Taylor-Couette flow with asymmetric end-walls boundary conditions

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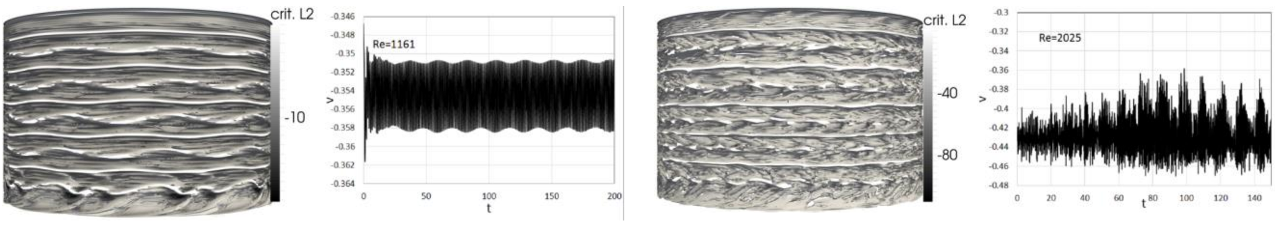
Abstract In the paper the authors present the results obtained during a numerical (Direct Numerical Simulation/Spectral Vanishing Viscosity method - DNS/SVV) and experimental investigations (Kalliroscope, PIV) of the Taylor-Couette flow with asymmetric boundary conditions. In the paper attention is focused on the laminar-turbulent transition process. The main purpose of the research is to investigate the influence of different parameters (aspect ratio, curvature parameter, end-walls boundary conditions) on the flow structure and on the flow characteristics. The transverse current J^{ω} is computed from the velocity field obtained numerically. The λ_2 criterion has been used for numerical visualization.

Introduction

In the paper the authors present numerical results (Direct Numerical Simulation/Spectral Vanishing Viscosity method, DNS/SVV) of the flow in rotating cavity of aspect ratios from the range $\Gamma = H/(R_2-R_1) = 11.76-1.04$ (Taylor-Couette flows). The authors research in a rotating cavity the influence of different end-walls (symmetric and asymmetric) boundary conditions, aspect ratio Γ and curvature parameter $Rm=(R_2+R_1)/(R_2-R_1)$ on the Taylor-Couette flow structure (where R_1 and R_2 denote radii of the inner and outer cylinder, respectively; the inter-disks spacing is denoted by H). In the study the consecutive bifurcations have been observed with an increasing Reynolds number $Re=(R_2-R_1)R_1\Omega/\nu$. The results are discussed in the light of experimental data obtained using Kalliroscope and PIV methods. The main purpose of the investigations of the phenomena which occur in Taylor-Couette flow is to answer the fundamental question concerning transitional structures, their origins and their role in creating stresses, [1]. This knowledge can help to control the boundary layer flow in more complex industrial configurations. The results presented in the paper are the authors first step towards such formulated scientific purpose. The Taylor-Couette flows are very important from fundamental point of view but they also appear in numerous machines (in ventilation systems, in cooling systems of gas turbines and axial compressors), and in geophysics and astrophysics.
The computations were performed in the Poznan Supercomputing and Networking Center. Experimental investigations were conducted in the Department of Aerodynamics and Fluid Mechanics BTU in Cottbus in the frame of EuHIT project. All presented numerical results are obtained with the use of DNS/SVV method with meshes of 2-30 million collocation points. The time scheme is second-order semi-implicit, which combines an implicit treatment of the diffusive term and an explicit Adams-Bashforth scheme for the non-linear convective terms, [2]. The spatial scheme is based on a pseudo-spectral Chebyshev-Fourier-Galerkin collocation approximation. The predictor/corrector method is used. All dependent variables have been obtained by solving the Helmholtz equation. In the DNS/SVV method an artificial viscous operator is added to the Laplace operator to stabilize the computational process for higher Reynolds numbers, [3].
The flow structure has been investigated experimentally using Kalliroscope method in a radial-vertical illuminated laser sheet, which was generated by a Nd:Yag laser. The flow has been visualized by adding a Kalliroscope AQ-1000 rheoscopic concentrate to water. The flow structure has been recorded by a digital Sony HD video camera. The stereo PIV method (2D3C PIV) has been also used which allowed the authors to measure three velocity components in an azimuthal plane, [3].

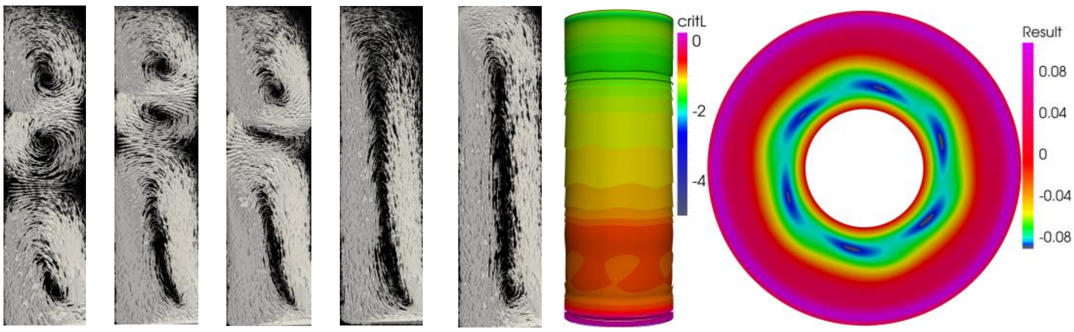
Results

In the paper three groups of flow cases are discussed. The first one with high aspect ratio $\Gamma=11.75$ and curvature parameter Rm=19 has been investigated only numerically for Reynolds numbers up to $Re=(R_2-R_1)R_1\Omega/\nu=2100$ and for symmetric and asymmetric end-walls boundary conditions. The obtained results provided material on the impact of end-walls boundary conditions on the consecutive states: Taylor-Couette vortices -TVF, wave vortices - WTVF, modulated vortices – MTVF, turbulent Taylor-Couette flow TTVF (the exemplary flow structures together with instability characteristics obtained for asymmetric end-walls boundary conditions are presented in Figure 1). The authors provide the radial profiles of the mean angular velocity, the mean angular momentum, radial profiles of contributions to the total current. The second flow case with aspect ratio Γ=3.76, curvature parameter Rm=2.2 has been investigated experimentally and numerically; the results are discussed in the light of Mullin and Blohm's [4] data. The processes of creating and collapsing the three-cells structure (Γ=3.76, Rm=2.2) are presented in Figure 2. To show the influence of curvature parameter on these processes the flow cases Γ=4.0, Rm=4.0 and Γ=4.0, 4.2 have also been investigated. The third flow case of aspect ratio Γ=1.04, Rm=2.2 has been also investigated experimentally and numerically (the flow in cavity of Γ=1.47, Rm=2.2 has been investigated for comparison). In the flow cases Γ=1.04 and Γ=1.47 the analysis is focused mostly on the Ekman boundary layer. The exemplary meridian flows obtained for Γ=1.04 numerically and experimentally using Kalliroscope method are presented in Figure 3.



a) b)

Figure 1. The flow structure and instability characteristics obtained for asymmetric end-walls boundary conditions, a) Re=1161, b) 2025, Γ=11.75, Rm=19, the inner cylinder and the bottom disk rotate.



a) b) c) d) e)

Figure 2. The meridian flow, a) Re=108, b) 200, c) 269.5, d) 281.5, e) 562.5 – transition to unsteadiness, azimuthal section of the rotor boundary layer , z=-0.8149, Γ=1.04, Rm=2.2, the inner cylinder (on the left) and the bottom disk rotate.

a) b) c) d) e)

Figure 3. The meridian flow, a) Re=3925, λ_2 criterion, b) Re=3925, Kalliroscope, c) Re=4579, λ_2 criterion, d) 4579, Kalliroscope, e) Re=7031, λ_2 criterion, Γ=1.04, Rm=2.2, the inner cylinder (on the left) and the bottom disk rotate.

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