Numerical and experimental study of the time dependent states and the slow dynamics in a von Kármán swirling flow

E. Crespo del Arco, a E. Serre, b J. J. Sánchez-Álvarez, c A. de la Torre, d and J. Burguete d

a UNED, P.O. Box 60.141, E-28080 Madrid Spain.
b UMR 6181 IMT Chateau-Gombert, 13451 Marseille, France.
c E.T.S.I. Aeronauticos Universidad Politecnica de Madrid, 28040 Madrid, Spain.
d Universidad de Navarra, P.O.Box 177, E-31080 Pamplona, Spain.

Abstract

The flow in a cylindrical container with two exactly counter rotating disks and a stationary sidewall is a particular case of the von Kármán swirling flows. At low values of the Reynolds number, Re, the flow is axisymmetric and the succeeding transitions leading to steady states with different symmetry properties have been investigated in recent research works. In a cylindrical cavity with its height equal to the diameter the axisymmetric flow is first unstable to an antisymmetrical instability with azimuthal wavenumber \( m = 1 \) which adds to the initially axisymmetric \( m = 0 \) flow. At increasing values of Re the flow is unstable to \( m = 2 \) perturbations and then the azimuthal modes \( m = 0, 1 \) and \( 2 \) contribute to the flow solution. The onset of the \( m = 1 \) mode is related with one cat’s eye pattern which can be observed in the \((r, z)\) velocity field, near the equatorial plane and the \( m = 2 \) with two cat’s eyes.

The results of the time dependent regimes described and studied in the literature are more puzzling. We present the results of direct numerical simulations of the flow showing that the time dependent oscillatory regime is related with pulsations of the cat’s eyes which remain in the same position and, at increasing Re, oscillate around the mean position. The results of an experimental study of a turbulent von Kármán flow show a time dependent regime with equatorial vortices moving with a precession movement. In the exact counterrotating case, a bistable regime appears and spontaneous reversals of the azimuthal velocity are registered. A three-well potential model with additive noise reproduces this dynamic. A regime of periodic response is observed when a very weak forcing is applied. The equatorial vortices observed in experiments and the cat’s eyes of the DNS simulations have in common the time frequency, which is related with the rotation frequency.

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