MEASUREMENTS OF SMALL RADIUS RATIO TURBULENT TAYLOR-COUETTE FLOW

Roeland C.A. van der Veen,[1] Sander G. Huisman,[1] Sebastian Merbold,[2] Chao Sun,[1] Uwe Harlander,[2] Christoph Egbers[2] & Detlef Lohse[1]

[1]*Department of Applied Physics and J. M. Burgers Centre for Fluid Dynamics, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands*

[2]*Department of Aerodynamics and Fluid Mechanics, Brandenburg University of Cottbus, Siemens-Halske-Ring 14, 03046 Cottbus, Germany*

Abstract

In Taylor-Couette flow, the radius ratio ($\eta = r_i/r_o$) is one of the key parameters of the system. For small η, the asymmetry of the inner and outer boundary layer becomes more important, affecting the general flow structure and boundary layer characteristics. Using high-resolution particle image velocimetry we measure flow profiles for a radius ratio of 0.5 and Taylor number of up to $6.2 \cdot 10^9$. By measuring at varying heights, roll structures are characterized for two different rotation ratios of the inner and outer cylinder. In addition, we investigate how the turbulent bursts coming from the inner and outer cylinder affect the flow profiles. These results exemplify how curvature affects flow in strongly turbulent Taylor-Couette Flow.

INTRODUCTION

The paradigmatic Taylor-Couette (TC) flow consists of flow between two coaxial cylinders that can independently rotate. Dimensionless control parameters are a combined Reynolds or Taylor number of the inner and outer cylinder rotation, a rotation ratio ($a = -\omega_o/\omega_i$), the ratio of the inner and outer cylinder radius (η), and the aspect ratio (Γ). In this work we focus on the linearly unstable and turbulent regime.

The radius ratio is a key control parameter [3] in TC flow and strongly influences the transitional Taylor number for the ultimate regime[1, 2] of TC turbulence [4, 5] and the rotation ratio for which optimal momentum transport occurs [4, 6]. Because the boundary layer thickness ratio scales as η^3, a strong asymmetry between the inner and outer boundary layer exists for small radius ratio. We aim to investigate how the strong curvature of a radius ratio of $\eta = 0.5$ affects turbulent TC flow.

SETUP

Experiments on small radius ratio turbulent Taylor-Couette flow have been carried out in the Cottbus Taylor-Couette facility [4, 7]. The inner and outer cylinder radii are 35 mm and 70 mm respectively, the height of the setup is 700 mm. This gives a radius ratio of $\eta = 0.5$ and an aspect ratio of $\Gamma = 20$. The maximum rotation rates are 5 Hz for both the inner and outer cylinder.

The end plates rotate with the outer cylinder. The top plate is transparent, making the setup ideally suited to use in combination with particle image velocimetry (PIV). A high-resolution PIV camera (LaVision Imager sCMOS) with a resolution of 2160 $\times$ 2160 pixels and a framerate of 50 Hz is installed above the top end plate pointing downwards. The flow is illuminated by a horizontal light sheet from a high-powered Nd:Yag dual cavity laser (Litron). The imaging of the

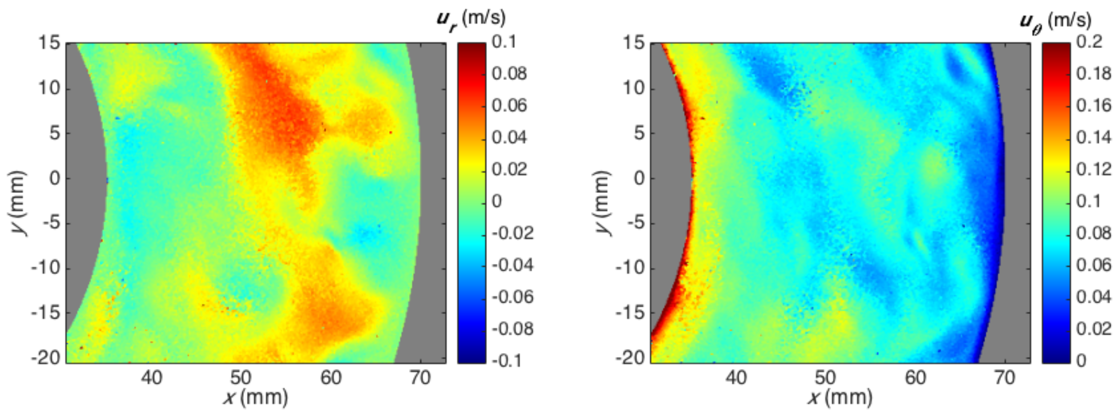

Figure 1. Snapshot of the radial and azimuthal velocity fields for $a = 0$ and $\mathrm{Ta} = 2.1 \cdot 10^8$.

full width of the gap combined with a vector grid of 16 × 16 pixels with 50% overlap results in a velocity vector spacing of 0.13 mm.

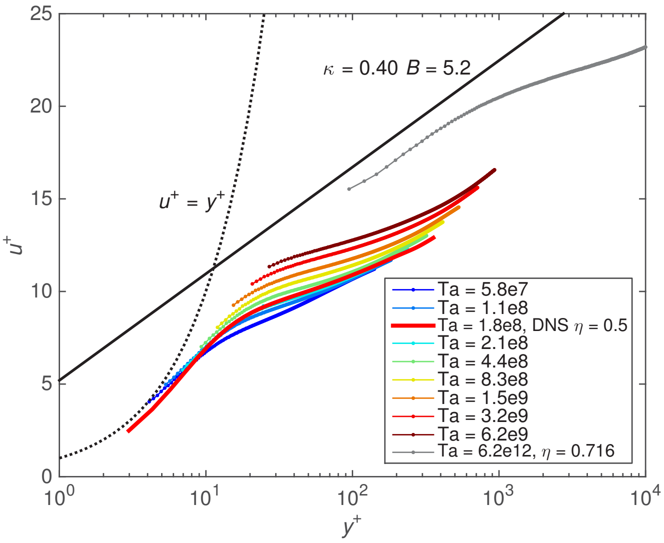

Figure 2. Azimuthal velocity profile of the inner boundary layer in wall units for inner cylinder rotation, for several different Taylor numbers. The figure also includes the logarithmic law of the wall from Von Kármán, the viscous sublayer $u^+ = y^+$, DNS data from [8] and measurement data from [9] for Ta $= 6.2 \cdot 10^{12}$ at an aspect ratio of 0.716,

RESULTS

As can be seen from Figure 2, the inner boundary layer of the flow slowly approaches the Von Karman log law, although at these Taylor numbers the log layer is not yet developed. The data show good agreement with direct numerical simulations from [8].

In addition to varying the Taylor number for inner cylinder rotation only, we also measure flow profiles at several heights for both $a = 0$ and $a = 0.2$. By visualizing the height dependence, it can be seen that there is no structure for a = 0, but that there exist strong roll structures in the mean flow for slight counter-rotation ($a = 0.2$). This finding is corroborated by recent work for higher radius ratio [10]. Within these rolls, either inner or outer cylinder velocity is advected, changing the flow profiles and moving the neutral line.

From the time resolved velocity fields, we extract the advective velocity of turbulent bursts coming from either the inner or outer cylinder and see how this quantity depends on several parameters, e.g. the position in the roll and Taylor number.

References

[1] Robert H. Kraichnan. Turbulent Thermal Convection at Arbitrary Prandtl Number. *Physics of Fluids*, **5**(11):1374, 1962.

[2] Siegfried Grossmann and Detlef Lohse. Multiple scaling in the ultimate regime of thermal convection. *Physics of Fluids*, **23**(4):045108, 2011.

[3] Bruno Eckhardt, Siegfried Grossmann, and Detlef Lohse. Torque scaling in turbulent Taylor–Couette flow between independently rotating cylinders. *Journal of Fluid Mechanics*, **581**(2007):221, May 2007.

[4] S. Merbold, H. Brauckmann, and C. Egbers. Torque measurements and numerical determination in differentially rotating wide gap Taylor-Couette flow. *Physical Review E*, **87**(2):023014, February 2013.

[5] Rodolfo Ostilla-Mónico, Sander G. Huisman, Tim J. G. Jannink, Dennis P. M. Van Gils, Roberto Verzicco, Siegfried Grossmann, Chao Sun, and Detlef Lohse. Optimal Taylor–Couette flow: radius ratio dependence. *Journal of Fluid Mechanics*, **747**:1–29, April 2014.

[6] Dennis P. M. van Gils, Sander G. Huisman, Siegfried Grossmann, Chao Sun, and Detlef Lohse. Optimal Taylor–Couette turbulence. *Journal of Fluid Mechanics*, **706**:118–149, July 2012.

[7] S Merbold, S Fischer, and C Egbers. Torque scaling in Taylor-Couette flow — an experimental investigation. *Journal of Physics: Conference Series*, **318**(8):082017, December 2011.

[8] A. Chouippe, E. Climent, D. Legendre, and C. Gabillet. Numerical simulation of bubble dispersion in turbulent Taylor-Couette flow. *Physics of Fluids*, **26**(4):043304, April 2014.

[9] Sander G. Huisman, Sven Scharnowski, Christian Cierpka, Christian J. Kähler, Detlef Lohse, and Chao Sun. Logarithmic Boundary Layers in Strong Taylor-Couette Turbulence. *Physical Review Letters*, **110**(26):264501, June 2013.

[10] Sander G. Huisman, Roeland C.A. van der Veen, Chao Sun, and Detlef Lohse. Multiple states in highly turbulent Taylor–Couette flow. *Nature Communications*, **5**(May):1–5, May 2014.