Onset of Three-dimensional Flow Structures in Rotating Flows

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Many flows generated by rotation or natural convection in axisymmetric enclosures break into non-axisymmetric patterns above a certain threshold of the governing parameters. Such symmetry-breaking instabilities are of interest in stability analysis and in various applications of flow machinery, such as bio-reactors or combustion chambers. In the present work we study the evolution of three-dimensional structures in a lid-driven cylindrical cavity, which constitutes a generic case for studying instabilities and onset to turbulence in rotating flows.

Rotating lid-cylinder systems have been extensively studied both numerically and experimentally, in particular in connection with vortex breakdown (e.g. [1] and [2]). A change of the flow structure in a closed cylindrical container depends on two parameters: Aspect ratio h (ratio of the container height to the disk radius *H/R*) and Reynolds number Re = $\Omega R^2/\nu$, where Ω is the disk angular velocity and ν is the kinematic viscosity of the working fluid).

In the present study onset of three-dimensional flow behavior is measured by combining the high spatial resolution of Particle Image Velocimetry (PIV) and the temporal accuracy of Laser Doppler Anemometry (LDA) (see Fig. 1).

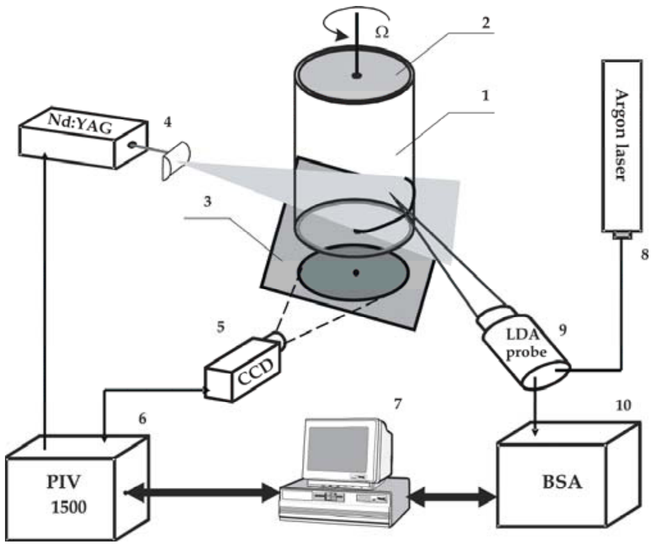

Fig. 1: Schematic diagram of the experimental set-up and the instrumentation.

A detailed mapping of the transition scenario from steady and axisymmetric flow to unsteady and non-axisymmetric flow has been investigated for aspect ratios up to 5.5. The flow is characterized by the generation of azimuthal modes of different wave numbers. In an earlier study [3] a range of different modes was detected and critical Reynolds numbers and associated frequencies were identified and compared to the numerical stability analysis of Gelfgat et al. [4]. In the range 3.3 < h < 3.5 the experiment revealed the existence of a stable triplet. As a continuation of this study we have performed a series of experiments at higher aspect ratios, up to 5.5, showing that the onset of unsteady flow generally is associated with the existence of stable three-dimensional flow structures, such as duplets, triplets, quadruplets, etc. We here present the results from a systematic study of the onset of three-dimensional flow structures (see Fig.2) and propose a new analytical framework to explain the existence of stable three-dimensional flow structures [5].

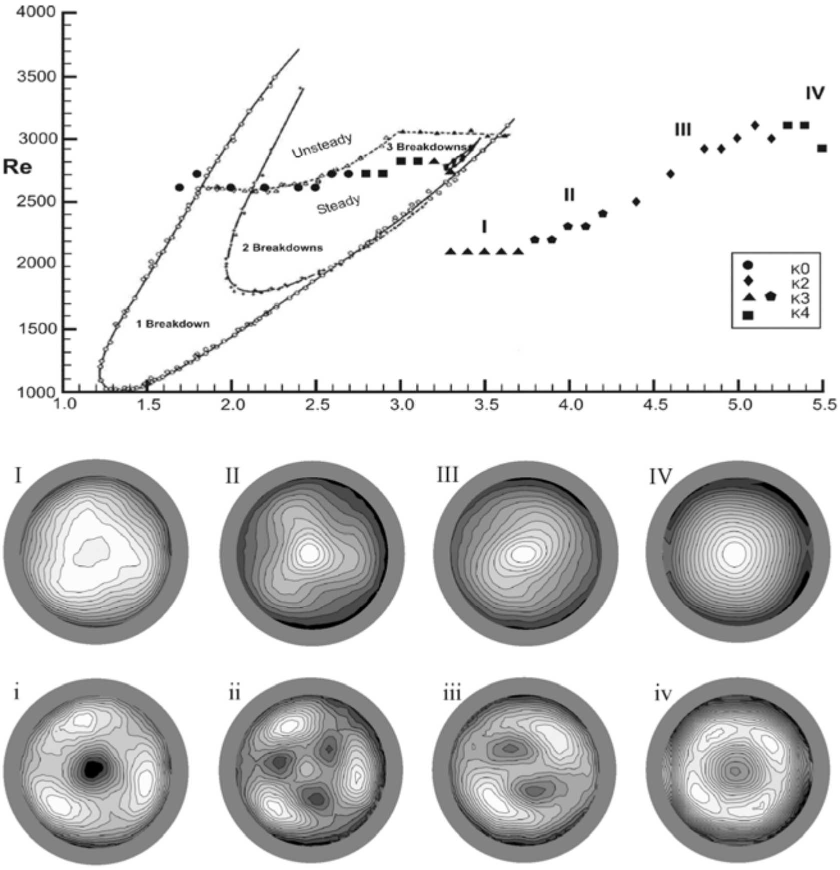

Fig. 2: Stability boundaries between oscillatory and steady flows in the (Re, H/R)-plane and the original diagram of Escudier [1] plus examples of the typical flow patterns of the second stability branch: I-IV – Original (PIV-measurements of vorticity fields in a horizontal cross-section at (Re = 2200; H/R = 3.35), (Re = 2400; H/R = 4.2), (Re = 2600; H/R = 4.4), and (Re = 3100; H/R = 5.5); i-iv – vortex triplet, double triplet, double duplet and quadruplet derived by subtracting indicated a Gaussian vorticity distribution from the original PIV measurements.

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