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VORTEX SHEDDING FOR DROP CREATION

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Summary Atomization is the process by which a liquid body may become a cloud of droplets. This happen through a cascade of instabilities. This is often done using the Kelvin-Helmholtz instability in the configuration of a two-phase mixing layer: the liquid and a stream of gas. We describe the creation of droplets by following the evolution of a self-similar solution of this system: a nonlinear localized wave. We show that vortex shedding downstream of this wave is an important event for the creation of drops, and demonstrate that the large ejection angle for the drops is due to a centrifugation mechanism during the shedding.

INTRODUCTION

The configuration that we consider is shown in figure 1. There is a fast gas stream on the top of a slow liquid stream (air and water). The two streams are put into contact just after a splitting plate. The configuration is a two phase mixing layer. For a general discussion of atomization, please see [Eggers & Villermaux(2008)]. The liquid contains a fluorescent dye and is illuminated both using ambient light and a vertical laser sheet in order to see the 2D structure of the wave of instability and to have as well insights on the three dimensional structure of the process. The wave is of large amplitude and shelters in its wake a gas recirculation vortex. For large density ratios between the gas and the liquid, as for here with air and water, the vortex tends to leave the wave in a sequence of events reminiscent of vortex shedding behind a bluff body.

The picture is extracted from an high speed movie recording of the phenomenon, just at the time where the top of the wave bursts into a cloud of droplets. The purpose of this work is to associate this atomization event with the shedding of the recirculation vortex. The video of made in the two-phase mixing layer experimental set-up described in [Matas *et al.*(2011)].

Since the density of the liquid is much larger than that of the liquid, the velocity of the wave is slow. For this reason, the liquid body of the wave appears to the fast gas stream almost as a fixed obstacle. This induces first a deflection of the gas stream and a local acceleration of the gas particles. This acceleration induces a pressure drop, which is responsible for the growth of the wave. This gas-liquid interaction takes the form of a self-similar wave whose growth is algebraic. This nonlinear wave is studied in details in [Hoepffner *et al.*(2011)].

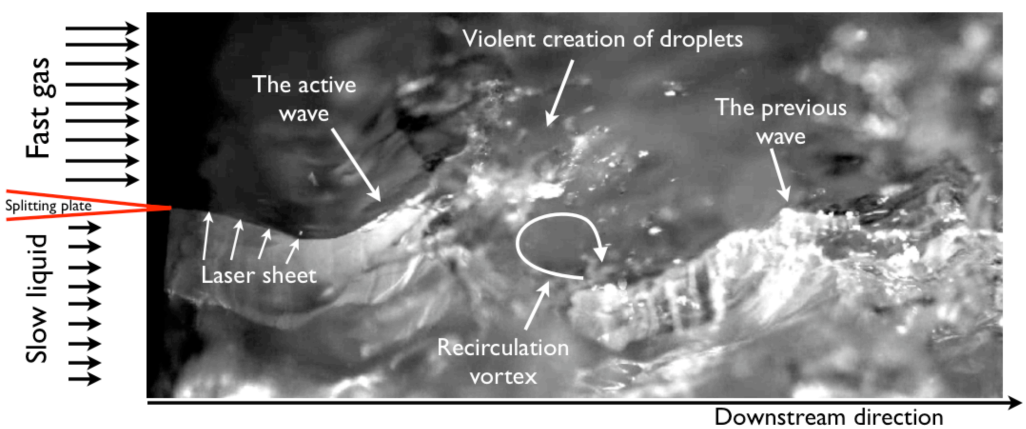

Figure 1. Description of the configuration of our study; here using an image extracted from an high speed video recording of the instability. The liquid surface is lit using ambient light and a vertical laser sheet.

CENTRIFUGATION DURING THE SHEDDING

Figure 2 shows the process of shedding and drop ejection from simulation of the Navier–Stokes equations. We have represented the liquid interface evolving in time, showing the shape of the wave and the droplets. The instantaneous streamlines are shown in light gray. We see here two shedding events. We have highlighted the position of the vortices using a red dot.

The Navier–Stokes equations are solved in a periodic computational domain using the open source software Gerris Flow Solver. The discretization uses the finite volume scheme and the liquid/gas interface is tracked using the Volume Of Fluid

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method, see [Popinet(2009)].
In our simulations we observe the vortex shedding when the gas density is less than about 0.05 that of the liquid. The result shown in figure 2 corresponds to a density ratio of $r = 0.02$.

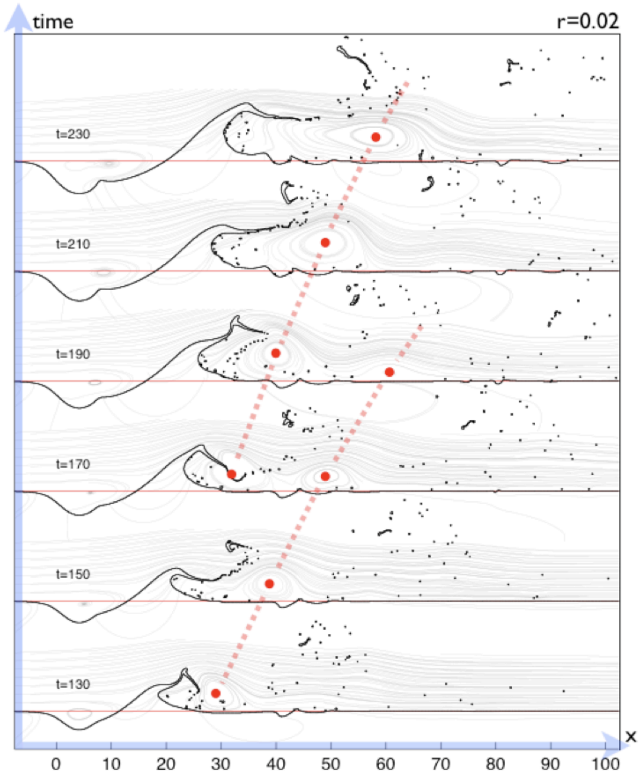

Figure 2. Numerical simulation of the wave in a periodic domain, showing as a black line the liquid-gas interface and the streamlines in light gray. The vortex are highlighted by a red dot at their center.

We can understand the sequence of the shedding as follows: initially, the flow is detached, the gas stream is deflected upward and leads to a vortex downstream of the wave. Since the wave is slow this vortex detaches. Just after detachment the gas flow reattaches, as shown on the figure at time $t = 150$. Since this flow is attached, it carries with it downward the liquid tongue of the wave. This tongue is a thin liquid film, which is light with a large surface of interaction with the gas. Shortly after, a new vortex is created behind the wave, at a time when the liquid film is still in its low position. Thus, the liquid is trapped inside the newly created vortex. The last part of this process can now happen: as the vortex is gaining strength through the roll-up of the gas shear layer due to the reattachment, the liquid is centrifuged and violently sent off upward. We observe this for instance at time $t = 210$ and $t = 230$.

CONCLUSION

The mixing layer is a flow configuration for which initially all the velocity is horizontal. An the other hand we observe in atomization scenarii that the droplets created from the two-phase instability are ejected with a high angle. This supposes a mechanism for transformation of the horizontal momentum into vertical momentum. There is an analogy with athletics: the pole vaulter is able to accumulate a large horizontal momentum by running along the track, and needs to transform this horizontal momentum into hight. This transformation can be smoothly operated through the use of the elastic bending of the pole. For atomization, the vortex plays the same role as the pole: by its rotation, it can act such as to redistribute the direction of the momentum, leading here to ejection of the drops away from the active regions where they were created.

References

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