

Proposal for a Master 2 internship

Effect of viscoelasticity on mucus plug formation in the pulmonary airways.

with C. de Blois (Charlotte.De-Blois@universite-paris-saclay.fr), & G. Dietze & N. Grenier
Laboratoire FAST, Université Paris-Saclay, CNRS 91405 Orsay, France

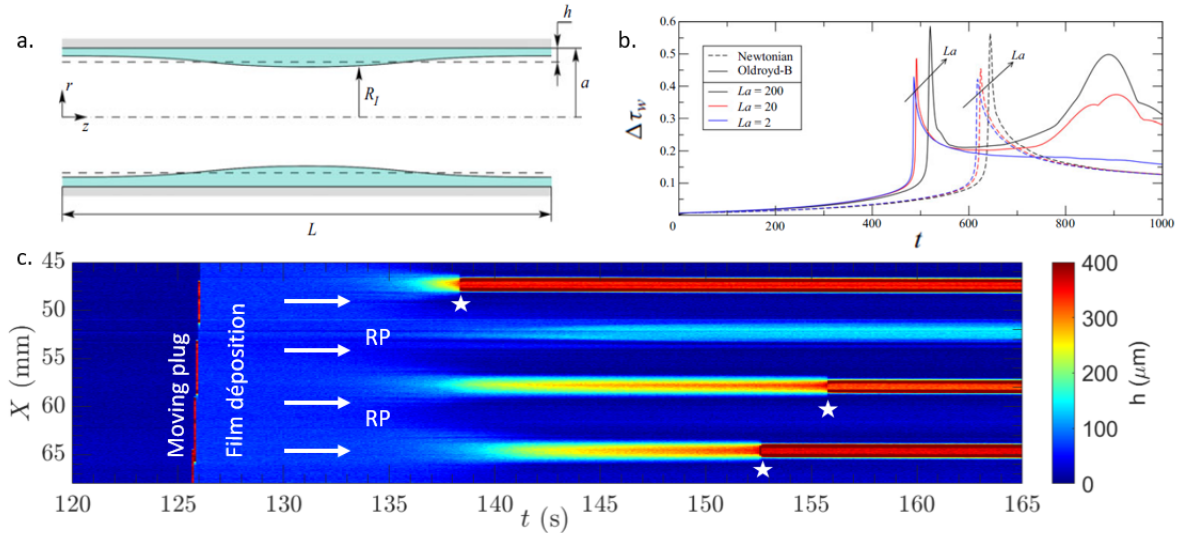


Figure 1: (a) and (b) from [1]. (a) Geometry of the airway model: the rigid tube has radius a , length L and is coated by a liquid film (light blue) of thickness h and surrounded by a gas core. (b) Tangential stress distribution along the wall for three Laplace numbers. Two constitutive models for the liquid phase, i.e. the Newtonian (dashed lines) and the viscoelastic fluid (Oldroyd-B model, solid lines), are compared. (c) Experimental observation of a Rayleigh-Plateau instability : a plug moving a constant velocity deposit a film of constant thickness in the channel. The film destabilise into a liquid bulge that grows through the Rayleigh Plateau instability, eventually forming a liquid plug (white stars).

The human respiratory system relies on mucus to trap and clear inhaled impurities, ensuring the protection of the airways. This clearance is primarily achieved through mucociliary transport-driven by the coordinated beating of cilia-and coughing, which generates high airflow rates to expel mucus. However, in respiratory diseases such as cystic fibrosis or chronic obstructive pulmonary disease (COPD), alterations in mucus production or composition disrupt its rheological properties. Excessive mucus production may leads to the formation of mucus plugs, which obstruct the airways and impair breathing. Furthermore, the formation of a plug might induce wall shear stress high enough to damage the epithelial cells [2].

In a cylindrical airway, Fig 1(a), mucus plug formation can be described by Rayleigh-Plateau as a destabilization of the liquid film coating the walls, where liquid bulge grow and coalesce to eventually block the airway [3]. Numerical studies [1] modeling the airway as a pipe coated with a viscoelastic liquid (e.g., Oldroyd-B or FENE-CR models) have shown that, for a sufficiently thick coating, the Plateau-Rayleigh instability leads to plug formation. While the pre-closure phase is dominated by Newtonian behavior, and induces a first peak of wall shear stress, viscoelasticity plays a critical role in the post-coalescence process, introducing a second peak linked to an elastic instability from polymeric stresses, Fig 1(b), potentially inducing a second damaging response in epithelial cells.

This internship will focus on experimental investigations using artificial mucus to observe plug formation in real time, Fig 1(c). High-speed, high-resolution imaging will capture the shape of a plug in a cylindrical glass channel during formation, allowing us to infer their relationship with wall stress. Understanding this link is vital, as excessive stress can damage epithelial cells, exacerbating respiratory conditions.

Internship duration: 4 to 6 months, with the possibility of continuing in a PhD research project starting in fall 2027.

References: [1] F. Romano et al. JFM, vol. 913, A31, 2021. [2] Gauglitz et al. Chem. Engng Sci. 43, 1457-1465, 1988 [3] S. Bian et al. JFM, 647:391-402, 2010