Measurements of turbulence parameters at a density interface

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Introduction

One of the main causes of turbulence generation in stably stratified flows is the breaking of Kelvin–Helmholtz (KH) billows. One of the open problems is the parameterization of the turbulence variables that play a role in the flow dynamics. To this end, this paper focuses on the determination of some variables of interest, such as turbulent fluxes of mass and momentum, obtained by means of a series of lock exchange experiments reproducing a gravity current flowing over bottom roughness of different types. The data are used to calculate the turbulent Schmidt number as a function of Ri_G.

Methods

The experiments are conducted in the water tank of the Hydraulic Laboratory of the Department of Civil, Buildings and Environmental Engineering of Sapienza. The tank (7.4 m long, x-axis) has a rectangular cross-section 0.35 m high (z-axis) and 0.25 m wide (y-axis) with lateral walls made of transparent glass to permit optical access. The channel is subdivided into two separated volumes, initially at rest, by means of a movable gate. The left part of the channel is filled with a mixture of fresh water and salt (heavier fluid), whose density is higher than that of the fresh water (lighter fluid) contained in the right part (Fig. 1). The water depth in the two volumes is H=20 cm. The left volume is premixed with a fluorescent dye (Rodhamine-WT). The experiment starts by removing the gate, which permits the denser fluid to flow from left to right beneath the lighter fluid. The density difference set in the experiments is small enough to avoid any significant distortions in the path of the laser light rays used for the measurements.

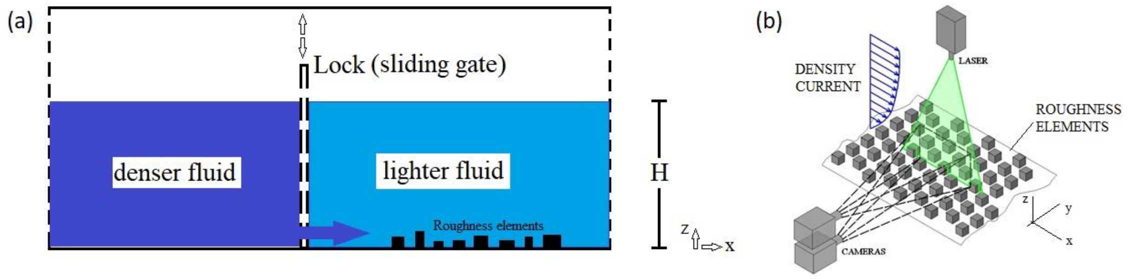

Fig. 1. (a) Sketch of the lock exchange apparatus (b) the canopy and the experimental setup.

Velocity and dye concentration are measured simultaneously on the vertical section (x-z plane) passing through the longitudinal axis of the channel. The acquisition facility consists of a green laser (5 W) emitting a light sheet illuminating the acquisition plane and of two synchronized cameras, acquiring 100 frames per second at 1024x1280 pixels in resolution. The framed area is 90 mm wide (x-axis) and 70 mm high (z-axis). The first camera acquires the positions of the non-buoyant particles premixed in both the fluids and allows us the evaluation of the instantaneous

velocity fields by means of a feature-tracking algorithm (Cenedese et al. 2005). A Gaussian interpolation is applied at each time instant to the scattered samples on the x–z plane to obtain the instantaneous velocity field on a regular 102x128 grid (~0.7-mm spatial resolution). Planar laser-induced fluorescence (PLIF) is used to measure the fluid density via the optically measured dye concentration premixed within the denser fluid. Images are calibrated so that the dye concentration at a given pixel (directly related to the fractional volume of the dyed fluid) is proportional to its luminosity, which, in turn, is proportional to the salt concentration (i.e., fluid density). Each array of roughness elements considered for the experiments is designed by means of uniform, sharp-edged cubes (15x15x15 mm^3) (Fig. 1). Three arrangements will be investigated corresponding to the plan area indices $\lambda_P=A_P/A_T=0.1$, 0.25, and 0.4, where A_P is the plan area occupied by the cubes and A_T is the total area.
After the passage of the gravity current front, a steady regime lasting several tens of seconds takes place, during which the time averages of the variables are determined. Namely, the mean density, ρ, the mean velocity components (streamwise, <u>, and vertical, <w>), as well as the vertical momentum flux, <u'w'>, and the vertical turbulent flux of mass, <w'ρ'>, are determined (here, prime indicates fluctuation around the mean, < >).

Results

Here, some preliminary results are shown. The vertical profiles of the mean streamwise (U) velocity component and the mean density profiles shown in Fig. 2b refer to the region of the interface between the gravity current and the overlying fluid for $\lambda_P=0.25$. The right panel in the same figure shows the corresponding vertical profile of the inverse of the turbulent Schmidt number, i.e., $Sc^{-1}=K_\rho/K_M$, where $K_m=-\langle u'w'\rangle/(dU/dz)$ and $K_\rho=-\langle w'\rho'\rangle/(d\rho/dz)$ are the turbulent exchange coefficient of momentum and mass, respectively, obtained based on first order closure. Sc^{-1} is not constant within the density interface and shows a maximum, ~1, in correspondence of the location where the density gradient attains its maximum. Figure 2a shows Sc^{-1} versus the gradient Richardson number, i.e., $R_g=N^2/(dU/dz)^2$, where N is buoyancy frequency. The trend is in reasonable agreement with previous results found in the literature (e.g., Strang and Fernando, 200

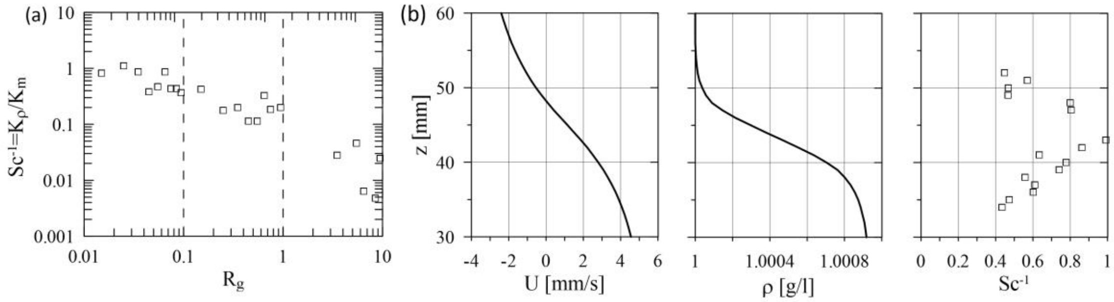

Fig. 2. (a) The inverse of $Sc^{-1}=K_\rho/K_m$ as a function of the gradient Richardson number for $\lambda_P=0.25$ (b) Vertical profiles of the streamwise velocity, density and Sc^{-1}.

References

Cenedese, A., Del Prete, Z., Miozzi. M., & Querzoli. G. (2005) A laboratory investigation of the flow in the left ventricle of a human heart with prosthetic, tilting-disk valves. *Experiments in Fluids*, 39.
Fernando, H.J.S. (1991) Turbulent mixing in stratified fluis. *Annual Review of Fluid Mechanics*, 23.
Strang, E.J., & Fernando, H.J.S. (2001) Entrainment and mixing in stratified shear flows. *Journal of Fluid Mechanics*, 428.