

"Time-Space characteristics of stratified shear layer from UVP measurements"

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Introduction

The flow pattern studied, is a stratified shear layer, consisting of a fresh water flowing on a salted water bed. The instabilities developing under the effect of the velocity gradient are mainly convective and thus develop with time and space during their propagation downstream. A European contract¹ on the estuaries of rivers constitutes the framework of this study, which deals in particular on the interaction between fresh water and sea water, zone in which occur, under the control of the hydrodynamic conditions, the main part of the physicochemical and biological phenomena. The measure of a velocity profile in space and time, as given by Ultrasonic Doppler Method (UVP device from Met-Flow), is well adapted to analysed the stability of such a flow and allows a comparison between the waves properties experimentally observed and the theoretical results given by a linear stability analysis.

Experimental conditions

The experiment is performed in a water channel schematically represented in figure 1. Two layers of equal depth ($D=10$ cm) and different densities are initially superposed and progressively sheared. The tunnel is 20 cm wide, 30 cm deep and 300 cm long. In the upper layer, the fresh water flows from the left side to the right side of the tunnel at a given flow rate corresponding to the mean velocity U_1 . In the under layer, the salty water (initial concentration of NaCl : 10g/l) is coming from the right side and its flow rate is driven by a fixed pressure condition.

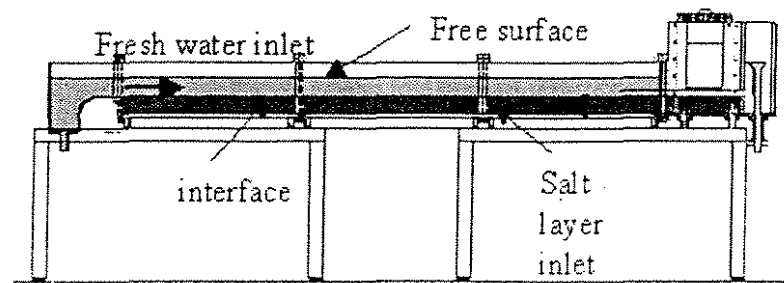


Figure 1: Experimental loop

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The ultrasonic probe is placed horizontally in the middle of the shear layer. The zero of the space co-ordinate is located at 4 cm from the entrance. The specifications of the UVP used, are tabulated below:

Basic ultrasonic frequency	4 MHz
Spatial resolution	2.22 mm
Number of points in space	128
Number of points in time	1024
Acquisition frequency	16.39 Hz

Results

The development of the instabilities is illustrated in figure 2. Rhodamine is added to the salty water which appears red in the laser sheet. The local gradient of concentration is still very steep, while the waves are developed enough for the expression of non linearity. The initial conditions $\{U_i, \rho\}$ of the layer are characterised by a global Richardson number $Ri_D = \frac{g}{\rho} \frac{\Delta \rho}{\Delta U_i^2} D$.

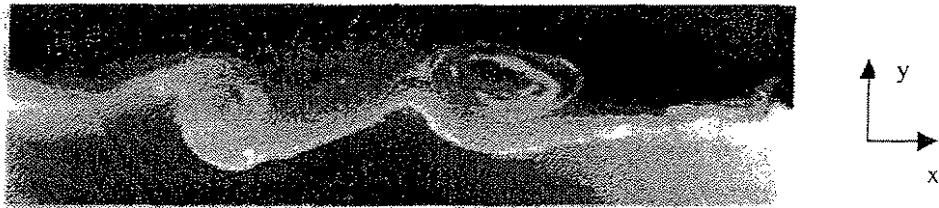


Figure 2 : Interface between fresh and salty water under unstable conditions.

The ultrasonic probe gives the longitudinal (horizontal) component $u(x, t)$ of the velocity. An example of the velocity field is given (Figure 3), for $Ri_D = 8.14$. The instabilities of the concentration gradient layer are clearly visible on the longitudinal component of the velocity. A large spectrum of wave length and celerity is observable, even some waves which propagate upstream. In order to measure the dispersion relationship $f(\omega, k) = 0$ the 2D Fourier transform $\tilde{u}(k, \nu)$ of $u(x, t)$ is applied (Figure 4). $f(\omega, k) = 0$ is given by the line of the maximum of energy in the Fourier plan, which then appears as a very powerful tool for analysing the dynamics of the instabilities.

This experimental dispersion relationship is compared, with success, to the theoretical dispersion relationship, obtained from a linear stability model derived from the temporal model proposed by Lawrence et al. [1991] (Figure 6). The velocity and concentration profiles used are given in figure 5.

Different analysis of the signal $u(x,t)$ are processed using the combinations between the variables of the 2 conjugated planes $P\{x,t\}$ and $\bar{P}\{k,v\}$. Figure 7 gives an example of the measure of the spatial growth rate k_x of a given frequency v using the plan $\tilde{u}(x,v)$.

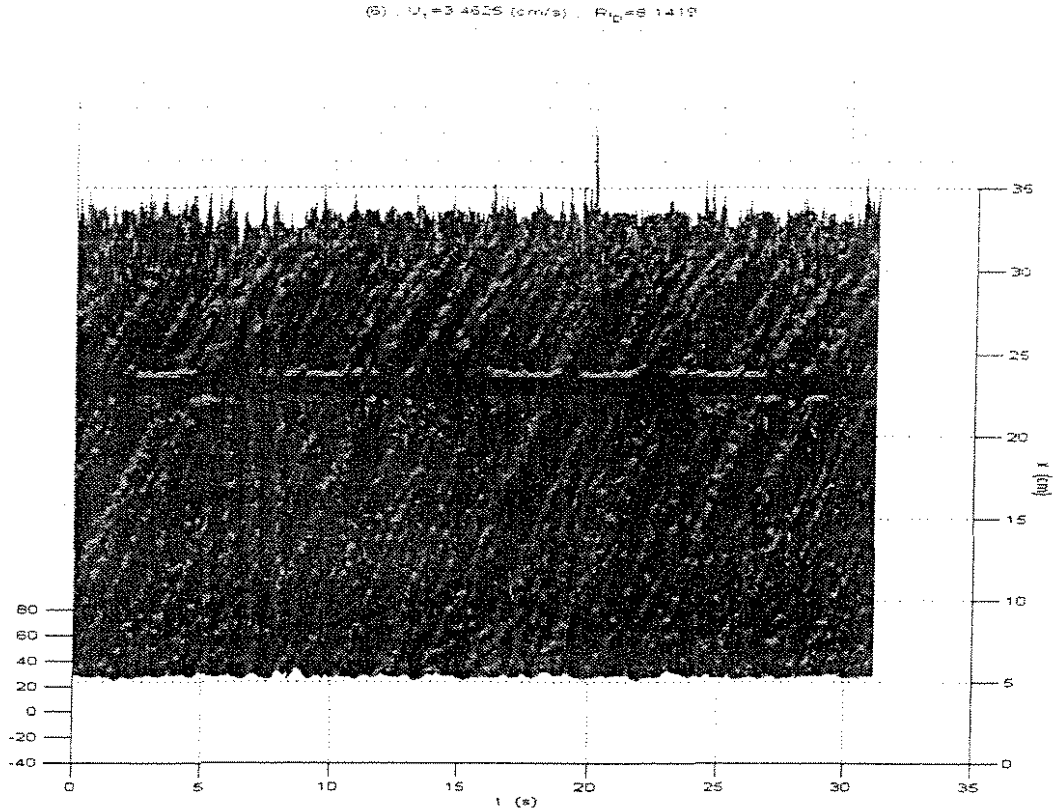


Figure 3 : Velocity profiles versus time and space for a concentration of 10g/l NaCl and a velocity $U_1=3.46\text{cm/s}$.

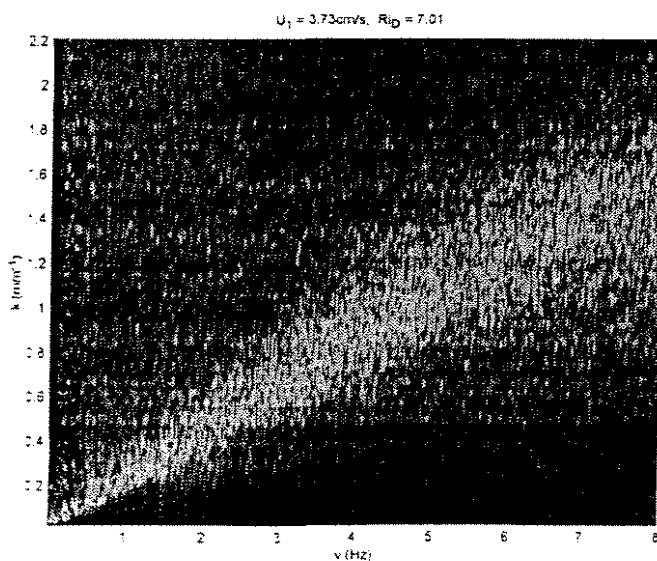


Figure 4: Velocity amplitudes $\tilde{u}(k,v)$ in the Fourier plan.

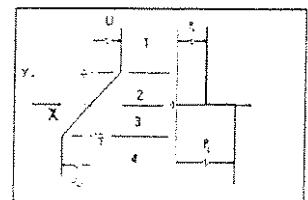


Figure 5: From Lawrence 1991

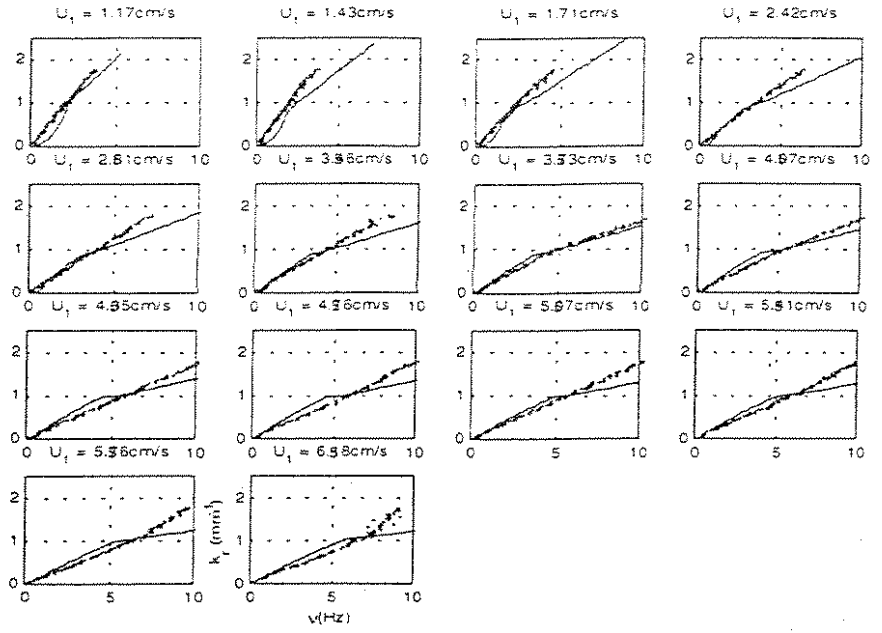


Figure 6: Dispersion relationship for 14 values of U_1 corresponding to $Ri_D = \{71.4, 47.7, 33.4, 16.7, 12.3, 8.14, 7.01, 5.89, 5.16, 4.31, 3.79, 3.33, 2.94, 2.55\}$:- dots results from the experimental Fourier plan, -line results from the linear stability analysis

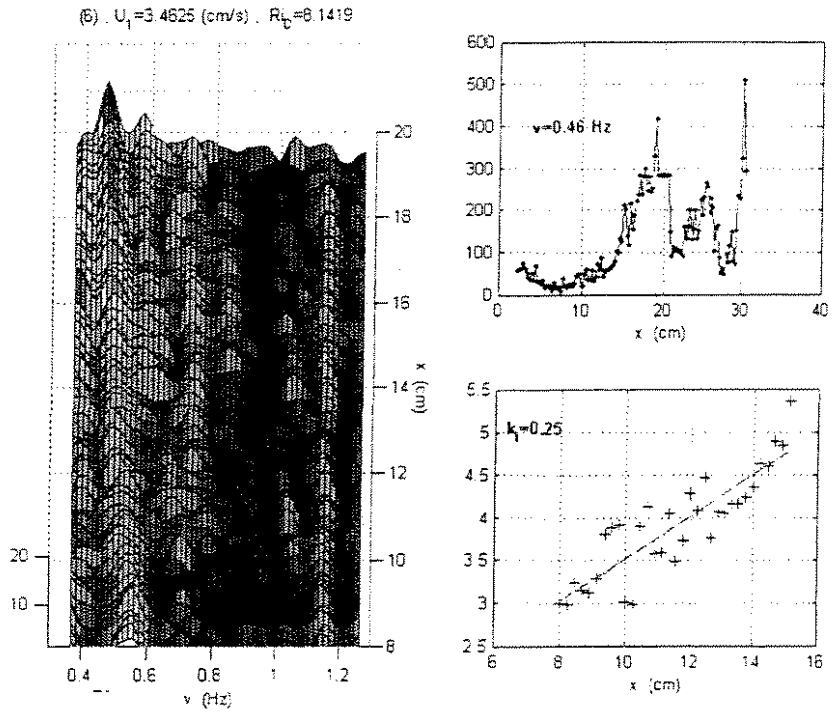


Figure 7 : Measure of the spatial growth rate k_x of a given frequency $\nu = 0.46 \text{ Hz}$ using the plan $\tilde{u}(x, \nu)$ for $Ri_D = 8.14$.

Reference

Lawrence et al. *J. of Fluid Mechanics*, 1991.