Three dimensional instabilities in the wake of a confined circular cylinder

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ABSTRACT

This paper presents two- and three-dimensional direct numerical simulations of the flow around a circular cylinder placed symmetrically in a plane channel. Results are presented in the Reynolds number range (based on the cylinder diameter and centerline velocity) of 10 to 390, for a blockage ratio (ratio of the cylinder diameter to the channel height) of 0.2. The aim of this work was to investigate in detail the confinement effect due to the channel's walls on the generated flow regimes, the force coefficients and the associated Strouhal numbers.

Present results indicate that up to $Re = 180$ the flow remains 2-D. For higher values of the Reynolds number, $Re \geq 210$, the flow develops 3-D effects which are depicted on the time history of the lift, C_L, and drag, C_D, coefficients. Two discontinuous changes were detected in the St–Re curve corresponding to different spanwise instabilities in the wake. We have confirmed for the first time, that these two critical points are also reflected in the C_{pb}–Re relationship, in a similar fashion to the unconfined case [1]. Mode A 3-D vortex shedding was observed for $Re = 210 - 240$, and mode B instabilities were detected for $Re \geq 300$. The intermittent presence of naturally occurring vortex dislocations was also demonstrated. This is the first time that the existence of these instabilities, has been confirmed via full 3-D simulations for the confined circular cylinder in a channel.

The shape and evolution of mode A and mode B instabilities were found to be strongly affected by the confinement of the channel walls only further downstream. In the near wake region, both instabilities were clearly identifiable while further downstream the structure of the confined wake departed from that of a standard unconfined cylinder wake. In the case of mode A, at $5 < x/D < 17$, the hairpin structures of the braid shear layer can still be identified, but their motion and shape is significantly modified. These differences may be attributed to the inversion of the Von Karman vortices caused by wall interactions [2]. For $x/D > 17$, the confined wake was found to be much more fragmented, without a clear presence of primary vortex cores, which tend to persist further downstream in the unconfined case. Analysing this fragmentation, we demonstrate that it is caused by interactions between the streamwise vortex pairs and the channel walls. Induced velocity drives low velocity fluid towards the centreplane of the wake and high velocity fluid towards the channel walls generating pairs of "streaks" with low and high velocity fluid regions aligned in the streamwise direction. This pattern is systematic and all primary vortex cores were found to stretch and eventually break down in a similar manner, around the same spanwise positions. In the case of mode B the downstream evolution of the cylinder wake also seems to be strongly affected by confinement in a similar manner with mode A. For higher values of Re, the break down of the primary vortex cores ensues further upstream (up to $x/D = 12$ for $Re = 390$) and the flow becomes more fragmented.

REFERENCES

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