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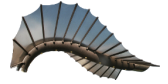
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## AN EXPERIMENTAL STUDY OF LAMINAR-TURBULENT TRANSITION OF A ROTATING-DISK FLOW

Shintaro Imayama, P. Henrik Alfredsson & R. J. Lingwood  
*Linné Flow Centre, KTH Mechanics, SE-100 44 Stockholm, Sweden.*

### 1 INTRODUCTION

The main objective of this experimental study is to measure the laminar-turbulent transitional region of the rotating-disk boundary layer. In 1921, von Kármán (1921) derived the exact similarity solution of the Navier-Stokes equations for the basic laminar flow on an infinite rotating disk. Typically 28 to 32 stationary vortices are observed within the convectively unstable region in unforced experiments (e.g. Gregory et al. 1955), which are excited by unavoidable roughnesses fixed at the disk surface, but the flow is unstable to travelling modes as well. Lingwood (1995a) suggested that instability on the rotating disk is not only of convective nature but also that the flow becomes absolute unstable at  $R=510$  ( $R = r^*(\Omega^*/\nu^*)^{1/2}$ , where  $r^*$  is the radius of the disk at the measurement position,  $\Omega^*$  is the rotational speed of the disk,  $\nu^*$  is the kinematic viscosity of the flow and  $*$  means dimensional value). In the present work we map the flow regimes from the stable laminar flow region, through the unstable and transitional regions, into the fully turbulent region.

### 2 EXPERIMENTAL CONDITIONS

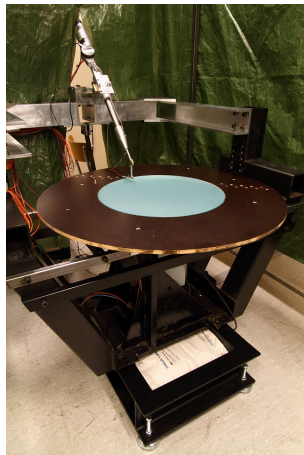


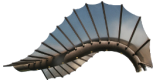
Figure 1: The experimental setup of the rotating disk.

The measurements were performed on a rotating disk shown in Figure 1. The apparatus is in principle the same as used by Lingwood (1996) and has been lent by Cambridge University to KTH, where it has undergone certain modifications. The disk is now made of glass and has a diameter of 474 mm and a thickness of 24 mm and is mounted on the original aluminium-alloy disk. The aluminium-alloy disk is connected to DC-servo motor through an iron disk and a vertical shaft. The air bearing mounted around the shaft is operated with high pressure air to achieve low noise and vibration levels. The surface of the glass disk is polished and the roughness is within  $1 \mu\text{m}$  and the imbalance within  $10 \mu\text{m}$  at the edge of the glass disk. To attenuate the effect of the disk edge, a stationary wood plate is fixed around the glass disk. A single hot-wire probe, operated by a constant temperature anemometer (CTA) with overheat ratio 0.8, is used for the velocity measurement. The sensitive area is made of platinum, with a diameter of  $5 \mu\text{m}$  and a length of 1 mm. The signal from the CTA is digitized using a computer with a 16 bit A/D converter and is sampled at a rate of 720 data points per revolution. The hot-wire is mounted on a two-axis traverse system. One of the traverses moves in the horizontal (radial) direction, and the other traverse is mounted on the horizontal traverse at a  $45^\circ$  inclination to not disturb the axial flow which approaches the rotating disk from above.

The hot-wire orientation makes it mainly sensitive to the circumferential velocity component (i.e. the axis of the sensing wire is aligned with the radial direction) and although the flow is three-dimensional this component is much larger compared to the radial and axial components. The calibration of the hot-wire is carried out on the rotating disk using the theoretical laminar mean profile. The hot-wire was calibrated using a modified King's law to extend the low velocity range (Johansson & Alfredsson, 1982). The measurements were carried out at a fixed radius position of 198 mm, varying the Reynolds number with the rotational speed.

### 3 RESULTS AND DISCUSSIONS

Measured circumferential mean velocity profiles spanning the range  $R = 430 - 630$  are shown in Figure 2. The abscissa axis is the non-dimensional circumferential velocity ( $V = V^*/(r^*\Omega^*)$ , where  $V^*$  is the circumferential velocity). The vertical axis is the non-dimensional height from the wall ( $z = z^*(\Omega^*/\nu^*)^{1/2}$ , where  $z^*$  is the wall normal position of hot wire). At Reynolds number  $R$  from 430 to 510, the experimental data correspond to theoretical laminar profile shown as a solid line, except in the very low velocity region where effects of heat convection on the hot-wire are observed. At  $R = 550$ , deviations of the experimental data from the theoretical



laminar profile can be observed. Lingwood (1995a) suggested that the absolute instability appears at  $R = 510$  triggering nonlinear effects that one would expect to generate Reynolds stresses thereby distorting the laminar velocity profile. As the Reynolds number increases, the velocity profile changes completely. At  $R = 630$  the boundary-layer thickness has become much larger and the velocity gradient has increased close to the wall.

Figure 3 shows the non-dimensional intensity of the circumferential velocity fluctuation ( $v_{rms} = v_{rms}^*/r^*\Omega^*$ , where  $v_{rms}^*$  is the root mean square of the circumferential velocity) against the wall normal position. At  $R = 510$ , the peak appears at  $z = 1.3$ . At  $R = 550$ , the rms has a higher value not only at  $z = 1.3$  but also  $z = 4$ . At  $R = 630$ , fluctuations develop over the entire boundary-layer height. Figure 4 shows the spectra at each Reynolds number measured at  $z = 1.3$ . At around  $\omega^*/\Omega^* = 30$ , peaks start to appear and the intensity increases with Reynolds number. This result corresponds to the previous study that between 28 and 32 stationary vortices are observed once the individual patterns (generated by individual fixed roughnesses) have merged and filled the whole circumference of the disk. Above  $R = 510$  harmonics of the basic frequency starts to appear, but at  $R = 630$  the spectrum becomes flat without any distinct peaks characteristic of fully-developed turbulence.

The talk will include a further investigation of the transition region including intermittency and higher moments, as well as details of the turbulent flow itself.

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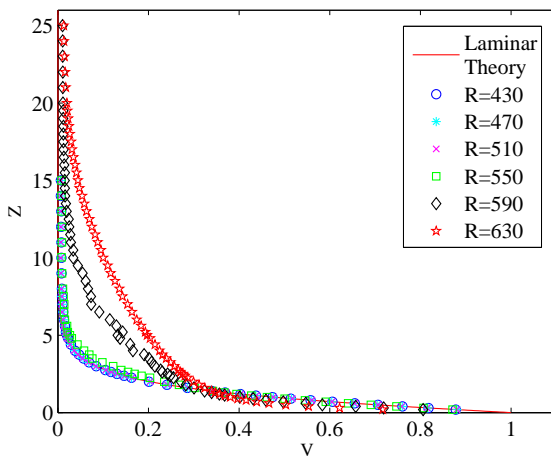


Figure 2: Mean velocity profiles in the range  $R = 430 - 630$ , spanning the stable laminar region, the unstable, transitional and turbulent regions.

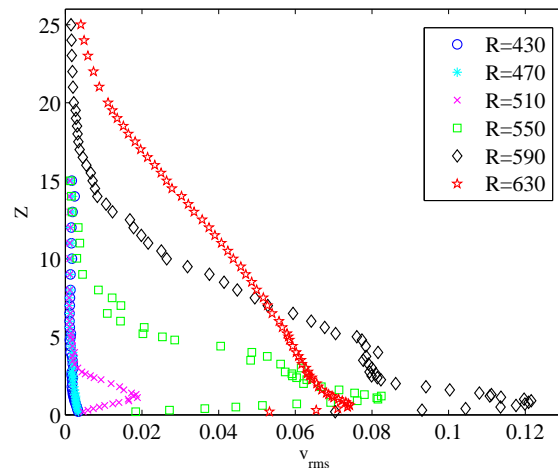


Figure 3: The rms-profiles for the same cases as in Figure 2.

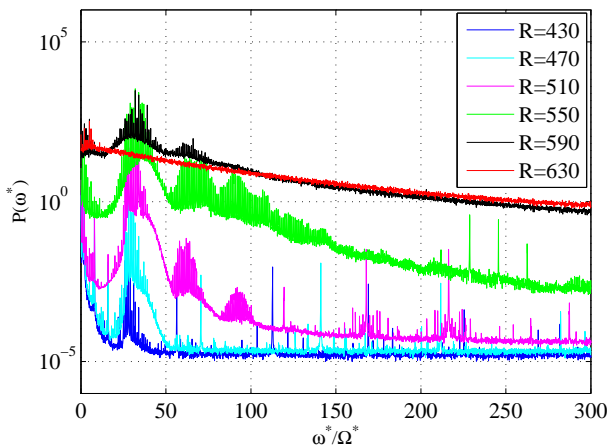


Figure 4: Fourier power spectra for ensemble averaged time series, for  $z = 1.3$ .

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