PhD Proposal 2017

School: ÉCOLE CENTRALE DE LYON	
Laboratory: LMFA	**Web site: http://lmfa.ec-lyon.fr**
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Title: Chaotic advection in flow between two eccentric cylinders
Scientific field: hydrodynamic instabilities, chaotic mixing
Key words: three-dimensional flows, dynamical systems, numerical simulations

Details for the subject:

Background and context

Mixing in fluids comes with two mechanisms: *stirring*, which consists in moving the fluid particles as efficiently as possible so as to create high gradients of concentration that are thereafter smoothed by *molecular diffusion*. Although mixing generally implies turbulent flows, it is now very well known that chaotic advection enables efficient stirring even when the flow is laminar. What is less known is what happens in between, i.e. for unstable flows that sustain finite-amplitude perturbations (generally referred to as nonlinear propagating waves) without undergoing a complete transition to a turbulent regime. Indeed, chaotic mixing requires at least a three-dimensional phase space, a necessary condition which is already fulfilled by two-dimensional periodic perturbations.

The "Turbulence and Instabilities" research team of "Laboratoire de mécanique des fluides et d'acoustique" has internationally renowned expertise in fluid dynamics instabilities and in chaotic advection. By combining these two related but distinct areas of research it is possible to study new fundamental configurations and acquire better understanding of flow phenomena prevailing in a wide range of applications, from microfluidic devices to oil-well drilling procedures.

The proposed research has become achievable by our recent results in chaotic mixing [1] and eccentric Taylor-Couette-Poiseuille flow [2,3].

Research subject and work plan

This research proposal is a fundamental problem with potential applications in a range of practical configurations.

The objective is to finely characterize transport and mixing properties for several related open flows displaying increasingly complex features: from channel Poiseuille flow to Taylor-Couette-Poiseuille flow between eccentric cylinders.

For each of these flows, beyond certain values of the control parameter(s), linear instability leads to fully developed finite-amplitude travelling wave solutions. In mildly unstable situations, the total perturbed flow fields may be quite similar to the unperturbed base flow, while transport and mixing properties may already be greatly affected by these (weak) perturbations. Among others, by comparing "time of flight" distributions of the fully developed flow and of the associated base flow, the aim is to identify the relevant flow features that significantly affect advection properties.

Theoretical and numerical methods will first be implemented and validated for plane channel flow. The base Poiseuille flow is analytically known and its transport properties are trivially obtained. Beyond the critical Reynolds number, finite-amplitude Tollmien-Schlichting waves are selected and the first task will be to charactize how they affect transport and mixing properties.

Then, the Taylor-Couette flow between concentric cylinders will be considered. Again, the base flow is obtained analytically. Here the first instability leads to Taylor vortices which are axially periodic and azimuthally invariant. A second instability leads to wavy Taylor vortices characterized by azimuthally propagating waves. Experimentally it is known that almost no mixing occurs between different vortices in the Taylor-vortex regime, in contrast with the wavy regime that has been found to greatly enhance migration of particles along the axial direction. Here, the aim is to quantify and interpret these drastically different behaviours by precisely computing transport properties for all fully developed flows in this configuration.

Adding an axial pressure gradient drives an additional axial flow. The resulting Taylor-Couette-Poiseuille flow between concentric cyclinders will be similarly investigated.

Finally, Taylor-Couette-Poiseuille flow between eccentric cylinders will be considered. Here, the steady base flow is already intrinsically three-dimensional and gives rise to complex transport properties that have never been studied. In unstable situations, fully developed flow structures are selected which may be interpreted as the eccentric counter-part of Taylor (wavy) vortices. The objective is to determine their impact on advection in the associated potential applications.

The numerical implementation of this project will be based on codes that have been developed at LMFA to compute linear and nonlinear dynamics of open flows in a range of configurations, including those required in this project. Only minor adjustments will be necessary to carry out the simulations of this research project.

Skills learned during the thesis

The successful candidate will learn a broad range of skills in fluid dynamics (linear and nonlinear stability analyses, transition, mixing, dynamical systems...) and scientific programming (direct numerical simulations, spatio-temporal discretization, data processing, high performance computing...).

References

[1] F. Raynal & Ph. Carrière, *Phys. Fluids*, **27**, 043601 (2015),
The distribution of "time of flight" in three dimensional stationary chaotic advection.
[2] C. Leclercq, J. Scott & B. Pier, *J. Fluid Mech.*, **733**, 68-99 (2013),
Temporal stability of eccentric Taylor-Couette-Poiseuille flow.
[3] C. Leclercq, J. Scott & B. Pier, *J. Fluid Mech.*, **741**, 543-566 (2014),
Absolute instabilities in eccentric Taylor-Couette-Poiseuille flow.