Dual PhD programme proposal (case for two students)

University of Liverpool (UoL) and National Tsing Hua University (NTHU)

Proposed UoL supervisors: Dr David Dennis (djcd@liv.ac.uk) and Dr Rob Poole (robpoole@liv.ac.uk)

Proposed NTHU supervisor: Prof. Chao-An Lin (calin@pme.nthu.edu.tw)

Online application at:
http://www.findaphd.com/search/projectDetails.aspx?PJID=54330
http://www.findaphd.com/search/ProjectDetails.aspx?PJID=54331&LID=2125

Project title: Turbulent Couette-Poiseuille flow inside a square duct.

Turbulent flows inside a square duct are of considerable engineering interest, e.g. in heat exchangers or in district heating and cooling plants. All previous *experimental* studies have concentrated on the case of purely-pressure-driven flow (i.e. Poiseuille flow) and have shown that the flow is characterised by the existence of a secondary flow. Although this secondary flow is quite weak in magnitude, it has been shown to be able to enhance both momentum and heat transfer in different devices. The combined effects of wall translation (the Couette component) have hitherto only been studied numerically using Direct Numerical Simulation (DNS) and Large Eddy Simulation (LES) by Prof. Lin's group at NTHU [1-2]. Thus, the first major aim of the project, and the key objective of PhD student #1, is to provide experimental validation for such combined Couette-Poiseuille (CP) square-duct flows of Newtonian fluids. This will be achieved by modifying an existing square-duct facility at the UoL [3] and performing high-speed stereoscopic particle image velocimetry measurements [4] to obtain the three-component velocity field over the entire cross-section of the duct, as well as two-component, point-wise laser Doppler velocimetry measurements in regions of particular interest.

It is well known that the addition of minute amounts of polymers or surfactants can massively reduce the drag in turbulent wall-bounded flows [5] and the second aim of the project, and the primarily objective of PhD student #2, will be to implement a viscoelastic model within the existing NTHU DNS code. In addition UoL has extensive expertise in this area and the effects of drag-reducing additives on the turbulent structure within the combined CP flow in a square duct will be probed experimentally. An example application here would be reducing energy losses in a district heating and cooling system. Thus, in addition to implementing a viscoelastic model into the existing NTHU numerical code based on the so-called FENE-P model, a secondary objective for PhD student #2 would be to undertake some novel experiments utilising such fluids to validate their simulations. Finally the possibility of using wall translation as a possible means of flow control to encourage "hibernating" turbulence will be probed by PhD student #1 (supporting current EPSRC project EP/J018163/1 and providing proof-of-concept data for follow-on proposal).

PhD student #1: Experimental investigation of turbulent Couette-Poiseuille flow inside a square duct
http://www.findaphd.com/search/projectDetails.aspx?PJID=54330

PhD student #2: Numerical investigation of turbulent Couette-Poiseuille flow inside a square duct
http://www.findaphd.com/search/ProjectDetails.aspx?PJID=54331&LID=2125

Refs
1. H-W Hsu, J-B Hsu, W Lo and C-A Lin (2012). *J. Fluid Mech* **702** pp89-101.
2. W Lo and C-A Lin (2006). *Phys. Fluids* **18** 068103
3. S Smith and M P Escudier (2001). *Proc. R. Soc. Lond. A* **457** pp911-935
4. F M Sogaro and D J C Dennis (2013) Proceedings of the 66th Annual Meeting of the American Physical Society Division of Fluid Dynamics. APS, Pittsburgh, Pennsylvania pp E20.04
5. M P Escudier, A K Nickson and R J Poole (2009), *J. Non-Newt. Fluid Mech*. **160** pp2-10

List of major facilities to be used at NTHU and UoL

1. Lin group 64-core cluster or 12 GPU and national facilities up to 512-core
2. Bespoke square duct rig at UoL (capital cost £25k)
3. Stereoscopic Particle Image Velocimeter (capital cost £200k)
4. Two-component Laser Doppler Velocimeter system (capital cost £150k)

Expected pattern of study

PhD student #1

Years 1-2: 24 months at Liverpool commissioning experimental rig and undertaking experiments at 3 Reynolds numbers with three levels of Couette component (plus base Poiseuille flow) for Newtonian fluid (*developing experimental facility)*.
Year 3: 12 months at NTHU running dedicated DNS and LES simulations to match experimental conditions (*user of code)*.
Year 4: 12 months at Liverpool conducting additional experiments using rig as a flow control device to minimise skin friction drag (to support possible EPSRC bid with proof-of-concept data)

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PhD student #2

Years 1-2: 24 months at NTHU learning DNS code, implementing FENE-P viscoelastic equation (*developing numerical code)*
Years 3: 12 months at Liverpool using rig to obtain data at a single Reynolds number for three levels of Couette component (plus base Poiseuille flow) for dilute polymer solution and a surfactant solution (*user of experimental facility*).
Year 4: 12 months at NTHU running dedicated DNS and LES simulations to match experimental conditions

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Additional notes

If deemed necessary to attract the best candidate, top-up support for stipend for UoL-based students could be provided at a rate of £4k per annum during UoL stay from management fee from Poole grant (EER10524).