DYNAMICS OF A DROP TRAPPED INSIDE A CIRCULAR HYDRAULIC JUMP

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Summary We investigate the dynamics of a drop trapped inside a circular hydraulic jump : in our experiment, a circular hydraulic jump is formed by a viscous jet impacting a horizontal glass disk. A drop of the same liquid, deposited in the jump does not coalesce, and remains trapped at its periphery, because of the air entrainment linked to the high drop rotation speed. Depending on the flow rate, the drop can exhibit complex dynamics, from regular rotation along the jump to "chaotic" behaviour. We also studied in detail hydrodynamics of the liquid drop and its interaction with the jump.

INTRODUCTION

There is presently growing interest in the dynamics of levitating liquids such as in the Leidenfrost effect[1], or in the situation of delayed coalescence between liquids[2, 3, 4, 5]. These conditions arise when a very thin layer of air or vapor remains trapped at the interface preventing the liquid from spreading on a solid or from coalescing with a free surface of the same liquid. These unusual situations of nonwetting give rise to surprising liquid dynamics of great fundamental interest. One can refer for instance to Poincaré's figures of equilibrium observed by Aussillous and Quéré for drops coated with hydrophobic grains rolling down a solid substrate, or to the striking particle-wave duality evidenced by Couder et al. on drops walking on a vibrated liquid.

HYDRAULIC JUMP

We consider here another system : a circular hydraulic jump[7, 8, 9] is created by impacting a vertical jet on an horizontal plate. A drop of the same liquid is deposited inside the jump and is trapped along the jump as shown on figure 1. The jump is the transition between a supersonic flow near the jet (high velocity, low height) and a subsonic flow (low velocity, high height).

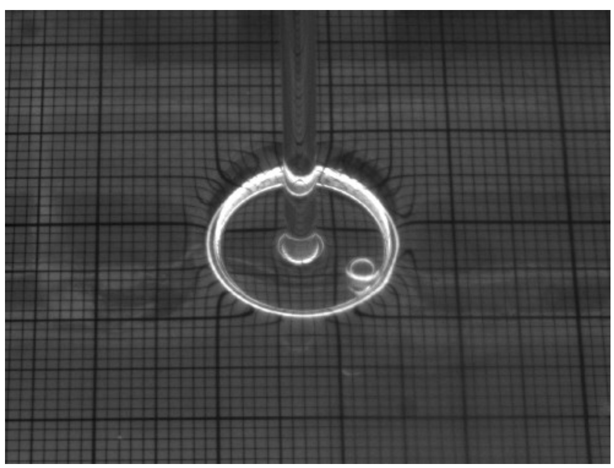

Figure 1 : *The hydraulic jump and a drop trapped along the jump*

The interaction between the jump and a drop of the same liquid have been previously studied in the case of very large drop[5] : the drop is trapped on the jump and is stationary where a thin film of air driven by the flow prevents coalescence. We also studied the case a small drops inside a slightly inclined jump[10] : nontrivial oscillatory dynamics of the drop are observed along the lowest point of the jump and can be interpreted by a model leading to a gyroscopic instability.
Here we present experiments with an horizontal jump leading to a striking dynamical behavior of the drop that rotates around the jump.

DYNAMICS OF THE DROP INSIDE THE JUMP

Depending on the size of the drop a and on the flow rate Q, different dynamics are observed. Figure 2 presents space-time diagrams of the motion of the drop inside the jump ; the angular position of the drop inside the jump is represented as a function of time :

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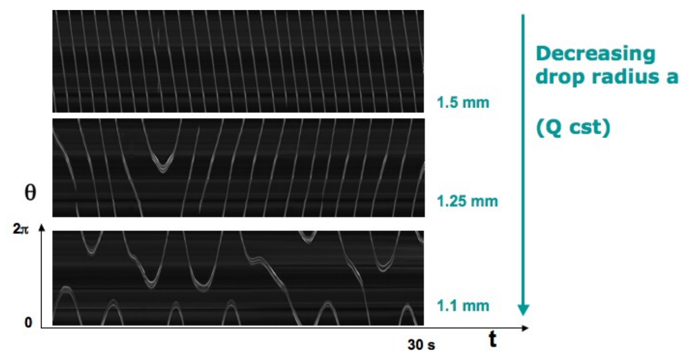

Figure 2 : *Space Time diagrams of the drop motion for different drop sizes a at constant flow rate Q.*

In the first case (drop size $a = 1.5$ mm), we observe a very regular rotation of the drop inside the jump at constant velocity. In the second case (drop size $a = 1.25$ mm), the rotation is still regular, at constant velocity, with just an inversion of the rotation direction. We refer for such cases as "intermediate behaviour". In the last case, for the smallest drop ($a = 1{,}1$ mm), the motion becomes very irregular with frequent changes in the direction and the velocity : "chaotic" behaviour.

The phase diagram

We present on figure 3 a phase diagram showing the behavior of the drop : a is the drop radius and R is the jump radius which is directly related to the flow rate Q : $R \propto Q^{5/8}$.

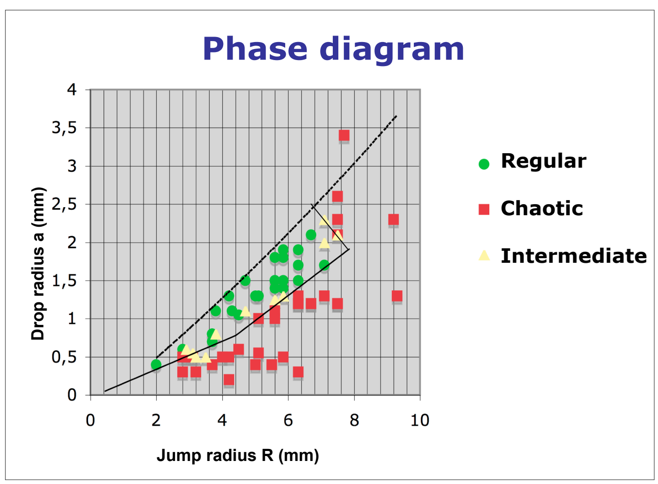

Figure 3 : *Phase diagram for the drop rotation inside the jump.*

Separation lines in the phase diagram can be interpreted by steric considerations (upper line) or interaction between the drop and the jump (transition to "chaos").

We also investigated internal motion inside the drop and observed different regimes for the internal rotation of the drop depending on its size.

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