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TAYLOR-VORTEX FLOW CONTROL USING RADIALLY OSCILLATING INNER CYLINDER

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Abstract. *The hydrodynamic stability of a viscous fluid flow in an annular space between a rotating inner cylinder having a sinusoidally variable radius and an outer fixed cylinder is considered. The basic flow is axis-symmetric with two counter-rotating vortices each wavelength. A finite-volume CFD code is used to simulate the flow behavior. The flow control strategy aims to localize the transition and to assess the flow response to the imposed boundary motion.*

1 INTRODUCTION

Since the seminal paper of Taylor [1], a large number of experimental and theoretical studies devoted to the onset of Taylor Vortex Flow (TVF) are developed. Due to its cellular nature, the Taylor–Couette Flow (TCF) is claimed to be one of the rare flow types combining *intense* local mixing with a limited axial dispersion, Baron [2]. It allows the enhancement of heat and mass transfer at the cylinder walls, and several possible applications of the unique reactor performance have been proposed covering the fields of catalytic and biocatalytic, counter-current extraction, tangential filtration, crystallization, and electrochemical, photochemical and polymerization reactions, Muzishina [3].

In this study, we consider a flow control strategy capable of spatially localizing the Taylor vortices between two concentric rotating cylinders. To this end, we proceed by actuating the geometry of the TCF to affect vortices appearing in the radial direction along the length of the apparatus. Particularly, we are interested in investigating the impact of a pulsatile radial motion of the inner rotating cylinder on the TVF in an infinite length cavity. It is found that a destabilization of the TVF results from the interplay of the imposed oscillating radial flow and the flow resulting from the Taylor instability.

2 NUMERICAL APPROACH

We briefly describe the numerical procedure used to solve the problem. The grid is generated using the GAMBIT program and saved on a structured quadrilateral grid as shown in Fig. 1. The mesh is uniformly distributed in the axial direction and linearly condensing in the radial direction. The solution is carried out using the computational fluid dynamics package FLUENT. An implicit scheme is used to discretize time, and a third-order MUSCL scheme is used to discretize the convective terms in the momentum equations. Pressure implicit with splitting of operators is used as the pressure–velocity coupling scheme. The time integration of the unsteady momentum equations is performed with a second-order approximation. The time step is fixed equal to Δt=0.002. Modulation of the inner cylinder diameter is carried out using the “moving mesh” FLUENT program. The maximum number of iterations each time step is 1,000.

2.1 Validation and comparison with experiment

The Taylor–Couette device is in its classical configuration; a stationary outer cylinder and a rotating inner cylinder. The flow structure for Tc_1=41.33, corresponding to the first instability appearance is given in the Fig. 2. This numerical result is in good agreement with the experimental value of Tc_1=41.2 reported by Bouabdallah et al. [4]. To characterize the effect of the inner cylinder diameter variation, an influencing parameter ε is defined as: $\varepsilon=(R_2-R_1)/R_1=\Delta r/R_1$, where R_1 and R_2 are respectively the maximum and minimum radii of the inner cylinder. The natural state corresponds to ε=0%.

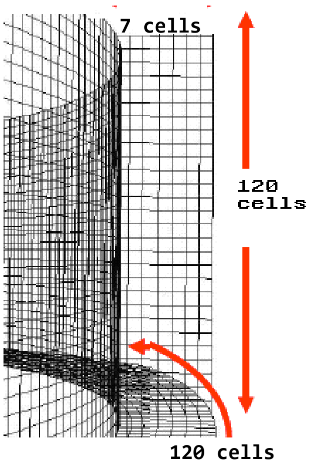

Fig.1: 3-D grid with 2×10^{3} quadrilateral cells.

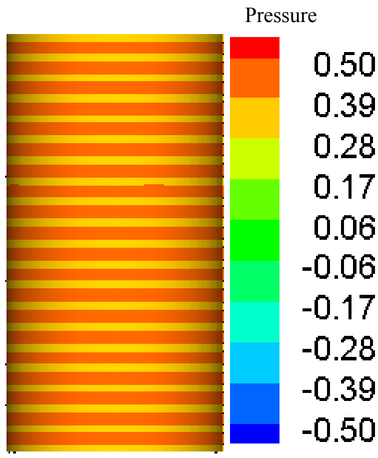

Fig.2: Present results for the first critical Taylor number Tc_1

3 IMPORTANT FEATURES

The variation of the first critical Taylor number with the amplitude of deformation is seen in Fig. 3. It is noticed that when ε exceeds 0.1% the critical Taylor number decreases rapidly from Tc_1= 41.33 to Tc_1=17.66 for ε=5%, corresponding to a reduction rate of 57%. The Fig. 4 depicts the evolution of the axial vorticity as the deforming amplitude increases from 0 to 5%. The boundary layer is clearly discernable in the natural case—no actuation applied. The boundary layers on the inner and outer cylinders are surrounding two rows of structures evolving anti-symmetrically in the cylinders' gap with a phase shift of π, as shown in Fig. 4a. When the inner cylinder diameter oscillates, the boundary layer on the outer (stationary) cylinder vanishes completely even for the smallest value of the deforming amplitude considered in the present study, ε=0.1%. This behavior is observed for the entire range of the applied deforming amplitudes from 0.1 to 5%. The boundary layer on the inner cylinder, however, shrinks significantly for the small deforming amplitude and resist the applied perturbation until ε=2%, as shown in Fig. 4c. Over this threshold value, the inner boundary layer completely disappears for all the higher values of the deforming amplitude and the two structure rows are pushed outwardly. The vortices are of larger scale, axially elongated and connected. Axial and radial symmetries are both altered, as shown in Figs. 4c and 4d. The threshold value ε=2% quite surprisingly coincides with the local maximum value of axial vorticity depicted in Fig. 5. Over the value ε=2%, the axial vorticity decreases drastically to reach its lowest value, about 60% lower than that of the natural basic flow, Figs. 4a and 4d. Similar of response to the radial perturbation is observed for the radial vorticity as shown in Fig. 5. The maximum radial vorticity significantly diminishes, up to 75% compared to the basic flow value, indicating even higher sensitivity to the radial oscillation. The decrease in the maximum radial vorticity is accompanied by an enhancement of the flow re-organization. The Taylor–Couette structures become axially closer to each other and radially squeezed in a more organized pattern, as depicted in Fig. 4 d.

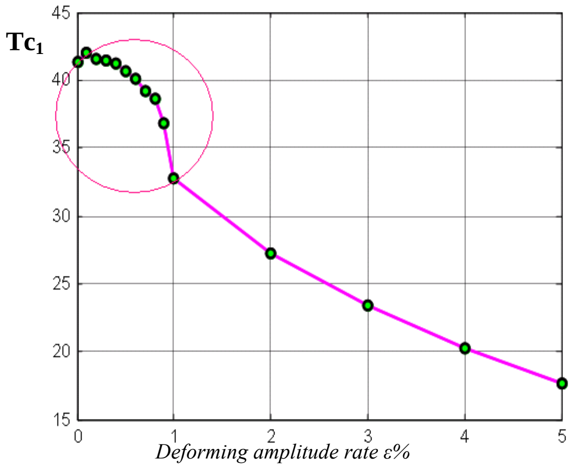

Fig.3 Critical Taylor number Tc_1 versus deforming amplitude ε%

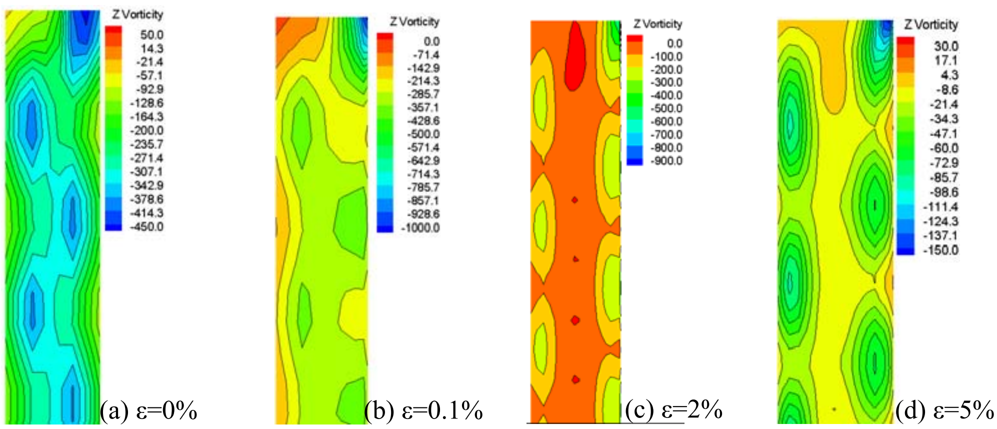

Fig.4: Axial vorticity for the Taylor Couette flow versus the deforming amplitude ε%

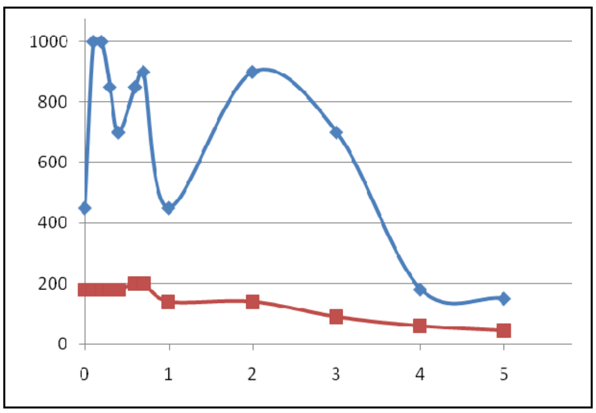

Fig.5 Maximum vorticity versus deforming amplitude ε%

4 CONCLUSIONS

We characterized a novel behavior of the Taylor Vortex Flow by radially deforming the inner rotating cylinder in a Taylor–Couette apparatus. As a result of the oscillations, axial and radial symmetries are broken, significant reduction in the maximum vorticity values is achieved, and substantial enhancement of the transition from the Taylor-Couette basic flow to the Taylor-Couette vertical flow is observed. The skin friction response is in current investigation to be presented in future works.

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