Understanding Rotating Polygons with Numerical simulations and Experiments.

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Abstract :
Rotating flows driven by a spinning disk are a classic and rich topic in fluid mechanics, with relevance to rotating machinery and geophysical flows. In our experimental setup, a free surface adds an original twist: at low rotation rates, the instability takes the form of large vortical structures at the fluid's periphery, with only a weakly deformed surface, while at faster rotation the centrifugally deformed free surface becomes actively involved in the instability. Our team has studied these flows for several years, but the connection between these two types of instability is still not well understood — and that is the question this project addresses. The goal of the internship is to take part in developing a linear stability code that accounts for free-surface deformation. The approach combines numerical simulations and experiments: you will collaborate with Yann Fraigneau (LISN, Paris-Saclay), who develops a 3D Navier–Stokes solver, and with Wen Yang's team at Civil Aviation University of China in Tianjin, which performs the experiments and has developed accurate measurement techniques for detecting instabilities and surface deformation. Working at this interface between computation and experiment, you will contribute to a better understanding of these intriguing flows and to more reliable predictions of their transition thresholds.

Project description :
Instabilities in rotating and recirculating flows driven by a rotating disk (or sometimes two disks facing each other) are a classic subject of study, because they are generic for understanding phenomena in rotating machinery and geophysical flows.



Figure 1. Artist view of the experimental setup.

The experimental setup (shown as an artist's view in figure 1) has allowed us to observe original instabilities arising from the presence of a free surface. At low rotation rates, the instability organizes itself into large vortical structures at the periphery of the fluid, with the free surface being only weakly deformed (figure 2, top row). At faster rotation rates, the free surface, strongly deformed by the centrifugal acceleration, becomes an integral part of the instability (figure 2, bottom row). Our team has made many advances over the past few years [1-5], but the link between these two types of instability remains mysterious, and our goal is to develop an arsenal of tools to better understand this link.

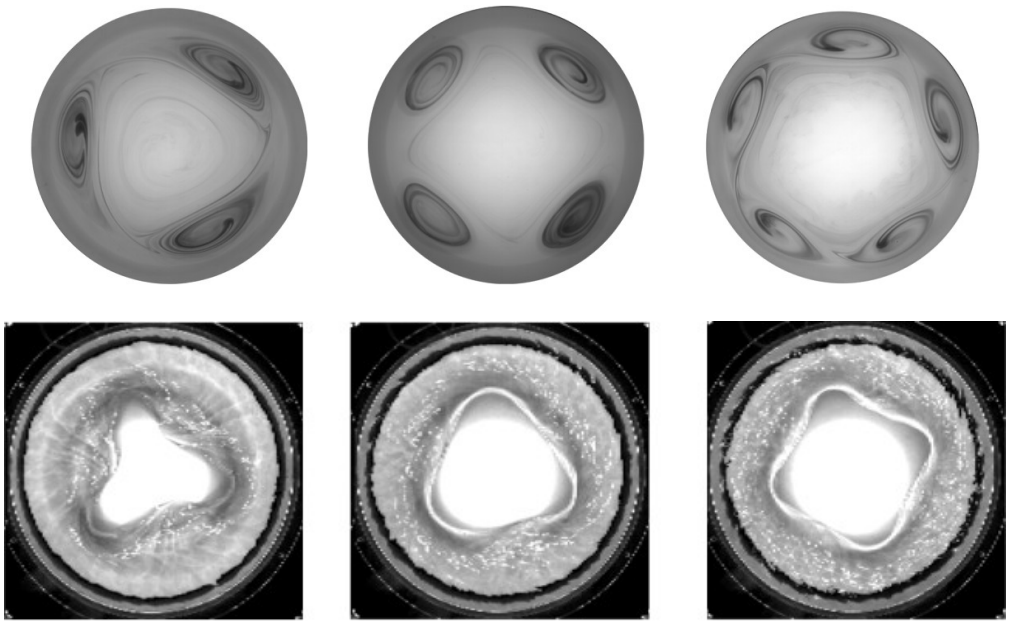


Figure 2. Typical instabilities observed in the set-up.

With an engineering approach, we are committed to ensuring that numerical simulations can be directly connected to experiments, which makes it possible to guide the development of computational tools, in particular for the reliable prediction of flow transition thresholds as a function of the control parameters: the initial fluid filling, the rotation speed of the disk, and the physical properties of the fluid, in particular its viscosity. The objective of the internship will be to participate in the development of a linear stability code that takes the deformation of the free surface into account. This work will be carried out in collaboration with Yann Fraigneau of the LISN laboratory in Paris-Saclay, who develops a three-dimensional code for the temporal integration of the Navier-Stokes equations, and with the team of Wen Yang at Tianjin University, who performs the experiments and has developed highly accurate measurement techniques for detecting instabilities and measuring the deformation of the free surface.

References :

[1] A. Faugaret, Y. Duguet, Y. Fraigneau & L. Martin Witkowski, A simple model for arbitrary pollution effects on rotating free-surface flows. J. Fluid Mech. 935, A2 (2022).
[2] A. Faugaret, Y. Duguet, Y. Fraigneau & L. Martin Witkowski, Influence of interface pollution on the linear stability of a rotating fluid. J. Fluid Mech. 900, A42 (2020).
[3] W. Yang, I. Delbende, Y. Fraigneau, & L. Martin Witkowski, Large axisymmetric surface deformation and dewetting in the flow above a rotating disk in a cylindrical tank: Spin-up and permanent regimes. Phys. Rev. Fluids, 5, 044801, (2020).
[4] W. Yang, X. Wang & L. Martin Witkowski, Dynamic three-dimensional measurement and analysis of rotating polygons. Phys. Fluids 36.9 (2024), p. 094122.
[5] W. Yang, J. Ruan & L. Martin Witkowski, Quantitative characterization of hysteresis in rotating polygon transitions. Phys. Fluids 37.9 (2025), p. 092130.