Study of liquid destabilization and stripping in a liquid-gas mixing layer

Jean-Philippe Matas [a)], Sylvain Marty & Alain Cartellier
LEGI, CNRS-Université de Grenoble,
BP53 38041 Grenoble Cedex 9 France

Summary We study experimentally and analytically the atomization of a liquid sheet by a parallel gas flow, in order to understand the conditions of destabilization of the liquid sheet and the conditions of drop creation. The inviscid stability analysis of the system is carried out with a velocity profile taking into account the wake of the splitter plate (zero speed at the height of the splitter plate): the influence of liquid velocity on the shear instability frequency turns out to be significantly stronger for this type of velocity profile than for classical ones. Frequency measurements carried out by a spectral method show a good agreement with this corrected law.

Based on the drop production mechanism proposed in previous studies, we then look via optical probe measurements at the size distribution of the drops produced downstream. The difficulty of these measurements resides in the decrease of the numerical drop flux at low dynamic pressure ratio M. Results obtained for the mean chord are consistent with previous studies. Diameter distributions can be obtained from chord distributions with a numerical conversion procedure, and confronted to expected distributions.

LIQUID DESTABILIZATION

Modern turbojet or cryogenic engines use two-phase nozzles to feed their combustion chamber with fuel and comburant. This kind of injection turns a liquid flow into a homogeneous spray under the action of a fast gas stream. A good quality of this mixture is needed to optimize combustion. Our experimental set-up models an injector with an infinite diameter and a large liquid flow thickness. With this geometry we avoid any 3D instability, like the flapping instability of a round liquid jet. Our injector is composed of two parallel channels: The channel below is fed with water from an overflowing tank. Liquid velocity is in the range 0.1 to 1 $m.s^{-1}$. The upper channel receives a gas stream from a compressor. The maximum gas velocity is near 100 $m.s^{-1}$. In order to limit velocity perturbations, honey combs are inserted in each channel, a porous plate in the gas one, and each channel ends with a smooth convergent profile. In addition to the geometrical characteristics of the nozzle and fluid properties we have two main parameters controlling the injection: gas velocity U_g and liquid velocity U_l.
Previous studies carried out on this set-up have highlighted successive mechanisms of destabilization [1]. First a shear instability controlled by the gas vorticity thickness has been clearly identified: this Kelvin-Helmholtz type instability induces longitudinal waves. On the crest of these waves a transversal instability takes place, a Rayleigh-Taylor instability caused by the acceleration of the liquid. The transversal perturbations are then stretched into ligaments, and eventually break into droplets.

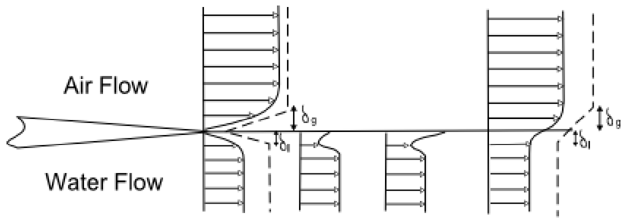

Figure 1: spatial variation of the mean velocity profile

One of the difficulty in the stability analysis is the choice of a relevant velocity profile for both flows. For their study Raynal et al (1997) used the final profile far downstream the injection (see figure 1), but neglected the vorticity thickness in the liquid flow [2]. They also showed that in the case of an inviscid analysis, the smooth velocity profile (solid line of figure 1, far from injection) can be modelled by a linear one (corresponding dashed line of figure 1). A new approach, by Matas et al (2011), takes into account the wake due to the splitter plate [3]. The stability analysis is therefore carried out with the dashed profile represented at the end of the splitter plate: The frequency of the most unstable mode is predicted to scale as $\omega_r=(\rho_g/\rho_l)(U_g/\delta_g)(1+(5/2)\sqrt{2}M^{-1/2})$. In order to compare this prediction to the experimental frequency, we use a LIF method. Fluorescein is mixed in the liquid phase, a longitudinal section of the flow is made with an Argon laser, and a high speed camera (Phantom V2) records flow motion in this section. Post treatment of the movie uses a Sobel filter to localize the water surface. We therefore obtain the position *h* of the surface as a function of time and downstream position. A Fourier transform of *h* yields the desired frequency, see figure 2a. The dimensionless frequency is plotted as a function of $M^{-1/2}$. Experimental series (◦, □ ,× and •) , display each gas velocity used, respectively 12, 17, 22 and 27 m/s. The dotted line corresponds to the prediction without a velocity deficit, and the solid line to the prediction above. Experimental points are collapsed around the solid line for all M, in agreement with the analysis where the deficit is included. From the interface position *h* as a function of downstream distance we can also extract the spatial growthrate k_i: A significant processing has to be carried out, see reference [3], in particular to exclude rare events. Figure 2b shows k_i as a function of gas velocity. The growthrate is mainly a function of gas velocity, and not M: this behaviour is not predicted by the inviscid stability analysis. We

[a)] Corresponding author. Email: matas@hmg.inpg.fr

believe it results from the large amplitude of the waves, which will itself impacts gas flow, a non-linear mechanism not included in the stability analysis.

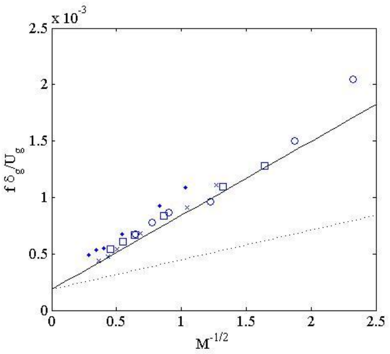

Figure 2a: measured frenquency vs prediction

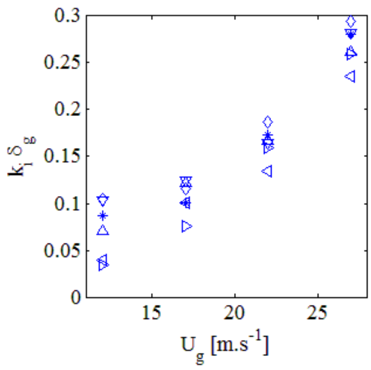

Figure 2b: measured spatial growthrate

DROP SIZE MEASUREMENTS

We now focus on droplets, produced at the last step of the atomization mechanism. Droplet size is measured with an optical probe. For detailed information about this device and the methodology, see references [4] and [5]. The optical probe has to be at the same position relative to the flow for all conditions: On a vertical axis, it is aligned with the splitter plate, and its downstream position is at the end of the theoretical liquid intact length L, given by $L/2H_l=6/\sqrt{M}$, where H_l is the initial height of water. Marmottant & Villermaux (2004) showed that the mean droplet diameter is proportional to the volume of the ligaments created by the transverse Rayleigh-Taylor instability. The size of ligaments being a function of the wavelength of the R-T instability, drop size can be expressed as a direct function of U_g (Hong 2003 [6]). This model is shown as a dotted line on figure 3. Results for drop size are presented in terms of the mean chord C_{10}, which is directly yielded by the optical probe, and which is directly proportional to Sauter diameter d_{32}. There is a good agreement between experimental measurements and the model for M=16. For smaller M ratios there seems to be a departure to this trend, possibly indicating a different mechanism. Finally, chord and diameter distributions were measured, and confronted to distributions issued from drop break-up mechanisms: Gamma distributions, expected at the end of the break-up process [1], are not able to fit satisfactorily these distributions. An exponential law provides a better fit to our experimental data, in particular for large diameters.

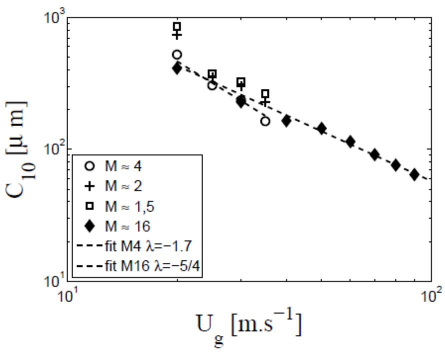

Figure 3 : mean chord as a function of gas velocity.

CONCLUSIONS

We have carried out frequency and spatial growthrate measurements for the shear instability of a planar two-phase mixing layer. Experimental frequencies were found to agree with the prediction of a linear stability analysis including a velocity deficit at the interface, while experimental growthrates were much larger than predicted, and exhibited a dependence on U_g not predicted by the analysis. Droplet size measurements were carried out with an optical probe. For M= 16, drop chord and volumetric flux follow the scaling law predicted by known mechanisms, in particular $C_{10} \sim U_g^{-5/4}$. For low dynamic pressure ratios, a different mechanism might be at play.

References

[1] P. Marmottant and E. Villermaux, "On Spray Formation", J.Fluid Mech.,498, **73** (2004)

[2] L. Raynal, E. Villermaux, J. Lasheras and E.J. Hopfinger ``Primary instability in liquid gas shear layers''. In 11th Symp. on Turbulent Shear Flows, **3**, 27.1 - 27.5, Sept. 7-10 Grenoble, France, OCLC 40626641, INP-CNRS-UJF (1997).

[3] J.P. Matas, S. Marty, A. Cartellier, ``Experimental and analytical study of a shear instability of a gaz-liquid mixing layer'' , Phys. Fluids, **23** 094112 (2011)..

[4] A. Cartellier and F. Ben Rayana,``Dispersed phase measurements in sprays using optical probes'', 3rd International Symposium on Two-Phase Flow Modelling and Experimentation (Pisa, 22-24 September 2004).

[5] M. Hong, A. Cartellier and E Hopfinger, ``Characterization of phase detection optical probes for the measurement of the dispersed phase parameters in sprays'', Int. J. Multiphase Flow **30** 615-648 (2004).

[6] M. Hong. Atomisation et mélange dans les jets coaxiaux liquide-gaz. PhD thesis, Institut National Polytechnique de Grenoble, 2003.