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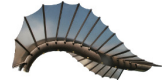
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EXPERIMENTAL INVESTIGATION ON TORQUE SCALING IN TURBULENT TAYLOR-COUPETTE FLOW

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1 Angular momentum flux and torque in Taylor-Couette

The concentric rotating Taylor-Couette flow (TC) is a well known system of instabilities in fluid dynamics (see Fig. 1a). In this work the transitions between different three dimensional flows of counter- and corotating Taylor-Couette flow and its dependence on different parameters is investigated. Depending on the rotation rate of the cylinders, one is able to create a linear stable (like pipe) or unstable flow (like Rayleigh-Bénard convection). From this background one can see TC flow as a link between Rayleigh-Bénard and pipe flow. [1, 2] also compare these three systems by an analytical derivation. It is possible to calculate the heat flux J_θ for Rayleigh-Bénard [3], a transverse u_z flux J_{u_z} for pipe flow, and angular momentum flux J_ω for Taylor-Couette flow, which have a similar analytical form [1]. The Analogy of these three systems is obvious. For the example of Taylor-Couette-flow this flux is given as

$$J_\omega = r^3 (\langle u_r \omega \rangle_{A,t} - \nu \partial_r \langle \omega \rangle_{A,t}), \quad (1)$$

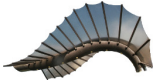
where $\langle \dots \rangle_{A,t}$ denotes a spacial temporal average over a cylindrical surface of height L at radius r . Analytically, J_ω has to be independent of all radii ($\partial_r J_\omega = 0$). So it is of great interest to quantify the angular momentum flux J_ω as a parameter for the flow. At the wall the magnitude of J_ω corresponds to the torque the fluid works on the cylinders: Thus the dimensionless torque $G = T/(2\pi L \rho \nu^2) = \nu^{-2} J_\omega$ can be used to quantify the angular momentum flux J_ω . So the scaling of the torque with the rotation rate of the system gives the scaling of the angular momentum flux [2]. How the Torque scales for different Rotation numbers of the inner and outer cylinders needs to be investigated.

2 Experiments in Taylor-Couette flow

Figure 1a shows a sketch of the experimental apparatus used in the present investigations. Both cylinders can rotate independently and relative to each other with Reynolds numbers of inner (1) and outer rotation (2) $Re_{1,2} = R_{1,2} \omega_{1,2} (R_2 - R_1) / \nu$ of order of 10^3 up to 10^5 for a radius ratio $\eta = R_1/R_2 = 0.5$. This includes single rotations of both cylinders as well as co- and counterrotation. The end plates of the concentric cylinder gap are also able to rotate separately at an aspect ratio up to $\Gamma = (R_2 - R_1)/L \leq 20$. As working fluid its used a silicone oil with a kinematic viscosity of $\nu = 0.65 \cdot 10^{-6} m^2/s$. The outer cylinder is made out of glass to enable optical measurements and is located inside a water box to keep the experiment isothermal. The inner cylinder is divided in three sections (Fig. 1b) where the middle section is constructed to measure the torque T the fluid interacts on the rotating cylinder wall. The two end sections are used to reduce the influence of the top and bottom end plates.

We use Particle Image Velocimetry (PIV) to measure the axial-radial and radial-azimuthal velocity fields (see Fig. 2) and to characterize different instabilities and flow patterns inside the cylinder gap. Laser Doppler Anemometry (LDA) is used to measure time series of the turbulent flow at different positions. The radial-azimuthal time dependent velocity field is measured in a second Taylor-Couette apparatus by LDA and PIV. This one has the identical geometry as the one used for torque measurements and is equipped with a transparent end plate attached to the outer cylinder. The azimuthal boundary layer profiles of inner and outer cylinder are also measured for different inner and outer Reynolds numbers. The measured velocity fields (i.e. angular velocity profiles see Fig.3) and the torque at inner cylinder are compared to verify equation (1). The radial conservation of the angular momentum flux ($\partial_r J_\omega = 0$) can be checked for turbulent Taylor-Couette flows.

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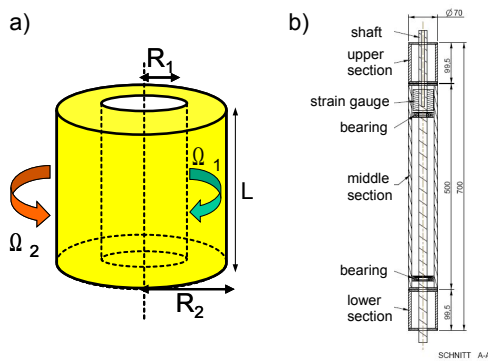


Figure 1: (a) Schematic drawing of the Taylor-Couette-system, $R_1 = 35\text{mm}$, $R_2 = 70\text{mm}$, $\eta = 0.5$, $\Gamma = 20$ (b) Drawing of the inner cylinder with torque measuring unit

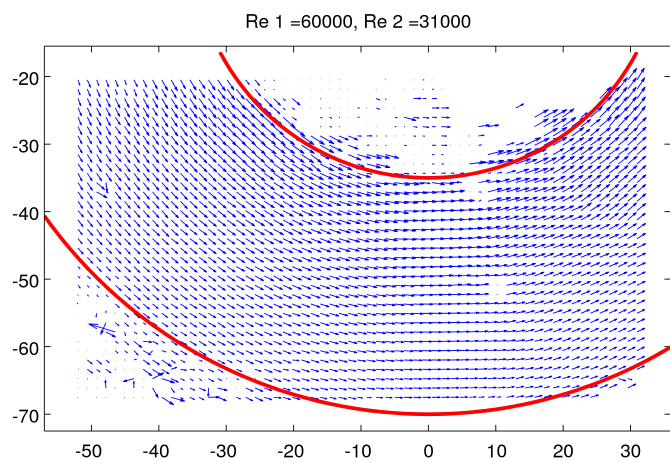


Figure 2: Radial-Azimuthal velocity field from PIV measurement for $Re_1 = 6 \cdot 10^4$, $Re_2 = 3.1 \cdot 10^4$

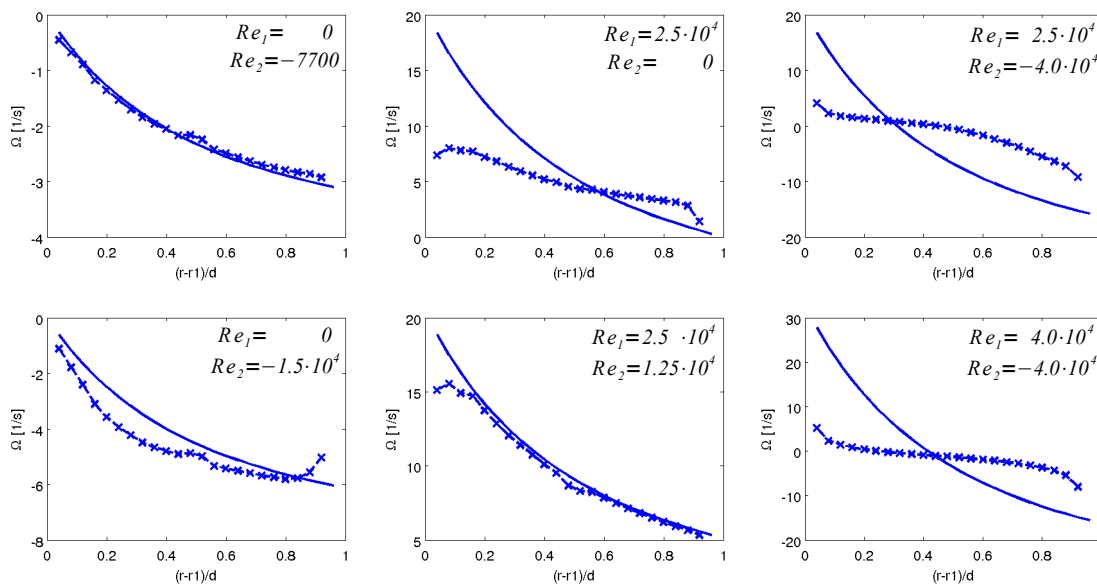


Figure 3: Angular velocity Ω over dimensionless gap width $(r - R_1)/d$. Temporal and azimuthal averaged over circular segments of $\pi/2$ (crosses) for different pairs of rotation Reynolds numbers Re_1, Re_2 . The solid line indicates a two dimensional Couette-profile $\Omega = Ar + B/r$ in comparison to the measured profiles.