Chair: Physics of Fluids group

The roughness distribution problem for minimised drag

Description

Drag reduction has been the focus of research due to its significance in real-world applications. The drag experienced by a surface when fluid moves over it consists of two parts, namely frictional drag and pressure drag. The former is caused by the fluid viscosity and the no-slip condition that 'pins down' the layer of fluid adjacent to the surface, whereas the latter is a result of the pressure difference rooting in the surface roughness and can usually be reduced by smoothing the surface. However, in practice, sometimes it is not possible to smooth the entire surface, and there must be a certain proportion of roughness left. Then, the question is: **would there be an optimum strategy to distribute this mandatory proportion of roughness to minimise the total drag?**

To answer this question, we will consider a canonical turbulence system: Taylor-Couette (TC) flow - the flow between two coaxial, independently rotating cylinders. Especially, in such a closed system, the wall-shear-stress can be directly measured with high accuracy. We will also restrain ourselves to considering only azimuthal smooth and rough strips of equal widths on the inner cylinder, thus a 50% of roughness coverage is maintained in all cases. We will first conduct experiments in the Twente turbulent Taylor-Couette (T^3C) facility (figure 1(a), and a video can be accessed here). We will measure the wall-shear-stress with different strip widths, and also time-averaged and instantaneous flow fields to understand the physics behind minimised drag, and then we will derive a theoretical model to predict the flow behaviour for other scenarios.

(a) (b)

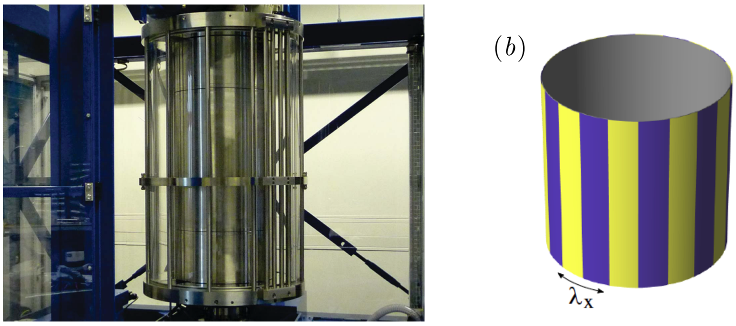

Figure 1: (a) A photograph of the T^3C system. (b) Schematic of the azimuthally varying roughness on the inner cylinder, adapted from Jeganathan *et al.* (2021). The dark blue and yellow colours represent high-shear-stress (rough) and low-shear-stress (smooth) patches, respectively.

Assignment

This project comprises both experimental and theoretical parts. The project is to be conducted by a master student.

Experimental characterisation of the flow

The first task is to modify the T^3C facility by attaching strips of sandpaper (figure 2b) to the inner cylinder, and create a periodic pattern as displayed in figure 1(b). Various configurations, with a wavelength of $\lambda_x = \pi r_i, \pi r_i/2, \pi r_i/4, ...$ will be considered.

The global wall-shear-stress will be measured by the torque sensor on the inner cylinder. Phase-locked particle image velocimetry (PIV) will be performed in the radial-azimuthal plane to reveal the internal boundary layers formed as the flow adjusting to the varying roughness (figure 2), and also in the radial-axial plane to study the modification to Taylor vortices. Radial velocity profiles will also be acquired by Laser Doppler Anemometry.

Additional measurements using multiphase flow, i.e. with bubbles in the flow, can be performed to extend on the research of (Bullee *et al.*, 2020).

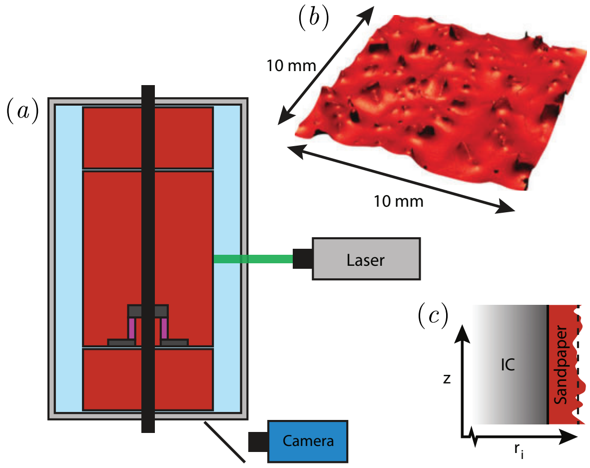

Figure 2: Schematic of the T^{3}C setup, adapted from Berghout *et al.* (2021). (*a*) Cross-section of the TC geometry featuring the PIV setup in the radial-azimuthal plane. (*b*) Three-dimensional visualization of the confocal scan of the used sandpaper. (*c*) Cross-section of the inner cylinder with the sandpaper attached to the surface.

Theoretical modelling

A schematic of a surface layer adjusting from a rough wall upstream to a smooth wall downstream is shown in figure 3. The flow adapts to the new surface condition firstly close to the wall, and the affected region (light blue shaded region) widens further downstream. This region, where the flow is modified by the new wall condition, is usually referred to as the internal layer or internal boundary layer (IBL) (Garratt, 1990). The mean velocity distribution downstream of a roughness change can be approximated by a piecewise logarithmic profile which has a slope corresponding to the downstream surface in the IBL and the upstream surface above it (Elliott, 1958). This velocity profile is then evolved in streamwise through the momentum equation. The classical logarithmic velocity profile for a flat-plate turbulent boundary layer has recently been extended to the TC flow (Berghout *et al.*, 2020, 2021). In addition to the viscous and outer length scales, a third length scale has been introduced to capture the effect of curvature in the TC flow system. In this part, we aim at adapting Elliott's model to include the curvature effect for the present TC system (figure 3*b*).

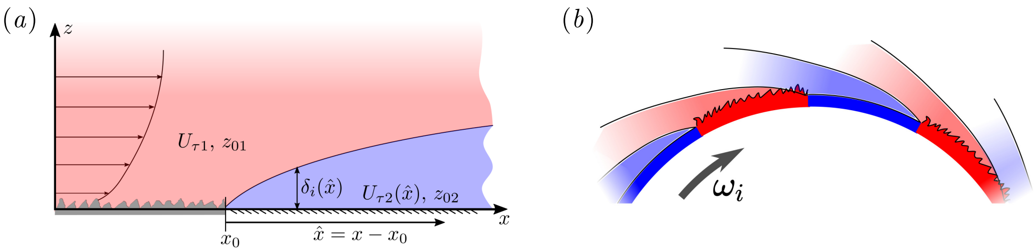

Figure 3: Schematic of (*a*) a surface layer over a rough-to-smooth change in surface condition and (*b*) a TC flow with azimuthal rough and smooth patches on the rotating inner cylinder.

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