Hydrodynamic and morphodynamic instabilities of spatially developing thin films on soluble rockbeds

Proposal

Thin film flows are omnipresent in both natural and industrial settings. Understanding the dynamics and stability of thin films is essential to technological applications such as nano-lithography. Recently, the natural regularity of coating flow has been exploited to design an inexpensive and rapid fabrication technique of hemispherical elastic shells. By coating a curved surface with a polymer solution, a nearly uniform shell is obtained, upon polymerization of the resulting thin film[4]. The natural instabilities of these films can also be harnessed to produce well controlled soft lenses.

Figure 1: Centrimetric rillenkarren in Sardinia.

In the context of natural thin-film flows along soluble rock, the presence of a free surface may serve as a canvas to the formation of spectacular patterns. A viscous liquid layer on the underside of a horizontal plate, for example, destabilizes into an array of drops, which transforms into a comb of rivulets when the plate is inclined[1]. Coupled to a deposition process, this hydrodynamic instability can imprint patterns in limestone caves[3]. Reciprocally, dissolution is the sculptor of equally impressive patterns forming on upward-pointing rock faces with a remarkable regularity, *rillenkarren*. Open questions concern the pattern's wavelength selection given environmental conditions but also the basic hydrodynamic and physical mechanisms behind the phenomenon[2].

The *rillenkarren* formation falls within the general question of pattern formation and morphodynamics. Examples range from the hexagonal cells on salt lakes to the dendritic structure of snowflakes, suggesting the existence of robust mechanisms underpinning the *genesis* of such patterns. We will investigate the pattern forming role of the hydrodynamic instabilities of thin film coating flows coupled to the calcite dissolution in in karst structures overrun by water flow.

The present project continues our past efforts to understand the role of transient instabilities and nonlinearities in the formation of anisotropic patterns in lubricating coating flows by focusing on two important but still unexplored facets : the non-parallelism of the flow and its rigorous coupling to substrate deformation. We will in particular analyze the origin of the anisotropy in the more complex case of flows above the substrate where inertia, streamwise diffusion of momentum and solute all matter equally. The suggested approach is a combination of numerical and analytical techniques, which shall allow to determine pattern selection in these spatially varying flows. The fundamental hypothesis to be investigated in this project is that nonparallel and nonlinear mechanisms govern pattern selection in these geomorphogenetic coating flows. Special care will be taken in exploiting depth-averaged models, wherever possible. Finally, we will strive to reconcile the competing views on *rillenkarren* formation by continuous film flow and discrete raindrop impacts dissolution.

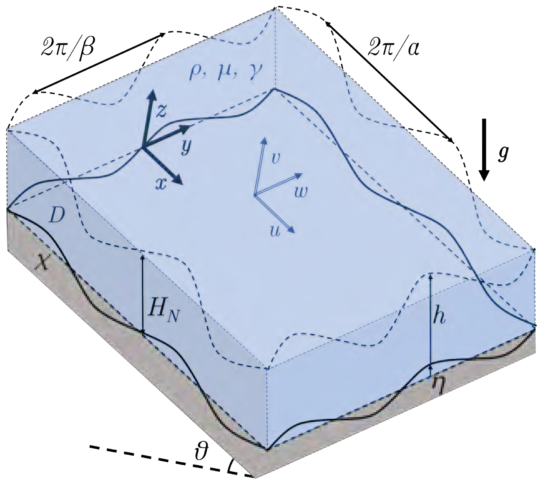

Figure 2: Sketch of coupled surface-rock interface deformation.

Profile

Essential: the candidates must hold a Master's degree (e.g. physics, engineering, or applied mathematics) and be highly motivated about theoretical/numerical aspects of fluid mechanics.

Desired: the candidates should have experience with flow stability, dynamical systems, weakly nonlinear analysis, reduced-order modeling, stochastic analysis, numerical methods, physico-chemistry, lubrication equations, ...

Additional information

The candidates will be part of the Laboratory of Fluid Mechanics and Instabilities (LFMI), which has a long experience in using hydrodynamic stability to study a wide range of topics from separated flows to jets and from microfluidics to thin-film flows. The group will grow significantly in the coming months with 5 new expected PhD candidates. The candidates will have to apply to EPFL's doctoral program in Mechanics. More information on admission at EPFL here. Applications of candidates with excellent files may be exceptionally considered outside of the formal deadlines found in these documents.

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References

[1] G. Balestra, N. Kofman, P. T. Brun, B. Scheid, and F. Gallaire. Three-dimensional Rayleigh-Taylor instability under a unidirectional curved substrate. *J. Fluid Mech.*, 837:19–47, 2018.

[2] M. B. Bertagni and C. Camporeale. The hydrodynamic genesis of linear karren patterns. *J. Fluid Mech.*, 913:A34, 2021.

[3] P. G. Ledda, G. Balestra, G. Lerisson, B. Scheid, M. Wyart, and F. Gallaire. Hydrodynamic-driven morphogenesis of karst draperies: spatio-temporal analysis of the two-dimensional impulse response. *J. Fluid Mech.*, 910:A53, 2021.

[4] A. Lee, P.-T. Brun, J. Marthelot, G. Balestra, F. Gallaire, and P. M. Reis. Fabrication of slender elastic shells by the coating of curved surfaces. *Nature communications*, 7:11155, 2016.