

# ATOMIZATION OF AN UNDULATING LIQUID SHEET

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**Summary** This paper presents an experimental study devoted to the understanding of break-up mechanisms of liquid sheets. A shear instability develops at the interface liquid/gas resulting in an undulated motion of the liquid sheet. These undulations trigger a Rayleigh-Taylor instability leading to azimuthal thickness modulations. A model including the development of both instabilities allows us to predict the sheet and drops sizes.

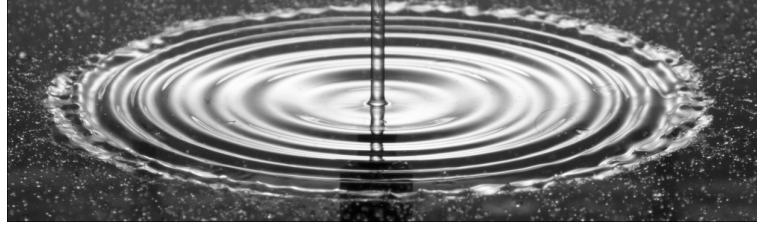


Figure 1: Snapshot of a liquid sheet formed by the impact of a round jet on a vertically vibrating solid rod.

## INTRODUCTION

The atomization of a liquid sheet into dispersed droplets is a widespread phenomenon embracing many natural and industrial processes [1]. The main questions of the atomization are the following: how does a compact volume of liquid become a set of drops and what is the resultant drops size distribution? Here, we focus on the break-up mechanisms of a laminar liquid sheet expanding in air initially at rest. In this case, two regimes exist: a smooth regime, without interaction with the surrounding medium, and an undulated regime corresponding to the development of a shear instability at the interface liquid/gas [3]. For the second regime, the role played by the undulations in the atomization process is not yet well defined. We first describe the experimental set-up used for control the surface oscillations and present the observations on the liquid sheet features. Then a model is suggested for explain this fragmentation regime in presence of undulations and finally compared with experiments.

## EXPERIMENTS

### Experimental set-up

The studied liquid sheet is formed by the normal collision of a water jet on a solid rod. The impact rod diameter is twice larger than the jet diameter  $d_j$  which is equal to 3 mm. After the collision, the liquid expands radially forming a sheet shaped like a disk. The velocity in the sheet is constant and equal to the jet velocity  $u_j$ . The sheet thickness  $h$  decreases like  $1/r$ , where  $r$  is the radial location.

For low jet Weber numbers  $We = \rho d_j u_j^2 / \sigma$  where  $\rho$  is the liquid density and  $\sigma$  is the surface tension, the sheet stays flat, it is the smooth regime. If the Weber number increases, by enhancing the jet velocities in the present experiment, the sheet becomes unstable and flaps like a flag, it is the flapping regime. The critical Weber number is about 1000 in presence of air. In order to study this second regime, the impact rod is fixed on a vibrator which oscillates vertically. We perturb the initially stable sheet (smooth regime) with an amplitude  $a_0$  and a frequency  $f$  independently controlled. An example is shown on figure 1.

### Observations

As we can see on figure 1, the oscillation of the impact rod creates circular waves. These waves propagate towards the free rim of the sheet with a decreasing wavelength. The wave frequency is equal to the imposed one and the wave velocity decreases during their propagation. This means that the contrast velocity between the liquid and the waves increases with  $r$ , this will be crucial in the fragmentation scenario. Below a critical frequency, which increases with  $u_j$ , the wave amplitude is constant along a radius and nearly equal to the vibrator amplitude. Above this critical frequency, the amplitude is amplified and can reach a value 40 times larger than  $a_0$  for the highest jet velocity.

The sheet size increases with the jet velocity in the smooth regime then decreases in the flapping as noted by the Savart [2] in 1833. In our experiments, whatever the jet velocity the sheet extension decreases when the frequency or the amplitude of the perturbation are enhanced. An other consequence of the surface undulations

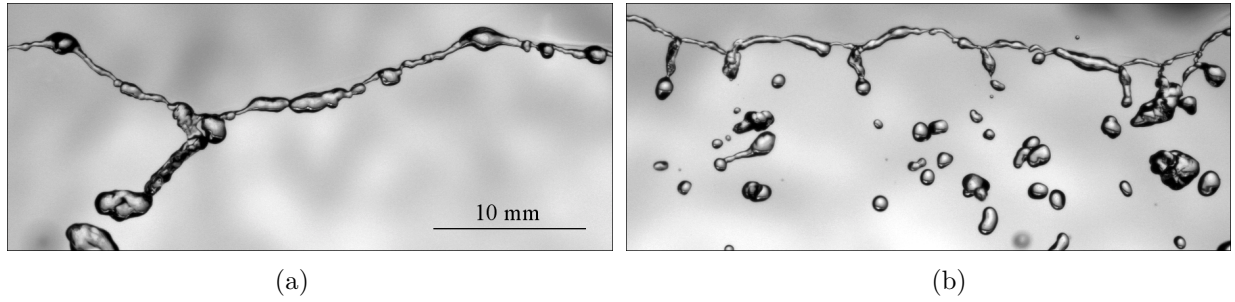


Figure 2: Top views of the free rim of a smooth liquid sheet (a) and a perturbed liquid sheet (b). The length scale is the same on each picture.

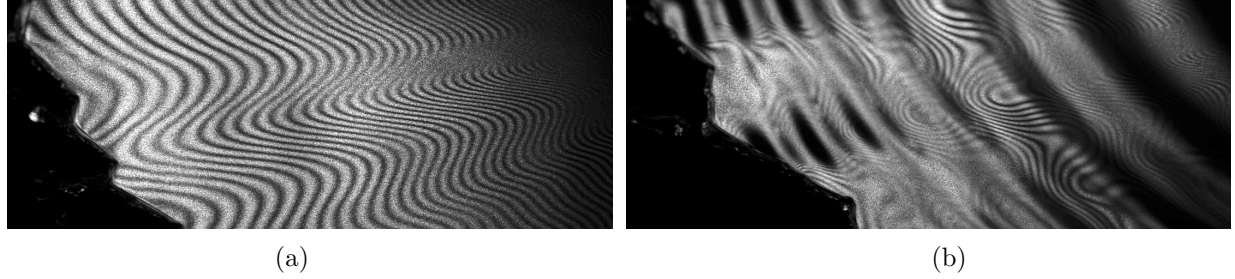


Figure 3: Thickness profiles revealed by a laser interferometric method of a liquid sheet without rod vibration (a) and with rod vibration (b).

is to diminish the drops size. The sheet is bounded by a set of cusps at the tip of which ligaments emerge and break, figure 2 . The distribution of the drops size normalized by the mean drops size has an unique shape independent of the control parameters ( $u_j$ ,  $f$  and  $a_0$ ). Therefore, if we can predict the mean drops size we know how the sizes are distributed in the spray.

The figure 3 presents the thickness field revealed by an interferometric method. The free case on figure 3a shows an azimuthal modulations of the interference fringes interpreted by a transverse thickness variation. The undulations enhance the initial thickness inhomogeneities, figure 3b.

### ATOMIZATION SCENARIO

Because of the velocity difference between the air and the liquid, the sheet develops a shear instability. The features of the waves (frequency, velocity, amplitude) are well described by a linear stability analysis [3]. The velocity contrast between the liquid and the waves induces an acceleration of the fluid particles as they move through the undulations. Higher the contrast is, larger the acceleration. This situation trigs a Rayleigh-Taylor type of instability [4] which amplifies initial thickness inhomogeneities observed on figure 3a.

The position of the rim can be deduced by a local balance between inertia of the fluid and capillary force which pulls back the rim. This balance depends on the local sheet thickness. The thickness field is deduced from the linear analysis of the development of the primary and secondary instabilities. The evolutions of the sheet size with the control parameters are well predicted by this scenario.

As shown on figure 2, the drops are the product of ligaments break-up which are formed at the tip of cusps bounding the sheet. The ligament formation is interpreted as a collision with coalescence of two jets representing both side of a cusp. The shape and the diameter of the free rim depend on the field thickness and impose the ligaments diameter and so the drops size. This model predicts a mean drops size in a good accordance with the experimental data.

[1] for example: Bayvel, L. and Orzechowski, Z. 1993 *Liquid atomization*. Taylor & Francis.

[2] Savart, F. (1833) Mémoire sur le choc de deux veines liquides animées de mouvements directement opposés. *Ann. de chim.* **55**, 257-310.

[3] Squire, H.B. (1953) Investigation of the stability of a moving liquid film. *Brit. J. Appl. Phys.* **4**, 167-169.

[4] Taylor, G.I. (1950) The instability of liquid surfaces when accelerated in a direction perpendicular to their plane. I *Proc. R. Soc. Lond. A* **201**, 192-196.