Instability, transition and turbulence in plane Couette flow with system rotation

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System rotation may drastically change the flow behaviour both for laminar and turbulent shear flows due to the effect of the Coriolis force. For rotating plane Couette flow the Coriolis force will either be stabilizing or destabilizing across the full channel width due to that the sign of vorticity of the basic flow profile is the same across the channel.

Key Words: *plane Couette flow, system rotation, instability, turbulence*

1. Introduction

It has been known for a long time that effects due to body forces, such as curvature (centrifugal effects) or rotation (Coriolis effects), may have strong influence on boundary layer development. In cases with system rotation, if there is a component of the rotation vector that is parallel to the wall and normal to the mean flow direction, the Coriolis effects may lead to an unstable "stratification" which may lead to the development of streamwise oriented vortices. If the flow experiences system rotation the Coriolis force may be stabilizing or destabilizing depending on the direction of rotation. If the mean vorticity is of the opposite sign as compared to the system rotation vector then the flow becomes destabilized (anticyclonic rotation), whereas the flow becomes stabilized if they have the same sign (cyclonic rotation) (see figure 1).

In plane Poiseuille flow the flow becomes destabilized on one side of the channel whereas in the other part of the channel it becomes stabilized (see e.g. Alfredsson & Persson, 1989). For plane Couette flow on the other hand, the Coriolis force will either be stabilizing or destabilizing across the full channel width.

There have been a few numerical studies made on plane Couette flow rotating around its spanwise axis. Bech & Andersson (1996, 1997) made simulations with destabilizing rotation and found that secondary flow in form of streamwise oriented vortices occurs also in this case both for weak and strong rotation. The paper by Komminaho et al. (1996) was mainly devoted to the non-rotating case, however they also showed that the flow can be relaminarized by weak cyclonic rotation.

Nagata (1998) studied stationary flow solutions which bifurcate from the two-dimensional streamwise vortex flow in rotating Couette flow. He showed that such a stationary solution may exist within a rather limited Reynolds number range and that for high Reynolds numbers these solutions would become time-dependent.

2. Theoretical considerations

For the flow under study there are two non-dimensional parameters of interest, namely the Reynolds number, ($Re=U_w h/\nu$) and the rotation number ($Ro=2\Omega\ h/U_w$), where 2h is the channel width, $2U_w$ is the velocity difference between the walls and Ω is the spanwise component of the angular velocity of the system rotation..

For plane Couette flow with spanwise system rotation, the Coriolis force will either be stabilizing or destabilizing across the full channel width giving rise to spanwise periodic disturbances in the form of roll cells. Lezius & Johnston (1976) showed that for rotating plane Couette flow the critical Reynolds number for such disturbances is given by the following expression

$$Re_c=10.3/[Ro(1-Ro)]^{1/2}$$

which gives the lowest Re_c as 20.6 for a rotation number Ro=0.5. The corresponding critical spanwise wave number is $\beta_c=1.56$ i.e. the spanwise size of each roll cell is equal to the channel height (2h). For Ro<0 and Ro>1 it is seen that the flow is stable.

3. Experimental set-up

The present Couette flow apparatus has been used in a number of reported experiments and its basic technical details are found in Tillmark & Alfredsson (1992), which justifies that only a brief description will be given here.

The Couette apparatus itself consists of two open tanks connected by a 1500 mm long open plane channel with vertical parallel glass walls. The channel has a rectangular cross section, its vertical extent is 400 mm and the distance between the walls is adjustable between 10 mm and 70 mm. The flow in the channel is set up by a transparent polyester plastic belt (360 mm wide) which runs along the facing inner glass surfaces of the channel. Vertical cylinders in each tank drives and steers the belt loop. A feedback controlled DC-motor drives one of the large cylinders and a tacho-generator on the other large cylinder, which is driven by the belt itself, monitors the band speed. The working fluid is water and for flow visualization it is seeded with light reflecting platelets (Merck, Iriodin 120).

4. Some experimental results

We show here only a few examples on flow phenomena that occur in the rotating plane Couette flow. Fig. 2 shows the Re-Ro-plane with the neutral stability curve and data points which verify the linear theory. We also depict various other types instability modes that occur in the flow field.

Fig. 3 shows a flow visualization photograph at low Re (=100) and Ro=0.05 where the roll cells have started to become wavy. An interesting aspect of this flow is that the roll cells eventually break down where after they reappear and the cycle repeats itself. These flow structures resemble the solutions found by Nagata (1998).

Rotating Couette flow show a number of interesting instabilities and other flow phenomena which makes it an intereseting flow for both theory and experiments. Future experimental work should aim at detailed velocity measurements of the flow filed. For this PIV would be the best technique.

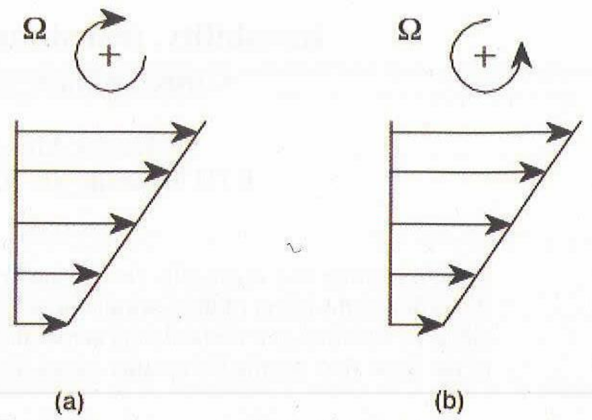

Figure 1. Superposition of rotation on a shear flow a) Stabilizing (cyclonic) rotation, b) Destabilizing (anti-cyclonic) rotation.}

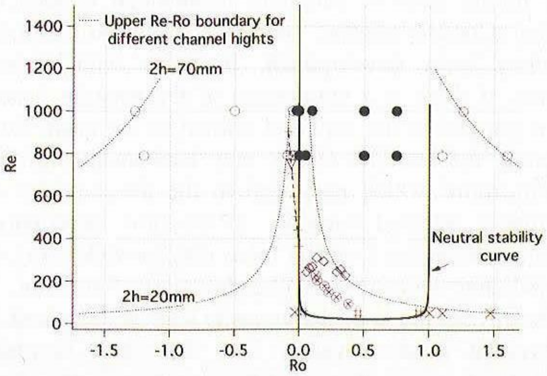

Figure 2. Stability diagram of rotating plane Couette flow.

Figure 3. Roll-cells with large-scale wavy pattern. Vertical dimension of roll cells is approximately 2h. Re=100, Ro=0.05.

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