynamics of such configuration is seldom reported in the literature.

Introduction

More than half a century of research has led to a significant understanding of the classical fluid mechanics problem of flow around a circular cylinder. A large body of work is however restricted to two dimensional bluff bodies in two dimensional upstream flow conditions and for low blockage ratios. In the past two decades, the complex three dimensional wake features of circular cylinder have been highlighted along with possible explanations, using tools such as Direct Numerical Simulation, particle image velocimetry, etc. The present study explores a less studied configuration: high blockage ratio flow around a circular cylinder, with the cylinder placed inside a circular pipe, and experiencing fully developed upstream flow condition. The complexity of the flow arises owing to the interaction of axisymmetric upstream flow profile with the two dimensional bluff body. The potential applications of such a configuration are in vortex flowmeter, heat exchanger, multi-hole pitot tube, combustion chamber, etc.

The study covers a wide range of Reynolds number (Re_D = 100 – 400000) and three different blockage ratio (0.14, 0.19 and 0.3). We therefore cover all the three regimes of pipe flow – laminar, transition and turbulent. The Reynolds number is based on pipe diameter and average pipe velocity. The qualitative three-dimensional insight into the vortex formation mechanism under laminar Reynolds number range is gained with conventional dye visualization technique. Turbulent flow visualization experiments are conducted with a shear-thickening and high extension viscosity fluid. The dye is most suitable for highly turbulent separated flows. The experiments are conducted in a circular pipe of inner diameter 105 *mm*. The static pressure distribution on the surface of the cylinder is measured with the help of 0.8 mm holes drilled on the surface of the cylinder. The spanwise static pressure variation is measured with eleven pressure taps at an interval of 5 *mm* along the span. The static pressures are measured with a 16 channel Scanivalve DSA 3217, with a range of 0-5000 *Pa* and an accuracy of ± 0.05% of the full scale. A single channel hotwire anemometer (TSI make) is used to capture the transient velocity fluctuations in the wake of the cylinder, and to quantify the vortex formation length, wake width and Strouhal number. Transient pressure measurements are performed with a fast response (5 *kHz* frequency response) pressure sensor to study the nature of the boundary layer on the surface of the cylinder and the trajectory of the convected vortices.

At very low Reynolds numbers (Re_D = 200), the rolling of shear layer is not observed. The onset of vortex shedding is observed at Re_D = 300. At Re_D = 400, three dimensional effects are visible as the vortices shed from the cylinders exhibit spiral motion. The videos are recorded in two orthogonal planes to capture this three dimensional effect. The streamwise and spanwise growth of the vortices is shown in a sequence of images (Figs. 1 and 2). These images highlight that the rolling of the vortices exhibits a spiral path. The vortex shedding is observed without any shear layer interaction, which is not inline with the classical theory [1]. At low Reynolds number, simultaneous rolling of vortices shed from the two sides of the cylinder is observed without any phase lag (symmetric vortex shedding), as shown in Fig. 3. The vortex shedding frequency does not scale with the wake width (see Figs. 4). The present study indicates that in spite of a larger wake width, the Strouhal number is higher in laminar flow as compared to turbulent flow condition. The shear layer instabilities appear around Re_D = 1100. At Re_D = 1800, the instabilities are predominant and regular primary vortex shedding disappears. The shear layer vortices from both sides of the cylinder are also observed in symmetric arrangement (no phase lag). The spanwise pressure measurements showed a delay in flow separation near the cylinder edge as compared to the cylinder centre; the delay is as high as 20° for 0.29 blockage ratio. The vortex formation length tends to reduce with an increase in the blockage ratio. However, a monotonous increase in the wake width is not observed with blockage ratio.

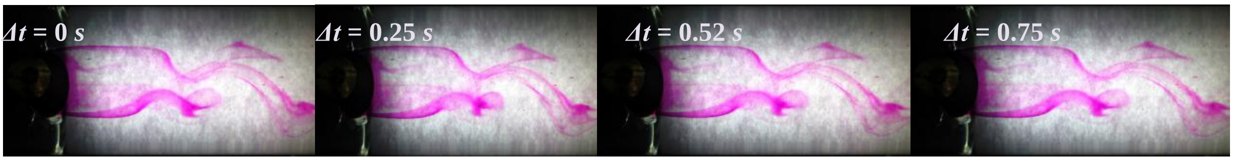

Figure 1: Sequence of images showing vortex growth at Re_D = 450

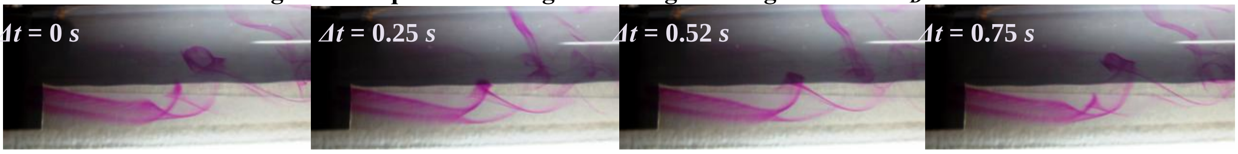

Figure 2: Sequence of images showing vortex growth along the span at Re_D = 450

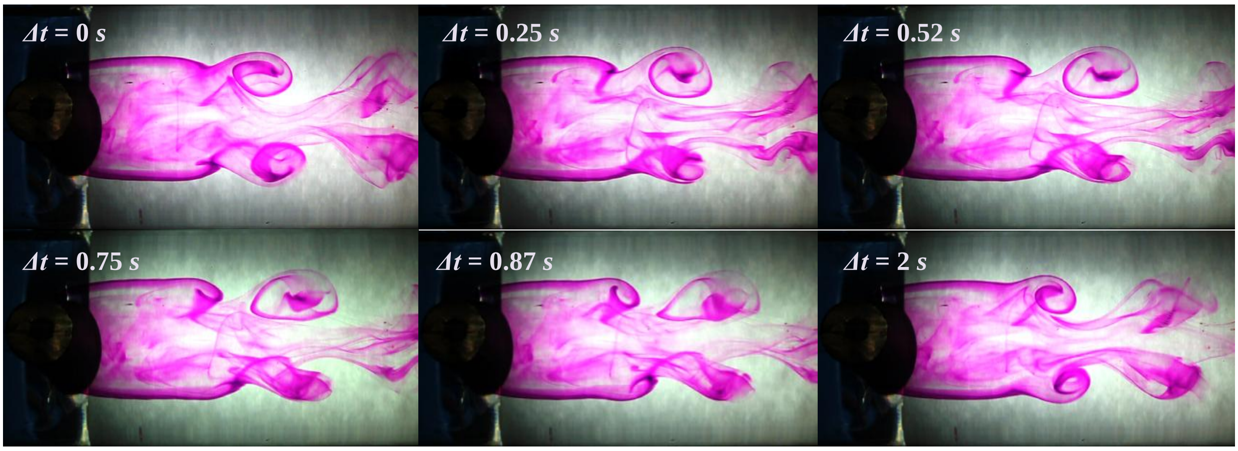

Figure 3: Sequence of images showing symmetric vortex shedding at Re_D = 650

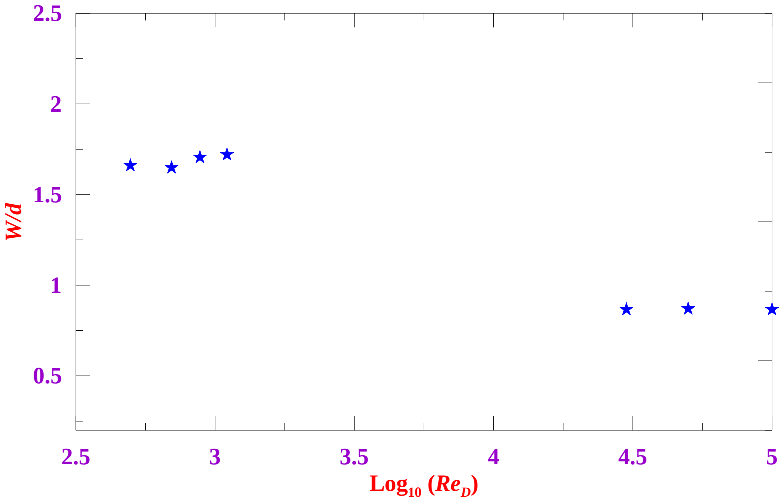

Figure 4: Wake width variation with Reynolds number for various blockage ratio 0.29

Acknowledgement

The authors are very grateful to acknowledge the funding supports from Department of Science and Technology, India for this research work.

References

[1] Gerrard, J. H., "The mechanics of the formation region of vortices behind bluff bodies." J. Fluid Mech., Vol. 25, part2, 1966, pp. 401 - 413.