Wavelet analysis of an unsteady air-blasted liquid sheet

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Abstract

In fluidmechanics wavelets analysis has been often used for modeling and simulation of turbulent flows, since the wavelets methodologies may help in representing the time fluctuations of the power spectra of the turbulent intensity and/or flow velocities. A large aspect ratio air-blasted liquid sheet is very suitable to study the complex mechanisms behind atomization, and in particular, the onset and growth of the instabilities that may lead to the liquid break up. The usual way to define the liquid sheet dynamics is either to measure through a microphone the pressure fluctuations near the sheet or to indirectly measure the sheet thickness through the obscuration of a laser beam. From the time series of such signals, it is possible to evaluate a typical frequency which is related to the liquid instabilities. Such methods are accurate for stationary conditions of the air-blasted liquid sheets, even if there are experimental evidences that various dynamics regimes may occur, changing the typical frequency for a given water and air velocity. The changes may consist in variations in time and in space, since there are transitions of the power spectra in time for a fixed position and in space for a short time interval, as captured by a high speed camera.

Introduction

In fluidmechanics wavelets analysis has been often used for modeling and simulation of turbulent flows, since the wavelets methodologies may help in representing the time and space fluctuations of the turbulent flow parameters [11]. Such methods may be applied also to free interface flows, such as liquid sheets and sprays, in order to characterize the regime transitions and give a robust mathematical description of the variation of typical frequencies either in the velocity field or in other dynamical parameters, such as the sheet thickness.

Over the last few years, the large aspect ratio air-blasted liquid sheet has been extensively analyzed to study the complex mechanisms behind atomization, and in particular, the onset and growth of the instabilities that eventually lead to the liquid break up. Although the first studies on liquid sheets initiated at the end of 19th century [1], only starting from 1980 [2,3] researchers are investigating experimentally the complex phenomena of the liquid break-up in air-blasted configurations. The analysis of instabilities needs a very accurate initial and boundary conditions, and for many studies only a phenomenological analysis is useful [4-6], since the possible discrepancies and the different regimes may be linked with the uncertainties of the nozzle profile, size or of the flow rates. Even if the set-up is well known and the statistical accuracy of the measurements is very high, the liquid sheet oscillations of increasing amplitude and eventually, the break-up, remain difficult to be described in a mathematical way [8-9]. Both the power spectra or the time series may represent only a given status in time and space of the liquid sheet, without offering to the researcher a more general scheme to exchange information and to define the kind of transition which eventually occurs.

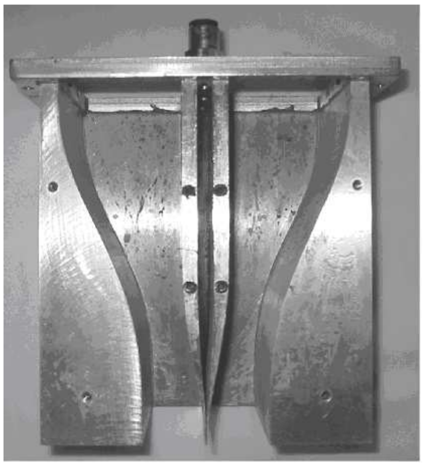

Figure 1: View of the nozzle head

Experimental setup

The test rig in which the present experiments have been performed has been describe in detail in previous papers [7, 10]. The atomizer head comprising the contoured gas and liquid nozzles, all of them with a span of 80 mm, is connected at the end of a wind tunnel that supplies a properly conditioned airflow. The exit width of the nozzles is 0.5 mm for the liquid sheet, and 3.45 mm for the gas streams. A photograph of the atomizer is displayed in Fig. 1. The water volumetric flow rate, controlled by a rotameter, has extended up to 600 l/h, corresponding to a maximum liquid velocity U_w of 4.16 m/s. The airflow has been varied with a frequency regulator connected to the impulsion fan. The maximum air velocity has been measured to be U_a = 80 m/s. The measurements obtained in these experiments are in very good agreement with those previously acquired in the same facility [7, 10].

Wavelet analysis

The wavelets are mathematical functions obtained by the translations and dilations of a basis function called "mother wavelet". Wavelets can be see as building blocks of wavelet transforms in the same way that the sin and cosines functions are the building blocks of the ordinary Fourier transform. But in contrast to Fourier functions, wavelets can be supported on an arbitrarily small closed interval which allows an adaptive localization in scale (frequency) and in time. The localization property enables to analyze physical situations where the signal contains discontinuities and sharp spikes. The wavelet transform provide an analysis of a signal at multiple levels of resolution (or scale) which allows to detect periodical and trend components. Basics on wavelets and its applications can be found in many texts, monographs, and papers (see for example, Daubechies (1992), Vidakovic (1999) and Nicolis and Vidakovich (2009). Fig. 1 shows the application of wavelet transform. The level of resolution 10, 11 and 12 clearly detect different transitions in the data.

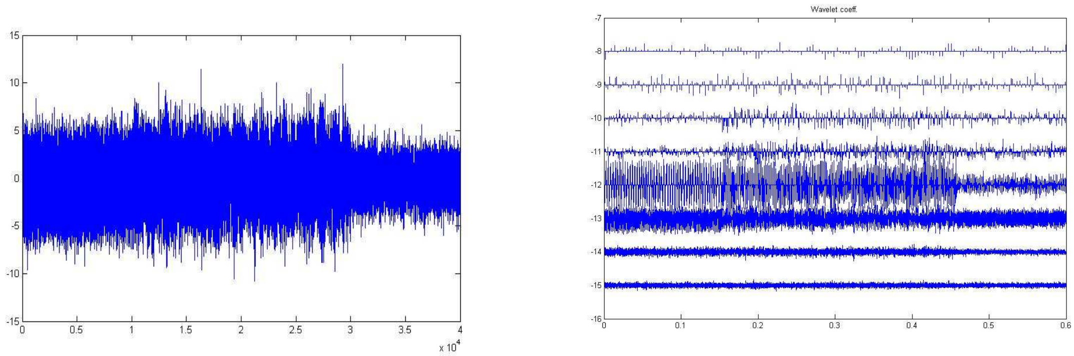

Fig. 1. Original data (left) and wavelet transform (right) – 25 m/s for the air and 340 l/h water

Results and Discussion

This work represent a first analysis of the liquid instabilities using a methodology widely applied for turbulence, also with interesting results [15]. The wavelets analysis is able in fact to capture the time variation of the signals in terms of a fluctuation of the power spectra, without the compromises of a boxed FFT, due to the difficulty of choose the right time interval (or window) for the "local" analysis. An advantage of wavelet transforms is that the windows *vary.* In order to isolate signal discontinuities, one would like to have some very short basis functions. At the same time, in order to obtain detailed frequency analysis, one would like to have some very long basis functions. A way to achieve this is to have short high-frequency basis functions and long low-frequency ones. The first goal is to understand if the dynamical transitions and instabilities can be captured by such methodology and if it is possible to describe the fluctuation with few parameters in order to reconstruct the regime in the most objective way. The present paper considers a first test to use the multilevel wavelet analysis to better understand such unsteady conditions of the liquid sheet. The final goal is in fact to obtain a quantitative tool to define the different dynamical regimes and to compare results from different experimental set-ups.

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