Proposal for a Master 2 internship

Effect of viscoelasticity on mucus clearance in the pulmonary airways.

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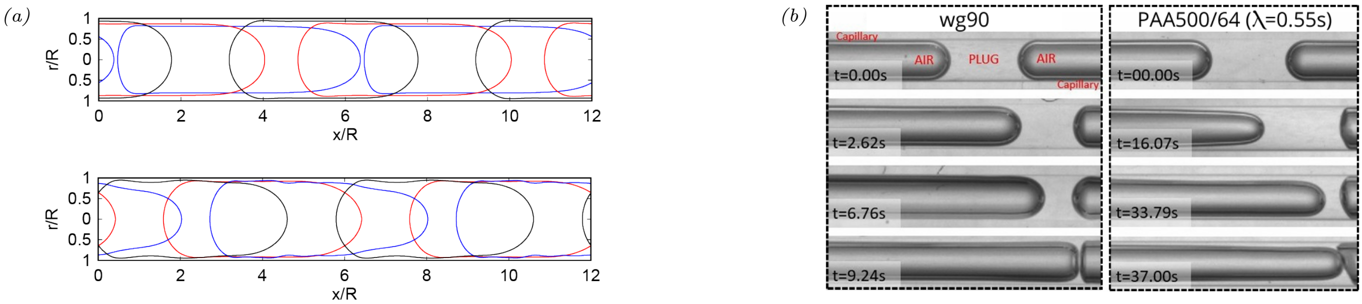

Figure 1: Rupture dynamics of liquid plugs within a cylindrical tube subject to a pressure difference Δp. *(a)* Preliminary simulations with `Basilisk` by Iris Fambart (M1). Time-constant Δp increased in steps (from black to red curves). Top: Newtonian liquid (μ=13 $\times$ 10^{-3} Pa s, σ=0.02 N m^{-1}), bottom: visco-elastic (μ=13 $\times$ 10^{-3} Pa s, σ=0.02 N m^{-1}, λ=0.01 s); *(b)* Preliminary experiments by Benjamin Thomas (M1). Time-oscillating Δp. Left: Newtonian (wg90); right: non-Newtonian (PAA500/64).

The clearance of mucus from the human tracheobronchial tree is ensured by two mechanisms. Firstly, mucociliary clearance, i.e. via the coordinated beating of cilia covering the epithelium. Secondly, via cough, i.e. a sudden increase in air flow rate, which produces a strong enough viscous stress and pressure gradient at the surface of the mucus film [1]. In both situations, the role of mucus rheology, and in particular its viscoelasticity, remains largely unknown, although its crucial character is recognized in the case of respiratory pathologies such as cystic fibrosis [2]. Reliable predictive models are essential [3], however, the complexity of the fluid-structure interaction between cilia and mucus as well as the three-dimensional airway geometry means that available numerical tools remain limited [4]. Via the CNRS-funded MUCUS project team, which involves researchers from FAST, LISN, ESPCI, Tokyo University of Science, and IIT Bombay, we investigate the hydrodynamics of both clearance mechanisms. In the current project, we will focus on the dynamics of liquid plugs resulting from airway occlusion events [6] under different breathing scenarios (normal breathing, assisted ventilation, cough):

- **Numerical axis:** Here, we will employ the academic solver `Basilisk` [5] to perform numerical simulations of liquid plugs subject to a time-constant or time-varying pressure difference. We will focus on the role of visco-elasticity in the rupture of liquid plugs. Preliminary results by Iris Fambart (figure 1a) suggest that visco-elasticity precipitates plug rupture, which may be the result of spatio-temporal oscillations within the residual film. Simulations will be performed on axisymmetric or fully three-dimensional computational domains, using the supercomputer RUCHE.

- **Experimental axis:** We aim to study the problem of occlusion events [6], which are of medical relevance, using a microfluidic model. The focus is on the dynamics and rupture of liquid plugs driven by a pressure gradient in viscoelastic fluids. Preliminary results obtained by the intern Benjamin Thomas (M1) highlighted the influence of viscoelasticity on the plug's shape and dynamics (Fig. 1b), an effect that remains to be further explored. In addition, the impact of a cough-like airflow will be investigated.

Depending on his/her skills and preferences, the intern will investigate either numerical or experimental axis. In both of them, solid background in fluid mechanics is expected.
Internship duration: 4 to 6 months. The internship can be followed in a PhD Research project starting in fall 2026.

References:
[1] M. King et al. J Appl Physiol, 58(6):1776-1782, 1985. [2] J. V. Fahy and B. F. Dickey. N Engl J Med, 363(23):2233-2247, 2010. [3] S. E. Spagnolie, editor. Springer, New York, 2015. [4] R. Levy et al. ICB, 54(6):985-1000, 2014. [5] S. Popinet and collaborators. Basilisk. `http://basilisk.fr`, 2013-2020. [6] S. A. Bahrani et al. JNNFM, 300:104718, 2022.