Cylinder Wakes and Transitions: Bend, Stretch, Rock & Roll

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Abstract

The richness of the wake structures and transitions of bluff bodies is enhanced when geometries and relative flow motions different to the generic fixed circular cylinder are involved. In this paper, an overview of the results of bluff body studies at moderate Reynolds numbers in recent years obtained by the FLAIR and IRPHE groups is presented. These include the effect on wake structure and transition due to bluff body geometry changes and of rocking and rolling of circular cylinders. In particular, the two dimensional wake structures and the order of wake transitions to three-dimensionality are found to vary enormously.

Introduction

The generic nature of the circular cylinder for the two-dimensional view of bluff body wakes emerged through the Universal Strouhal Number (USN), whereby the two-dimensional wake structures of different short bluff body shapes could be collapsed with respect to the vortex shedding frequency [12]. The USN is based on the velocity, which is related to the base pressure, just outside the shear layer at separation rather than the free stream velocity. The USN was also related to the distance between the free shear layers as they roll up to form vortices. A large range of bluff body shapes was studied in experiments which confirmed the USN [5].

Since then, many studies have looked at the appearance in the wake of circular cylinders of three-dimensional instabilities. These include both experimental investigations (1, 3-4, 27-30) and computational predictions [e.g. 2, 6-7, 11, 24-25], which have been undertaken of the transition to first mode A (at approximately Re = 190) and then a further bifurcation to mode B (at Re = 230-240). Some differences in the transition Reynolds number occur, particularly for mode B, depending on whether the analysis is a linear analysis, or direct numerical simulations/experiments in which the base flow is modified due to the saturation of mode A. A quasi-periodic mode (QP) is predicted by linear stability analysis to occur at Re = 377; however, it is usually not observed due to significant modification of the base flow by the saturation of mode B at this stage.

The FLAIR and IRPHE groups have undertaken a significant number of studies of the effect of body shape and motion on wake transition [8-10, 13-23]. In this paper, we consider the effect on the two dimensional structures and the three dimensional wakes and transitions of stretching the cylinder (with an aerodynamic nose and a square trailing edge), of curvature through the bending of an infinite two dimensional cylinder into tori, of rocking or transversely oscillating the cylinder, and of rolling the cylinder along a wall (see Figure 1).

Results and Discussion

Two-Dimensional Wakes of Bluff Bodies

Figure 2 shows the standard Bénard-von Kármán wake for a fixed circular cylinder and sample wakes for other geometries and motions. The wake behind the elongated plate displays a structure similar to the fixed circular cylinder. The wake behind the torus and the rolling cylinder show pairing and a lateral motion of the vortex pairs. The wake behind the oscillating cylinder displays a double row wake in the P+S mode. Furthermore, different transitions occur when bluff bodies undergo oscillations of varying amplitudes A* (scaled on the cylinder diameter) at the Strouhal number 0.2 (see Figure 2).

Three-Dimensional Transitions

Predictions of the three-dimensional modes in the wakes of the different bluff bodies have been undertaken via Floquet analysis on the base two-dimensional flows and via full three-dimensional simulations.

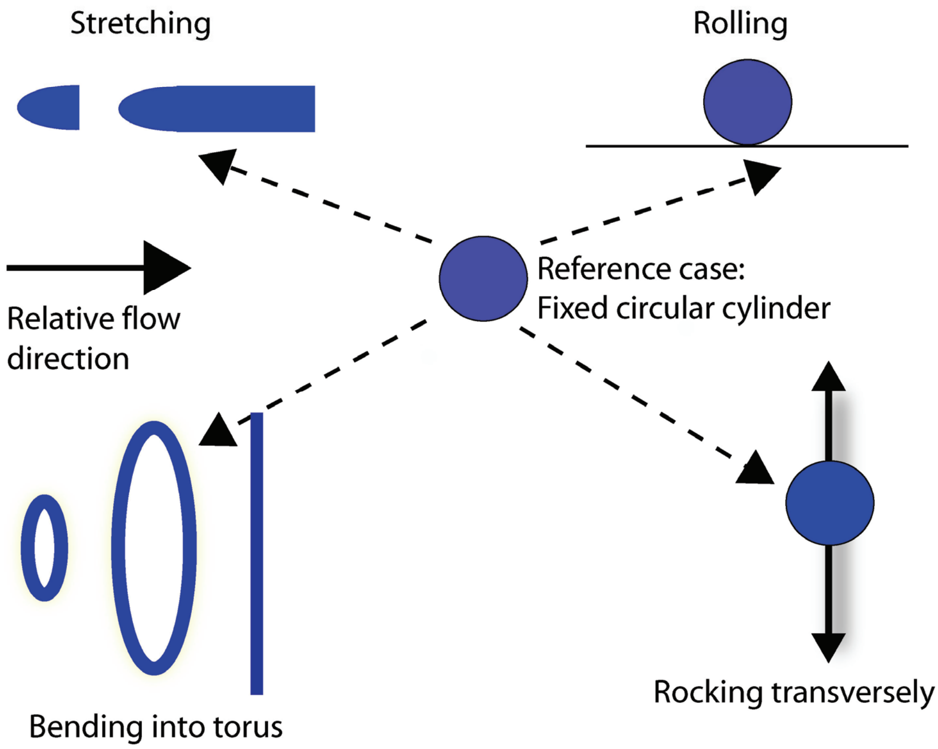

Figure 1. The different cases of geometry and motion change made to the reference case of a fixed circular cylinder in a uniform flow.

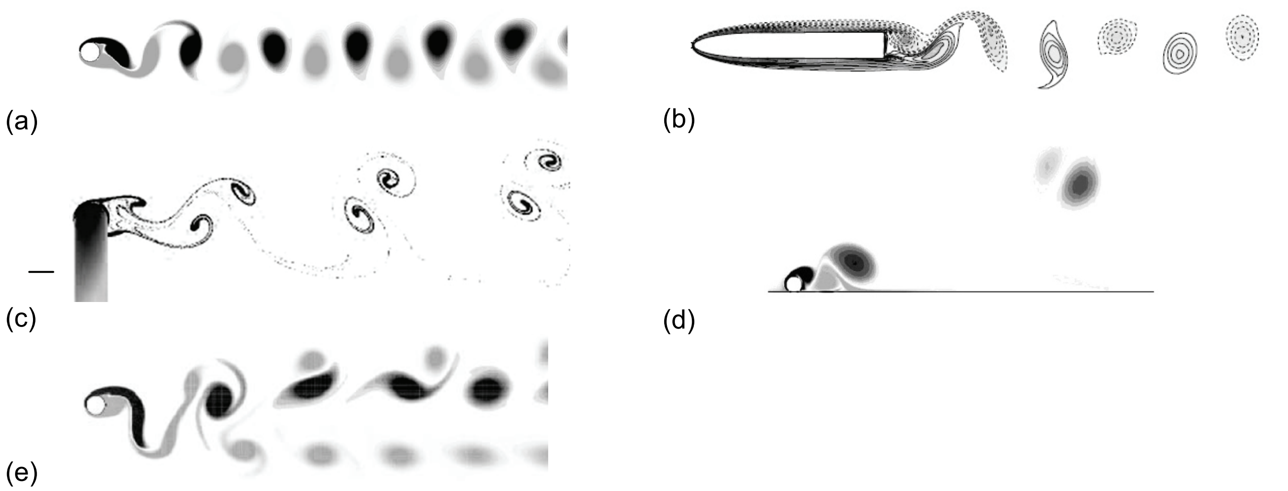

Figure 2. two dimensional wake cross-sections for (a) a fixed circular cylinder at Re = 200, (b) a elongated plate of aspect ratio AR = 7.5 and Re = 400, (c) torus of aspect ratio AR = 4.9 and Re =100, (d) a circular cylinder rolling along a wall at Re = 200, and (e) a circular cylinder oscillating transverse to the flow, St/St_{fixed} =0.95, Re = 200 and normalized amplitude A* = 0.7 (P+S mode).

In Figure 3, the different wake modes and Reynolds number at which they first appear are shown for the fixed circular cylinder, elongated plates (with aerodynamic leading and square trailing edges) for different aspect ratios (length to thickness), and tori for different aspect ratios (major to minor radii). Clearly seen is that in each case, there is a reversal of the appearance of the modes A, B and the quasiperiodic mode QP or mode C as the aspect ratio increases for the elongated plates and decreases for the tori.

Figure 3 also shows the case when the circular cylinder is oscillated transverse to the flow. There is a reversal of the modes A and B when the normalized amplitude A* has increased to 0.4. At A* = 0.7 and 0.8, two new subharmonic modes appear: a long wavelength mode SL and a short wavelength mode SS.

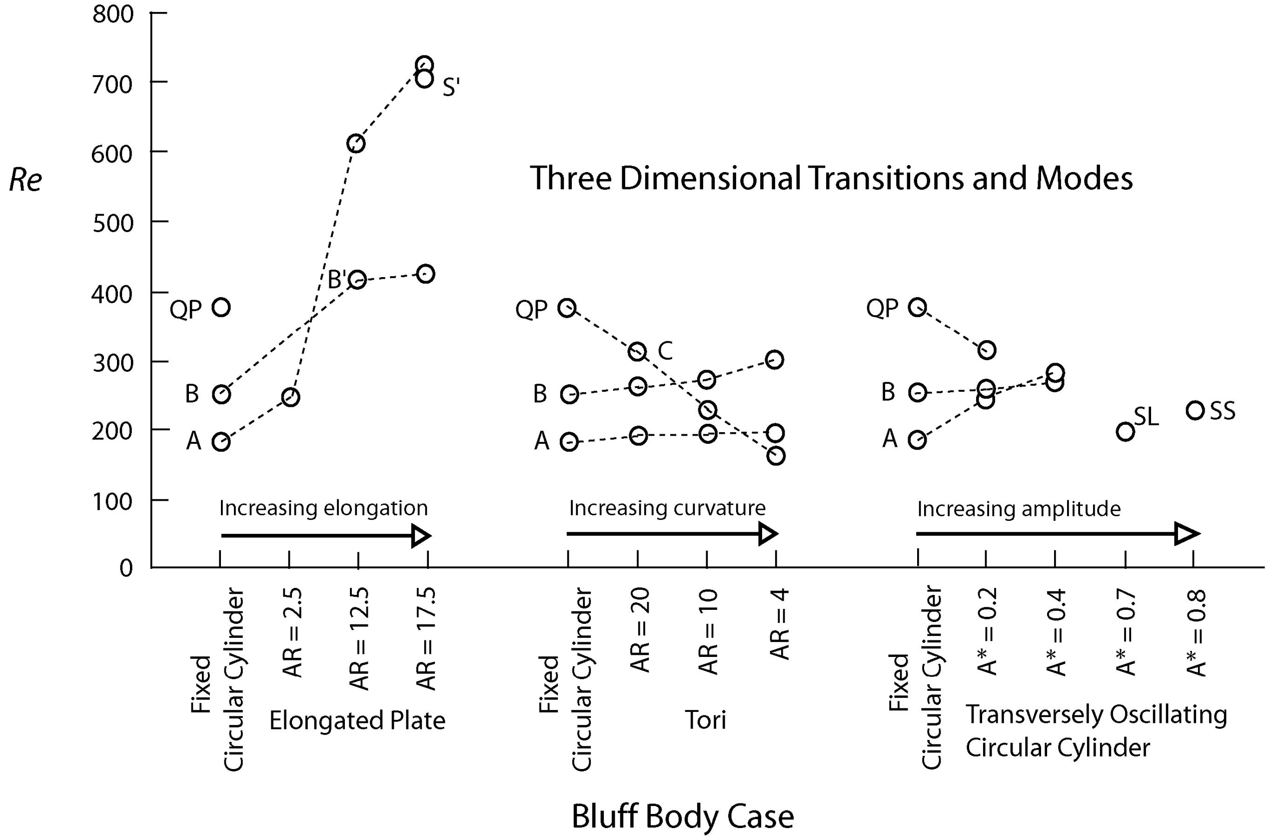

Figure 3. Sample of different types of modes and transitions for different types of bluff bodies and motions. Modes A, B, C are the same as for the circular cylinder, B' is similar to mode B but has much longer wavelength, mode QP is the Quasi Periodic mode, SL and SS are the long and short subharmonic S modes, respectively.

Other types of transitions and wake structures have been found as geometry and motion is varied. For example in the case of tethered cylinders, there are different branches of oscillation depending on the mass ratio of the cylinder [15]. Also, a range of sphere studies has been undertaken, such as sphere impact [26] and spinning spheres in swirling flows. In addition, stability analysis of wakes to determine the global frequency selection is being undertaken. An overview of the transitions and wake structures of these various bluff body studies will be presented at the conference.

Conclusions

The generic bluff body of a circular cylinder provides a useful reference point but is not necessarily representative of a wider variety of flows around circular cylinders that undergo topological change or different motions. A rich variety of wake structures and transitions to three-dimensions arises which may have implications for routes to turbulence.

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