



Liquid-gas entrainment as a Landau-Levich Drag-in flow

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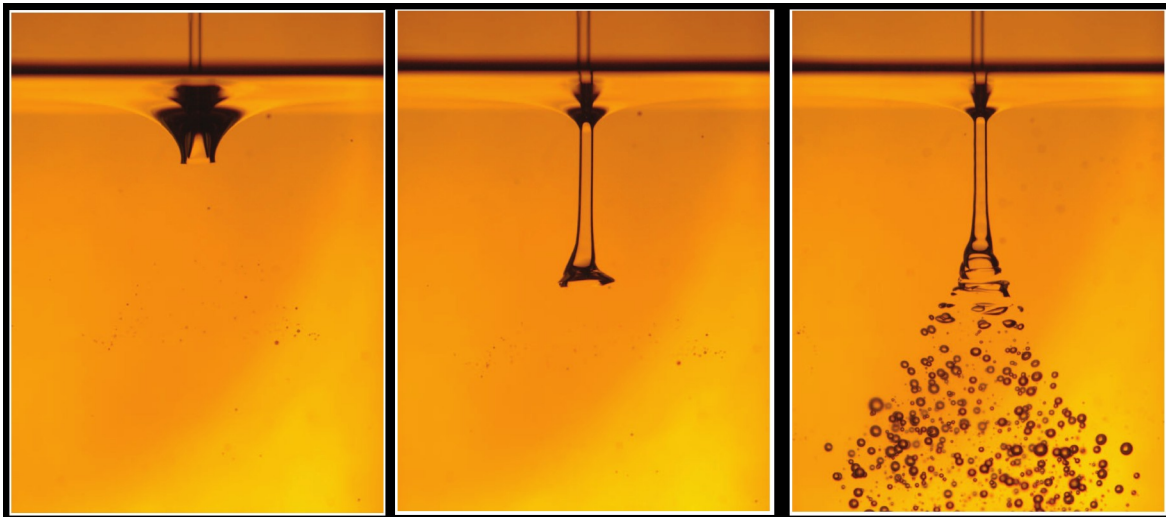
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Résumé : Landau-Levich problem in fluid mechanics is the study of the liquid film deposited on a moving plate when it drag-out liquid from a pool [1]. It is a canonical situation of crucial importance for all film coating processes. When a liquid jet plunges into a pool, and if the impact speed is sufficient, it can drag-in a thin air film along with it. This situation is analogous to the Landau-Levich problem wherein a moving liquid interface drags air into a pool of water. In fact, the quantity of air dragged-by a moving liquid interface is crucial for all plunging jet applications where air bubbles entrained during impact greatly influence industrial processes. We propose to investigate, using Direct Numerical Simulations, the viscous entrainment of a semi-infinite layer of gas into a liquid by a plunging jet.



Figure

1: A plunging viscous jet: (left) Cusped free surface; (middle) Film of air penetrates into the pool; (right) Entrained air film breaks-up into bubbles.[3] .

Sujet développé :

Photographs in Figure 1 from Reyssat et al. (2008) presents the morphology of a plunging viscous jet. On the left, the jet struggles to penetrate into the pool. But it spectacularly curves the air-liquid interface into a cusp -- a singular structure wherein the planar interface curvature increases exponentially with liquid viscosity μ , jet speed U and surface tension σ i.e., $\exp(\mu U/\sigma)$ [2]. As the jet speed increases, the lubrication force due to air flow reversal at the cusp (see Figure 2) can overcome surface tension and liquid shear stresses. This leads to rupture and air entrainment into the pool via a distinct air-water trumpet in Figure 1 (middle). Air entrainment in the form of bubbles

cannot be fully understood without a proper understanding of the physical origin of shape of trumpet, and the flow in it leading to rupture into air bubbles. One of the main aspect of the air-water trumpet is the air-film thickness due to plunging jet. However, both the cusp and the air-film flow after its rupture had never been studied using Direct Numerical Simulations. So, we propose to numerically explore two paradigms of air-liquid interface flows: (i) Flow in the vicinity of a viscous cusp as in Figure 2 (right), (ii) Viscous air film flow shown in Figure 1 (middle) wherein the jet drags-in air along with it. In the former case, we wish to impose a stagnation flow at the center of an initially horizontal interface. Thereby, we will study the free-surface deformation as the flow intensity is increased, for various liquid viscosity and surface tension. The rupture of the cusp will then be analyzed. In the latter case, the classical Landau-Levich flow due to a moving solid wall will be modified to properly take into account the air-liquid interface and the presence of hydrostatic pressure.

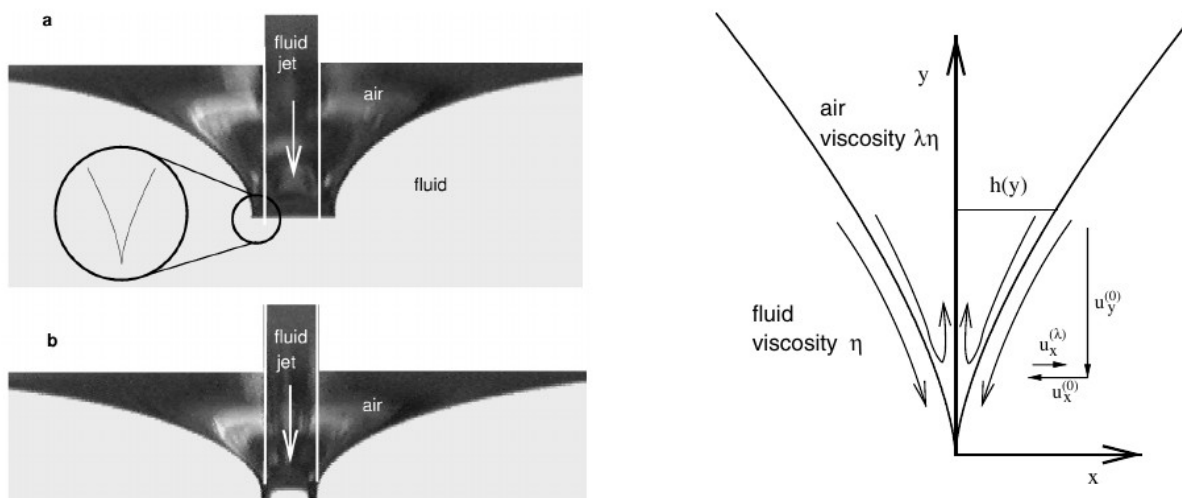


Figure 2: Air-water cusp due to jet impact, as depicted by Eggers (2001) [3]. Photographs (left) of jet impact and a schematic (right) of the air reversal flow at the cusp singularity are provided.

In the course of this internship, we wish to investigate the mechanism of air entrainment by a moving column of liquid in a pool using Direct Numerical Simulations. A description of the resulting sheet of air and its stability shall then be studied. Basilisk Flow Solver [5] is an open-source for Direct Numerical Simulation of multi-phase flows. It has been successfully used to make robust simulations of complex two-phase flows, including hydrodynamic instabilities of entrainment flows [5].

References:

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- [2] Reyssat, E., Lorenceau, E., Restagno, F., & Quéré, D. (2008). Viscous jet drawing air into a bath. *Physics of Fluids*, 20(9).
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