INSTABILITIES IN A TAYLOR-DEAN OPEN FLOW

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Summary The flow studied hereafter is produced in a system of two coaxial circular cylinders azimuthally opened. It is a combination of the inner cylinder rotation and a flow provided in the gap by external pumping. Our observations, however, indicate that the flow possesses certain distinctive features not present in the pure rotation of closed cylinders (Taylor-Couette flow) neither in the pure pumping (Dean flow). During the laminar-turbulent transition, for a wide range of τ, the ratio of pumping and rotation flow rates, the flow undergoes a series of instabilities giving rise for local or global patterns. These new regimes will be presented.

INTRODUCTION

The stability of a similar flow was first studied experimentally by Brewster et al.[1]. They were interested by the critical conditions of the formation of Taylor vortices and tried to find a common parameter for Dean and Taylor-Couette flows, or any velocity distribution. After then, the effect of a transverse pressure gradient on the stability of a Couette flow was considered theoretically by Di Prima who found an unusual behaviour of the neutral curve. Chandrasekar [2] offered a highly plausible explanation of the very peculiar dependence of the critical Taylor number on τ. Later theoretical studies were focused on the point τ=-0,222 where T.H. Hughes et al. found that the curve of the neutral stability exhibits two loops, due to a discontinuity in the critical wave number. They demonstrate that the two lowest stationary modes do not exist. D.C.Raney showed after them that the stationary modes are replaced by axially nonsymmetric oscillatory modes. On the other hand, these last years, experiments have been performed in the Taylor-Couette system when the cylinders are horizontal and the gap not completely filled. The flow obtained is called the Taylor-Dean flow. Elsewhere, new ideas have been formulated on the stability of open flows and shear flows. The purpose of this study is to investigate experimentally the transition laminar-turbulent of the Taylor-Dean flow with external pumping. The flow is schematised in fig.1. We call it the open Taylor-Dean flow.

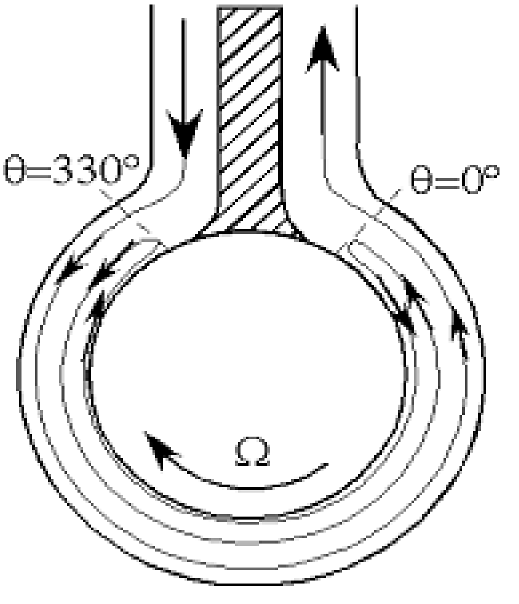

Fig.1 Sketch of the flow system

Experimental set-up and methods

The curved section consists of two concentric cylinders with an inner rotating cylinder of radius R_1 = 3.85cm, a gap d $=R_2-R_1$=0.6cm, a radius ratio η=0.865 and the cylinders length L=10cm, giving an aspect ratio $\Gamma = L/d$ = 16,6. We make our observations in a cell delimited axially between $0<z<10$cm and azimuthally between $0°<\theta<330°$. The inner cylinder can rotate in the range–17 rd/s $<\Omega<$17 rd/s. The flow rate varying from 0 to 1000 dm^3/h, is provided by a pump controlled by an electromagnetic flowmeter. The fluid is recycled from a tank. The system is either horizontal or vertical. The fluid is a mixture of water and Emkarox with added Iriodin for the visualisation. Experiments are down for different viscosities to obtain the first instability and the high turbulence in the range of rotation allowing easy observation. The viscosity is varied in the range $10^{-6}<\upsilon<5.10^{-6} m^2s^{-1}$.

Instabilities

The "entry" and the "exit" of the flow are defined following the direction of the rotating cylinder. The evolution of the flow is described in a two parameter space (Ta, τ), where Ta is the Taylor number. The figure 2 shows the rise and growth of the entry and exit instabilities for $\tau=0$, the so-called Taylor-Dean flow for which the flow is completely reversed : a)longitudinal vortices at the entry and the exit, b)bulb at ($z=10$, $\theta=0°$), bulbs and thin azimuthal vortices at the exit, c) bulb at ($z=0$, $\theta=0°$), "necking" cell near $\theta=330°$, d) tangle of the inclined cells propagating axially from $z=10$ to $z=0$ and inversely, e) corner vortex and diagonally propagating rolls.

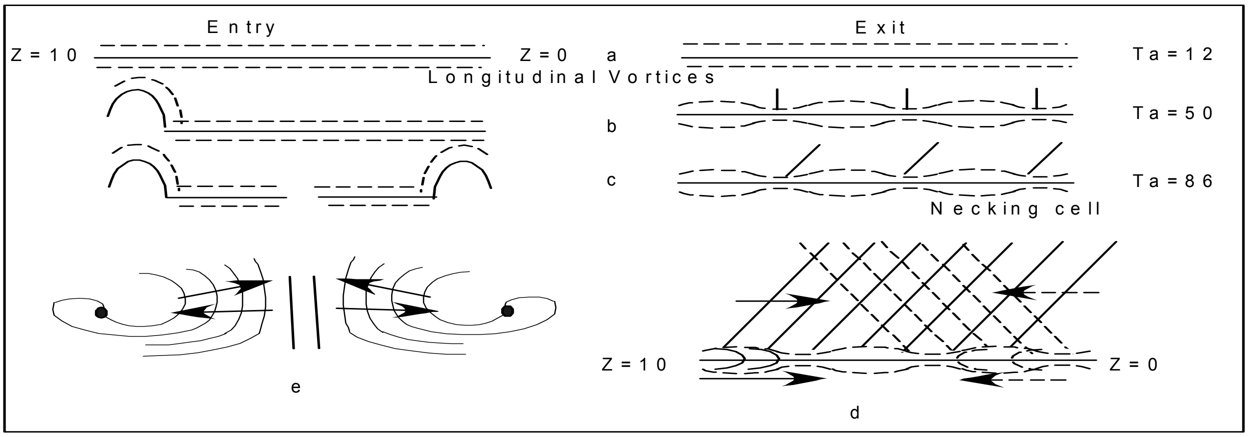

Fig.2 Rise and growth of the entry and exit instabilities for $\tau=0$

Flow regimes

We distinguish two cases:

1) Beyond $\tau = 2/3$, the reversed flow is not noticeable. Dean flow dominates.

2) For $-2/3<\tau<2/3$ the flow is partially reversed and gives rise, at the entry and exit zones, to the structures shown in figure 2, ie corner vortex in the entry and "necking" cell with inclined axially propagating rolls in the exit. The flow regimes observed in the core are presented in figure 3. The basic flow, combination of the Couette and Poiseuille flows, is purely azimuthal. At the instability onset, we can observe either axially regularly spaced cells for $\tau<0$ or spirals for $\tau>0$. With increasing Ta for a fixed De, the Dean number, a succession of transitions lead the flow to turbulence: split-merging of the cells, travelling waves with two trains in the same or opposite direction, turbulent bursts, vortex paths due to Kelvin-Helmoltz instability, diagonally travelling rolls, chaos where the different structures coexist and then the stochastic flow where all the structures crumble.

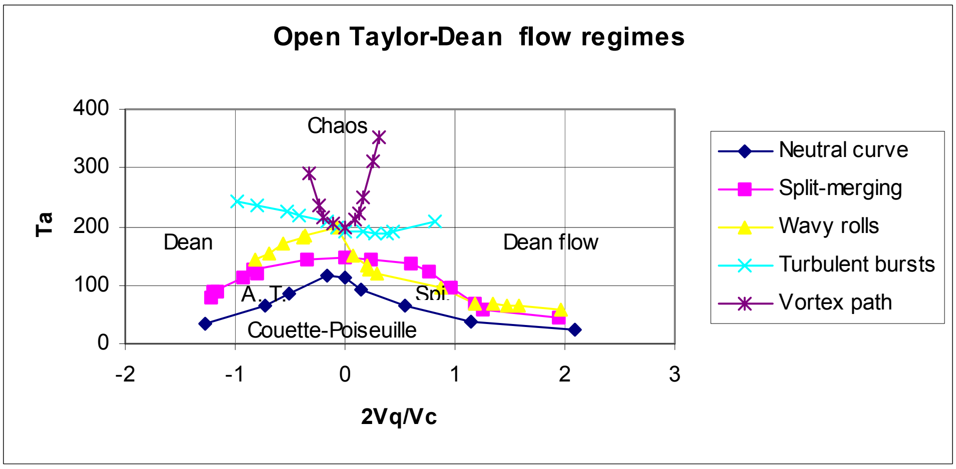

Fig. 3 Open Taylor-Dean flow regimes (A.T.: axially translation motion; Spi.: Spirals)

Conclusion

It is expected that an understanding of the origin of the observed instabilities and their role in the crumble process of the structures of the flow could help to throw some light on the rise of turbulence.

References

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[2] S.Chandrasekar, Hydrodynamic and Hydromagnetic Stability, Oxford University, London, 1961,343-361