Spanwise rotation effects on shear flow

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SPANWISE ROTATION EFFECTS ON SHEAR FLOWS

P. Henrik ALFREDSSON[1], Nils TILLMARK[1] & Takahiro TSUKAHARA[2]
[1]*Linne FLOW Centre, KTH Mechanics, Royal Institute of Technology, Stockholm, Sweden.*
[2]*Department of Mechanical Engineering, Tokyo University of Science, Japan.*

1 Introduction

Spanwise rotation on shear flows may give rise to strong instabilities due to the influence of the Coriolis force ($\mathbf{f}_{\text{Coriolis}} = 2\mathbf{U} \times \mathbf{\Omega}$). Here we define spanwise rotation as rotation along the z-axis, whereas the undisturbed flow U is in the x-direction and the shear is in the y-direction. In plane Poiseuille flow one half of the channel is destabilized whereas the other is stabilized. In plane Couette flow on the other hand the full flow field is either stabilized or destabilized depending on the direction of rotation (see figure 1). Another interesting complication arises if the flow in addition is affected by a centrifugal force which would occur if a curved channel flow is subjected to spanwise rotation. In certain limits these flows can also be described by the Taylor-Couette system. Both rotation and centrifugal effects may have strong influence in many technical applications such as rotating machinery (e.g. compressors, turbines, pumps and fans) but also in the natural sciences such as planetary flows and astrophysical situations.

In this presentation we will illustrate the strong influence on rotation in several laboratory shear flows, both stabilizing and destabilizing effects as well as in combination with centrifugal forces. The presentation is based on results obtained in our laboratory (see e.g. [1]) but also results from other experiments, theory and DNS.

2 Results from linear stability analysis

Rotating shear flows can be described by two parameters, one is the Reynolds number

$$Re = \frac{Uh}{\nu}$$

and the other describes the rotation effect as for instance

$$Ro = \frac{2\Omega_z h}{U} \quad \text{or} \quad \Omega = \frac{2\Omega_z h^2}{\nu}$$

The introduction of two different non-dimensional numbers characterizing the effects of rotation is due to the fact that the linear stability problem is preferably solved using Ro since the problem then has certain symmetry properties, whereas for an experimental study Ω is preferable since then Re can be changed by changing U without affecting the rotation parameter, i.e. Ω.

Assuming that the primary instability occurs in the form of counterrotating vortices we can write a neutral disturbance in the form

$$v = \hat{v}(y)\exp\left(i\beta z/2h\right)$$

and the stability equation reduces to

$$\nabla^6 \hat{v} - Re^2 Ro(U' - Ro)\beta^2 \hat{v} = 0$$

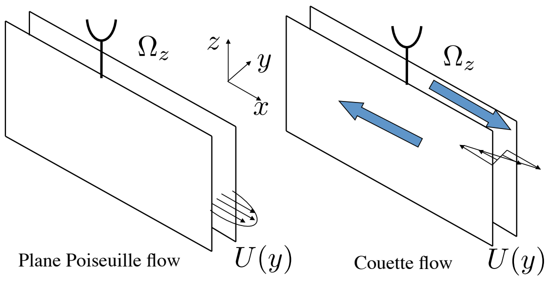

Figure 1: Schematics of spanwise rotating plane Poiseuille and Couette flows.

where $\nabla^2 = d^2/dy^2 - \beta^2$. For plane Couette flow where $U' = 1$ it is possible to show that the neutral stability curve can be given as (see ref. [2])

$$Re^2_{\text{critical}} = \frac{107}{Ro(1 - Ro)}$$

and this gives the lowest critical Re as 20.7 at $Ro = 0.5$. As can be seen instability only exists in the range $0 < Ro < 1$, otherwise the flow is stable.

3 Experimental results

The experimental apparatus used for the rotating Couette flow studies are shown in figure 2. The $Re - \Omega$ space has been mapped in great detail and up to 17 different flow regimes have been observed. One example is shown in figure 3. The details of this mapping and specific flow cases will be given in the presentation.

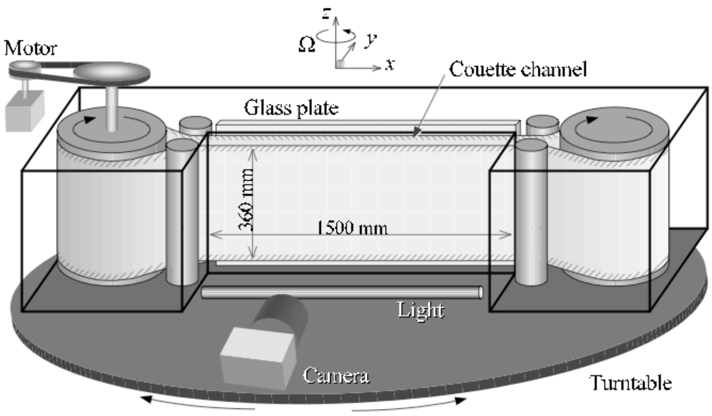

Figure 2: Schematic of the rotating Couette flow channel.

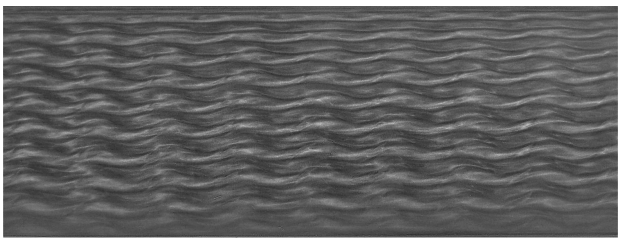

Figure 3: Flow visualization of rotating Couette flow at $Re = 250$ and $\Omega = 21$ from ref. [1].

References

[1] T. Tsukahara, T., N. Tillmark & P.H. Alfredsson 2010 Flow regimes in a plane Couette flow with system rotation. *J.* Fluid Mech. **648**, 5–33.

[2] Lezius, D. K. & Johnston, J. P. 1976 Roll-cell instabilities in rotating laminar and turbulent channel flows. *J. Fluid Mech.* **77**, 153–175.